# Shoreline Types of the Upper Texas Coast: Sabine-Galveston-Freeport-Sargent Areas

Final Report
Prepared for the

Texas Natural Resources Inventory Program
Texas General Land Office, Texas Natural Resource Conservation Commission,
and Texas Parks and Wildlife Department
under
GLO Contract No. 94-177R

and

Minerals Management Service
Gulfwide Information System at Louisiana State University
CMI-30660-19901

Robert A. Morton and William A. White

Bureau of Economic Geology
Noel Tyler, Director
The University of Texas at Austin
Austin, Texas 78713-8924

January 1995

CONTENTS

Figures

Tables

## EXECUTIVE SUMMARY

The following report describes how the Bureau of Economic Geology (BEG) classified and mapped the shores of the upper Texas coast for the Texas Natural Resources Inventory (NRI) Program, provides definitions of each shoreline type, and presents examples that illustrate how physical attributes of the shoreline habitats control the impact of spilled oil. This information is an integral part of the Environmental Sensitivity Index (ESI) maps used for oil spill response and contingency planning. Shorelines were classified according to an ESI scheme established by Research Planning, Inc. (RPI) and the BEG. The ESI rankings (1-10) are described, examples of each type are illustrated, and the common occurrences of multiple adjacent shoreline types are given.

Shoreline types were mapped on U.S.G.S. topographic quadrangles (1:24,000) using recent vertical aerial photographs, low-altitude color video surveys taken in 1992, oblique color slides taken in 1992 and 1994, an overflight in 1994, and previous field experience. All the maps were field checked in June 1994 from the air and some sites were checked on the ground. The Sabine to Sargent region was selected for the initial phase of ESI mapping in Texas because shore types there are diverse, it is densely industrialized, extant wetlands are environmentally sensitive, and a large volume of oil is transported through major shipping channels and the Intracoastal Waterway of the region.

ESI rankings characterize the sensitivity of the shore and associated biota to oil impacts and the relative difficulty of cleanup activities. Low numbers indicate low sensitivity to environmental damage whereas high numbers indicate priority areas that should be protected from damage. The ESI rankings for Texas are as follows: **1** Exposed walls and other structures made of concrete, wood, or metal; **2A** Scarps and steep slopes in clay; **2B** Wave-cut clay platform; **3A** Fine-grained sand beaches; **3B** Scarps and steep slopes in sand; **4** Coarse-grained sand beaches; **5** Mixed sand and gravel (shell) beaches; **6A** Gravel (Shell) beaches; **6B** Exposed riprap structures; **7** Exposed tidal flats; **8A** Sheltered solid man-made structures, such as bulkheads and docks; **8B** Sheltered riprap structures; **8C** Sheltered scarps; **9** Sheltered tidal flats;

**10A** Salt- and brackish-water marshes; **10B** Fresh-water marshes (herbaceous vegetation); **10C** Fresh-water swamps (woody vegetation); and **10D** Mangroves. All of these shoreline types are present along the upper Texas coast except for mangroves.

## INTRODUCTION

Shores are dynamic elements of the Texas coast that constantly change position due to local erosion and deposition. In some places these processes along with human activities cause changes in other physical attributes such as sediment composition, sediment textures, and nearshore slopes. The lengths and types of shores also determine their economic and recreational value, their ability to support certain plant and animal communities, and their value as productive nesting and nursery grounds for certain threatened and endangered species. Knowing shoreline characteristics also provides a fundamental basis for oil spill response and contingency planning and for post-spill damage assessments. Thus there are a number of reasons why an inventory of shoreline attributes in Texas would provide valuable information and should be included in the Natural Resources Inventory (NRI) of the coast.

The purpose of this coastal mapping project was to produce a set of large-scale, high-quality maps of shoreline characteristics of the upper Texas coast that were suitable for digitization and incorporation into a geographic information system (GIS). The shoreline maps and digital databases form an integral component of the Texas Natural Resources Inventory, and they also represent a significant element of Environmental Sensitivity Index (ESI) maps used for oil spill response and contingency planning by the State trustee agencies.

Inventories of shoreline types and updated ESI maps are needed for the entire Texas coast. However, the enormous size of the area, limited manpower capable of this specialized mapping, and limited funding resources prevent completion of this important work in a single year. The Sabine to Sargent region was selected as the first priority area primarily because the extant wetlands are environmentally sensitive and a large volume of oil is transported through major shipping channels and the Intracoastal Waterway of the region. The Sabine to Sargent region contains highly diverse shoreline types that undergo closely-spaced changes because the regional geology and shoreline orientations are diverse and human modifications of the shore are extensive and highly varied. The large estuaries and bays, barrier islands, navigation channels, and spoil islands of the region create more than 700 miles of shoreline that are represented on approximately 40 topographic quadrangle maps (Figure 1). A list of the quadrangle maps used as base maps is given in Table 1.

## RATIONALE FOR UPDATING SHORELINE INVENTORIES AND ESI MAPS

Environmental Sensitivity Index (ESI) mapping represents a conceptual advancement that recognizes different susceptibilities to environmental damage depending on shoreline characteristics. First developed for the shores of lower Cook Inlet in Alaska (Hayes et al., 1976; Michel et al., 1978), this method of classifying shoreline features has gained wide acceptance and is now a standard resource management tool used to develop contingency plans in the event of an oil spill or to minimize environmental damage during a spill.

ESI mapping employs a qualitative ranking system that characterizes the sensitivity of the shore and associated biota to oiling and cleanup activities. The ESI rankings typically range from 1 to 10 with low numbers indicating short persistence of stranded oil and minor susceptibility to environmental degradation, and high numbers indicating long-term oil persistence, difficulty of oil cleanup and a high sensitivity to damage. Standard ESI map units and symbols have been established by the National Oceanic and Atmospheric Administration (NOAA) in conjunction with Research Planning, Inc. (RPI) to facilitate the use of ESI maps nationwide by all potential users including state and federal officials, industry representatives, and oil-spill cleanup contractors (Michel and Dahlin, 1993).

ESI maps previously prepared for Texas (Gundlach et al., 1981; Texas Water Commission, 1989) do not conform to the current NOAA standards, and the classification on the Texas maps are not the same as those generally presented on most ESI maps. Also, the older ESI maps for Texas do not show other information that is pertinent to natural resources inventories and oil spill

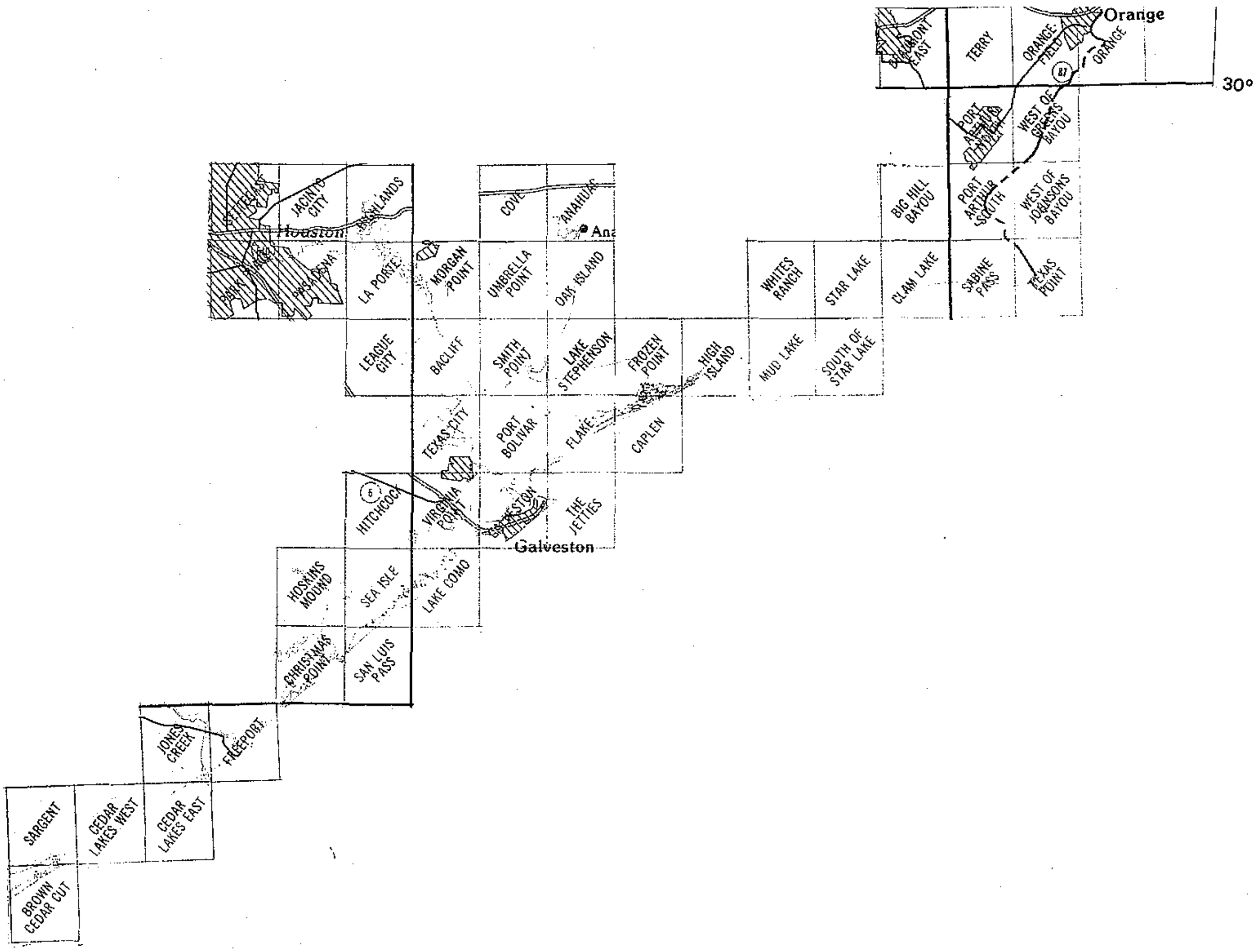



Figure 1. Index map of the study area showing the locations of 7.5-minute U.S.G.S. topographic maps.

Table 1. List of 7.5-minute topographic quadrangles used for the upper Texas coast.

| Name | Texas Code | Name | Texas Code |
|---|---|---|---|
| Anahuac | 2994-342 | Mud Lake | 2994-421 |
| Bacliff | 2994-422 | Oak Island | 2994-313 |
| Beaumont East | 3094-111 | Orange | 3093-212 |
| Big Hill Bayou | 2994-441 | Orangefield | 3093-221 |
| Brown Cedar Cut | 2829-313 | Park Place | 2995-424 |
| Caplen | 2994-244 | Pasadena | 2995-413 |
| Cedar Lakes East | 2895-432 | Port Arthur South | 2993-332 |
| Cedar Lakes West | 2895-341 | Port Arthur North | 2993-333 |
| Christmas Point | 2995-112 | Port Bolivar | 2994-234 |
| Clam Lake | 2994-414 | Sabine Pass | 2993-323 |
| Cove | 2994-331 | San Luis Pass | 2995-111 |
| Flake | 2994-243 | Sargent | 2895-342 |
| Freeport | 2895-434 | Sea Isle | 2995-114 |
| Frozen Point | 2994-311 | Settegast | 2995-431 |
| Galveston | 2994-231 | Smith Point | 2994-321 |
| High Island | 2994-422 | South of Star Lake | 2994-412 |
| Highlands | 2995-441 | Star Lake | 2994-413 |
| Hitchcock | 2995-141 | Terry | 3093-222 |
| Hoskins Mound | 2995-113 | Texas City | 2994-233 |
| Jacinto City | 2995-442 | Texas Point | 2993-324 |
| Jones Creek | 2895-433 | The Jetties | 2994-242 |
| La Porte | 2995-414 | Umbrella Point | 2994-324 |
| Lake Como | 2994-223 | Virginia Point | 2994-232 |
| Lake Stephenson | 2994-312 | West of Greens Bayou | 2993-334 |
| League City | 2995-411 | Whites Ranch | 2994-424 |
| Morgans Point | 2994-323 | | |

contingency planning and response efforts. The first ESI maps for Texas (Gundlach et al., 1981) only encompassed the lower coast south of Corpus Christi. They were prepared in 1979 at a scale of 1:24,000 to 1:40,000 (Michel and Dahlin, 1993). Subsequent ESI maps covering the entire coast were published at scales ranging from 1:32,000 to 1:125,000 (Texas Water Commission, 1989). These scales are convenient for viewing and handling, but they are too small for on site use. A scale of 1:24,000 is rapidly becoming the standard scale for mapping and digitization of ESI maps in the United States (Michel and Dahlin, 1993).

ESI maps for Texas are being updated because most of the developed shores have changed dramatically and more shores have been developed since the first ESI maps were prepared. Also current systematic mapping for the entire coast is needed that employs a standard classification scheme, large-scale format, and established digital cartographic techniques.

## PREVIOUS RELATED WORK

Numerous coastal studies previously conducted over the past twenty five years by the Bureau of Economic Geology (BEG) served as a foundation for the ESI rankings and mapping of shoreline types. Physical attributes of natural and artificial shores of the Texas coast had been mapped by the BEG, but none of the prior mapping projects inventoried the physical attributes of the shores or presented the data in a form suitable for oil spill response, contingency planning, or damage assessment.

Modern systematic geologic mapping of the Texas coast began in the late 1960s when the Environmental Geologic Atlas Series was conceived and implemented (Fisher et al., 1972, 1973). This multi-year Bureau-initiated program set the standard for comprehensive synthesis of physical, chemical, and biological data that were specifically designed to address the need for baseline inventories suitable for environmental investigations. The Environmental Geologic Atlas Series organized diverse types of information and presented it in tables, charts, and multicolor maps that were intended for use by planners and regulators as well as by scientists and engineers. The principal mapping techniques that supported this work involved interpretation of aerial photographs, extensive field investigations, and aerial over flights. To make the maps even more useful, other related data also were compiled such as ecological surveys, climatological and oceanographic records, engineering properties, locations of energy and mineral resources, and locations of transmission routes. The Environmental Geologic Atlas Series includes maps of (1) topography and bathymetry, (2) current land use, (3) man-made features and water systems, (4) environments and biological assemblages, (5) physical properties, (6) active processes, (7) rainfall, discharge and surface salinity, and (8) mineral and energy resources. The maps are accompanied by an interpretive text and users guide that explain the interrelationships among geological processes, physical substrates, and biological assemblages.

In the early 1970s, the BEG initiated a study of beach changes along the Texas Gulf shoreline including the upper coast between Sabine Pass and Sargent Beach (Morton, 1974, 1975; Morton and Pieper, 1975). This study was updated (Paine and Morton, 1989) to provide more recent information on shoreline movement. Results of these and similar studies for the bay shores (Paine and Morton, 1986) provide a basis for classifying shore stability in any of the bays and estuaries or the Gulf shore of the upper Texas coast.

In the mid 1970s, the BEG also initiated another atlas series that focused on the subtidal region of the Texas coast (White et al., 1985, 1987, 1988). The submerged lands were inventoried and significant physical, chemical, and biological properties were identified and measured. The resulting quantitative maps and reports, known as the Submerged Lands of Texas Atlases, cover the wetlands, bays, estuaries, lagoons, and inner continental shelf environments where navigation projects, industrial site development, and mineral resource extraction activities are being conducted or are planned for the future.

In 1992, the Bureau conducted a study of wetland and aquatic habitats in the Galveston Bay system in support of the Galveston Bay National Estuary Program (White et al., 1993). The work involved field descriptions and interpretations of the wetland habitats, mapping of wetlands on aerial photographs, digitizing the maps, processing the data in ARC/INFO, and illustrating the trends of gain and loss in wetland habitat. A final phase of the project involved assessing the impacts of agricultural practices, drainage modification, impoundments, dredging and filling, and construction on the wetlands.

Another coastal research project initiated in 1990 by the BEG involves mapping shoreline movement and calculating recent rates of shoreline change. This work, funded by the U.S. Geological Survey, established the most recent trend of Gulf beach stability in the area of interest and added to the information presented by Morton (1974, 1975), Morton and Pieper (1975), and Paine and Morton (1989). As part of the U.S.G.S. project, a low-altitude aerial reconnaissance video survey of major bays and the Gulf shoreline in Texas was conducted in July, 1992 (Westphal et al., 1992). This high-quality color video survey of the shores and accompanying oral descriptions of shoreline types served as a principal source of information for the ESI mapping project.

## METHODS OF MAPPING AND APPLYING ESI RANKINGS

### Mapping Procedures

Shorelines were mapped and classified using numeric or alpha-numeric codes that define the ESI rankings and shoreline types (Tables 2 and 3; Figures 2-18). The mapping procedure consisted of identifying shoreline boundaries, marking the boundaries on topographic base maps, and labeling each shoreline segment with the appropriate ESI code. Shorelines were delineated on the most recent U.S.G.S. topographic maps (scale 1:24,000) (Table 1). Areas that had been modified since the topographic maps were produced were updated using the most recent available aerial photographs and a Bausch and Lomb Zoom Transfer Scope.

Shoreline types were mapped by research staff at the Bureau of Economic Geology (BEG) primarily using low altitude aerial videotape surveys of coastal Texas produced by the Louisiana Geological Survey (LGS) (Westphal et al., 1992) and recorded during a cooperative helicopter flight in July of 1992 by staff of LGS and BEG. Videotapes were high quality and were accompanied by audio commentaries of shoreline types made by experienced coastal geologists.

Table 2. Standardized ESI Rankings for Texas.

| ESI No. | Shoreline Type |
|---|---|
| 1 | Exposed walls and other structures made of concrete, wood, or metal |
| 2A | Scarps and steep slopes in clay |
| 2B | Wave-cut clay platform |
| 3A | Fine-grained sand beaches |
| 3B | Scarps and steep slopes in sand |
| 4 | Coarse-grained sand beaches |
| 5 | Mixed sand and gravel (shell) beaches |
| 6A | Gravel (Shell) beaches |
| 6B | Exposed riprap structures |
| 7 | Exposed tidal flats |
| 8A | Sheltered solid man-made structures, such as bulkheads and docks |
| 8B | Sheltered riprap structures |
| 8C | Sheltered scarps |
| 9 | Sheltered tidal flats |
| 10A | Salt- and brackish-water marshes |
| 10B | Fresh-water marshes (herbaceous vegetation) |
| 10C | Fresh-water swamps (woody vegetation) |
| 10D | Mangroves |

Table 3. Annotated and combined ESI Rankings for Texas.

| ESI No. | Shoreline Type |
|---|---|
| Shorelines generally exposed to high physical energy | |
| 1 | Exposed walls and other solid structures made of concrete, wood, or metal |
| 2A | Scarps and steep slopes in clay |
| 2B | Wave-cut clay platform |
| 3A* | Fine-grained sand beaches |
| 3B | Scarps and steep slopes in sand |
| 4* | Coarse-grained sand beaches |
| 5* | Mixed sand and gravel (shell) beaches |
| 6A* | Gravel (Shell) beaches |
| 6B | Exposed riprap structures |
| 7 | Exposed tidal flats |
| * These types may be mapped (rarely) in sheltered areas | |
| Shorelines generally exposed to low physical energy | |
| 8A | Sheltered solid man-made structures, such as bulkheads & docks |
| 8B | Sheltered riprap structures |
| 8C | Sheltered scarps |
| 9 | Sheltered tidal flats |
| Wetlands | |
| 10A | Salt- and brackish-water marshes |
| 10B | Fresh-water marshes (herbaceous vegetation) |
| 10C | Fresh-water swamps (woody vegetation) |
| 10D | Mangroves |

Examples of ESI Combinations

| | |
|---|---|
| 1/6B or 8A/8B | Bulkhead shoreward of riprap |
| 6B/1 or 8B/8A | Riprap shoreward of bulkhead |
| 2A/10A or 8C/10A | Relatively narrow fringing marsh seaward of scarp |
| 10A/2A or 10A/8C | Typically, high marsh shoreward of low scarp |
| 2A/1 | Several possibilities:<br>Failed bulkhead or breakwater seaward of scarp<br>Short piers or boat docks seaward of scarp |

Examples of Energy Levels

| High-Energy Environments (Exposed) | Low-Energy Environments (Sheltered) |
|---|---|
| Gulf | Branch channels off of main ship Channels |
| and rivers | Bayous and creeks |
| Bays | Marinas and boat basins |
| Ship channels | Narrow bays with limited fetch |
| Intracoastal Waterway | |
| Major Rivers | |

(a)

(b)

Figure 2. Examples of coastal structures (a) exposed vertical seawall at Galveston with riprap and piers, and (b) typical port facilities with bulkheads and riprap such as this refinery at Baytown.

In addition, oblique 35 mm color slides were taken at low altitude of most shorelines during the flight.

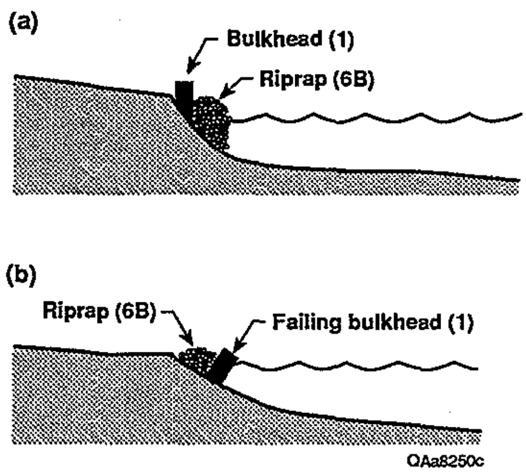
Shoreline types were classified and mapped while viewing the videotapes on a 27 inch high-resolution color monitor and using a video cassette recorder with slow and fast advance and reverse features. The color slides were used to provide additional fine detail on shoreline types in complex areas. In areas not covered by videography, shorelines were mapped using low and high altitude vertical stereographic aerial photographs taken during the years 1989 through 1993 (Table 4). Shorelines were analyzed using stereoscopes with a magnification of at least 6X.

Table 4. Date, type, and source of high- and low-altitude vertical aerial photographs used to map shorelines.

| **Date Flown** | **Scale** | **Color Infrared (CIR) or Black and White (BW)** | **Source** | **Primary Geographic Coverage** |
|---|---|---|---|---|
| Feb-Mar 1993 | 1:65,000 | CIR | NASA | Neches and Sabine Rivers and tributaries |
| Dec 1989 | 1:65,000 | CIR | NASA | Used throughout map area where more recent coverage did not exist |
| Dec 1992 | 1:24,000 | BW | Texas Dept. of Transp. (TDOT) | ICWW |
| Feb 1992 | 1:4,800 (enlarged from 1:24,000) | BW | TDOT (District Office) | Buffalo Bayou and tributaries |
| Feb 1991 | 1:24,000 | BW | TDOT | ICWW |
| Jan-Mar 1990 | 1:24,000 | BW | TDOT | Channels along ICWW |
| Oct 1989 | 1:24,000 | BW | TDOT | Clear Lake area |

## Application of ESI Rankings to Complex Shorelines

Along many segments of the Texas coast, several shoreline types occur in close proximity going from the water inland. Several ESI rankings are assigned to a shoreline segment where multiple shoreline types are subject to oiling. The ESI rankings are given in the order in which they occur going from the most landward to the most seaward position. For example, many shorelines have been armored by both riprap and bulkheads to prevent or to minimize shoreline erosion. Commonly, a vertical metal or wooden bulkhead will be protected along its seaward side by riprap (Figure 2a). Such a configuration would be designated on maps as 1/6B in a high energy or exposed setting, and 8A/8B in a protected or sheltered setting (Tables 2 and 3). The first alpha-numeric code, 1 and 8A in the above cases, refers to the landward most feature, or bulkhead, and the succeeding codes refer to the seaward most feature, or in the above cases, riprap (6B and 8B) (Figure 3). Along some shores, riprap may be placed landward of partially failed vertical bulkheads. These areas are designated as 6B/1 or, in sheltered areas 8B/8A, to designate the seaward progression from riprap to bulkheads.




## Delineation of Wetlands Using NWI Data

Figure 3. Multiple shoreline types consisting of exposed bulkheads and riprap. The shorelines are classified as 1/6B or 6B/1 depending on whether the bulkhead is landward (a) or seaward (b) of the riprap.

Locally, as many as three shoreline types may be recognized in an alpha-numeric sequence, such as 10A/5/2B, which details a shoreline that progresses from salt/brackish marsh to shelly washover terrace perched on a wave-cut clay platform (Figure 15b).

U.S. Fish and Wildlife Service National Wetlands Inventory (NWI) data were used by RPI to generate polygonal data depicting the areal distribution of wetlands to provide a more complete spatial view of these resources and the possible extent of wetland impact should the shoreline be subjected to an oil spill. The NWI data include only those polygons classified on NWI maps as emergent, scrub/shrub, and forested wetlands (table 5).

Table 5. General relationship between NWI wetland classes and ESI wetland types.

| ESI Ranking | NWI Classification | NWI Map Symbol |
|---|---|---|
| 10A Salt- and brackish-water marshes | Estuarine intertidal emergent wetland (persistent & non persistent) | E2EM |
| 10B Fresh-water marshes | Palustrine Emergent Wetland (persistent) | PEM |
| 10C Fresh-water swamps | Palustrine Forested Wetland and Scrub/Shrub Wetland (all subclasses) | PFO and PSS |
| | Estuarine Intertidal Scrub/Shrub Wetland (Broad-leaved deciduous) (Neddle-leaved deciduous) (Neddle-leaved evergreen) | E2SS 1, 2, &4 |
| 10D Mangroves | Estuarine Intertidal Scrub/Shrub Wetland (Broad-leaved evergreen) | E2SS3 |

## Field Verification and Modifications

The Environmental Sensitivity Index rankings and boundaries of each shoreline unit mapped by the BEG were checked while flying at a low altitude in a single engine fixed-wing aircraft (Cessna 172). Ground-speed was approximately 80 m.p.h. during most of the overflights, which were conducted on June 6 and 7, 1994. Relatively clear weather and microtidal conditions allowed continuous flying for extended periods.

The topographic base maps prepared by the BEG were arranged in sequential order so that locations of ground observations were maintained at all times. This allowed for detailed comparison of the maps with the field observations. Representatives from both the BEG and RPI were on board the aircraft. Changes in ESI ranking or boundaries were made only after consultation and concurrence of both parties.

Where necessary, corrections were made on the original maps. In a few instances, recent shoreline changes post-dated aerial photographs on which some shorelines were mapped. These areas were updated during the overflight. In addition, many of the shorelines on six quadrangles (Christmas Point to Brown-Cedar Cut; Figure 1) were mapped during the June 1994 overflight. Complex areas that could not be delineated adequately during the overflight were mapped using aerial photographs.

Some sites were field checked on the ground to verify anomalous shoreline conditions or to observe the arrangement of multiple shoreline types in densely developed areas. Examples of ground checks and verification involved examining gravel (shell) on the washover terraces along Gulf beaches east of Sea Rim State Park and gravel (shell) on Gulf beaches west of Sea Rim State Park. Ground checks were also conducted along the Houston Ship Channel in the vicinity of Green's Bayou, where the locations of riprap and other protective works could not be determined accurately from the aerial photographs.

## Quality Control

Researchers at the BEG were responsible primarily for mapping shorelines using procedures detailed in the methods section of this report. Research staff from both RPI and BEG were responsible for field checking and completing original work maps during a post-mapping overflight. Maps were field checked to ensure completeness and accuracy of shoreline designations. Completed and field checked maps were photocopied and the original maps were sent to RPI for digitization and entry into a Geographic Information System (GIS). The RPI staff was responsible for converting digital or hard copy data or information into a GIS product and for maintaining and filing GIS records.

Digitized shorelines were plotted in a preliminary hard copy of the GIS map. Shorelines on the hard copy were compared with mapped shorelines on the original 7.5-minute quadrangles for accuracy and completeness. If the GIS map and the original map were at the same scale, GIS maps were compared directly with the original map using a light table. BEG and RPI reviewers were responsible for determining if the GIS map adequately portrayed the original maps and if the GIS presentation had introduced any inaccuracies not present on the original maps. Areas needing correction were marked on the GIS map.

Reviewed maps were dated and initialed by the BEG reviewer. The BEG reviewer discussed needed corrections with the RPI staff. Once corrections were completed, the RPI staff produced a second draft of the GIS product that was checked for accuracy. To ensure that the highest quality products were produced, all maps were checked independently by research staff at both RPI and BEG.

## SHORELINE TYPES OF THE UPPER TEXAS COAST

Environmental Sensitivity Index rankings and classification of shoreline types represent an integration of several physical and biological attributes. These attributes refer to the materials that make up the shore, the dynamic processes acting on the shore, the locations along the shore where water is exchanged, susceptibility of biological community to oil-spill impacts, and water depths (bathymetry) near the shore, among others. From these attributes and additional information, other qualitative shoreline characteristics can be derived such as oil retention and trafficability.

Seventeen shoreline types ranked on a scale of 1-10 were identified for the upper Texas coast from field surveys, aerial videotape surveys, and coastal change analyses. The shoreline classification for Texas (Table 2) is similar to those used for the other coastal states, which have been standardized by NOAA/RPI (Michel and Hayes, 1992). The current ESI classification is modified from the classifications proposed for Texas by Gundlach et al. (1981) and Michel and Dahlin (1993). The physical and biological characteristics of each shoreline type as well as the general sensitivity, oil behavior, and cleanup concerns for the shoreline types are presented in the following sections. More detailed explanations of the environmental conditions and sensitivity rankings are presented by Gundlach and Hayes (1978), Hayes et al. (1980) and Michel and Hayes (1992).

The environmental parameters and physical settings characteristic of the upper Texas coast were used to classify the shoreline types. Exposure to or protection from wave energy was a major criteria used to determine the ESI ranking because wave energy also influences the natural ability of the environment to remove and disperse oil. Wind direction and fetch and shore morphology were guides to the energy exposure of a particular shoreline segment, but those parameters were not always indicative of the local conditions. For example, the Gulf Intracoastal Waterway has essentially no fetch. Nevertheless, frequent barge traffic generates waves that erode banks and construct sand beaches. Additional examples of sheltered and exposed shorelines are given in Table 3. Note that the wetland classifications do not contain specific taxonomic connotations.

All of the shoreline types are subject to modification by human activities and this is the primary reason why ESI maps need to be updated periodically. Most of the natural shoreline types are unaffected by temporal variability in nearshore processes but a few can change rapidly, especially after high energy events that produce strong waves and currents. For example, shell concentrations on Gulf beaches depend on short-term beach cycles that can either concentrate or dilute the amount of shell present on the beach surface. These general conditions apply to the erosional beaches of the Gulf shoreline, and they should be recognized and incorporated into the oil spill contingency planning process.

## Coastal Structures

The coastal structures category (Figure 2) includes ESI Rankings 1 (exposed seawalls), 6B (exposed riprap), 8A (sheltered seawalls), and 8B (sheltered riprap). Coastal structures are the various man-made hard structures that typically are used to protect the shore from waves and currents such as seawalls, jetties, breakwaters, groins, revetments, piers, and port facilities; they also include miscellaneous structures such as roads and bridges that cross open water. Jetties are constructed perpendicular to the shore and are used to protect navigation channels. In Texas, they are constructed mostly of blocks of granite or limestone. Seawalls and revetments are coastal protection structures built parallel to shore (Figure 2a) and constructed of rock, concrete, riprap, or junk such as old appliances and broken concrete. Breakwaters are built parallel to the shore but are detached from the shore so they block waves from reaching the coast. They are usually built of concrete, riprap, or wood. Groins are short, shore-normal structures that are designed to trap sediment and slow erosion. They also are constructed of granite, riprap, or wood. Piers are shore-normal structures on pilings built of concrete or wood (Figure 2a). They are typically used for recreation such as fishing, but some support restaurants, shops, and hotels. Port facilities describe the major developed waterfronts that include wharves, piers, seawalls, and other structures made of steel, rock, wood, and concrete (Figure 2b). Most of the miscellaneous other structures found in Texas, such as bridges, are constructed of concrete.

Coastal structures along the Gulf shoreline of the upper Texas coast include seawalls, riprap, jetties, groins, and piers. Wall-type structures are the steel sheet-piles bordering Rollover Pass and the failing steel walls made of guardrails along State Highway 87 in Jefferson County. A field of groins constructed of granite blocks is also located in front of the seawall on Galveston Island and the remnants of a single concrete rubble groin and foundations of several destroyed houses are located in Jefferson County west of Sabine Pass. Riprap is also present along the toe of the Galveston seawall. Long jetties constructed of large granite blocks are located at each of the major ship channels along the Texas coast. The three jetty systems of the upper Texas coast are located at Freeport Harbor, Galveston Harbor, and Sabine Pass. Long commercial fishing piers that extend into the Gulf of Mexico and are supported by pilings of concrete or wood, are located at Follets Island, Galveston Island, and High Island.

Most of the coastal structures within Sabine Lake are wharves, bulkheads, seawalls, and riprap revetments associated with industrial port facilities at Sabine Pass and on the western side of Sabine Lake at Port Arthur. The industrial shores also include short stretches of low bluffs around islands of dredged material and local marshes.

Major coastal structures within the Galveston Bay system include seawalls, breakwaters, jetties, groins, piers, industrial port facilities, and other structures that would be impacted by an oil spill. Most of the seawalls and revetments in the Galveston Bay system are associated with housing developments and small marinas at Follets Island, Bay Harbor-Sea Isle, Jamaica Beach, Pirates Beach, Eight Mile Road, Offatt Bayou, Port Bolivar, Rollover Pass, Smith Point, South Trinity Bay, Houston Point, Lynchburg, Morgan Point, LaPorte, West Galveston Bay, Swan Lake, Wilson Point, Basford Bayou, and Halls Lake. Most of the structures are designed to protect a single lot or tract of land and therefore their composition, design, and condition are highly variable. The only large breakwater structure in the Galveston Bay system is the long dike at Texas City. Numerous privately owned piers in the Galveston Bay system are associated with housing developments in West Bay, at Houston Point, LaPorte, and all along the West Galveston Bay shore. Industrial port facilities are located at Galveston Harbor, the refinery at Baytown, along the Houston Ship Channel, at Kemah/Clear Lake, and at Texas City. Other concrete structures in the Galveston Bay system are the San Luis Pass Bridge, the Interstate-45 Causeway to Galveston Island, and the Interstate 10 Bridge over the San Jacinto River. Another concrete structure is the cooling water outfall at the head of Trinity Bay. Remnants of roads and other structures are still present where the Brownwood subdivision of Baytown subsided and was permanently inundated.

Oil typically coats the coastal structures and the sparse plant and animal life associated with them. Vertical wall structures (seawalls, bulkheads) exposed to open ocean waves have the lowest ESI ranking because they are either self cleaning or they typically can handle the use of intrusive cleanup techniques such as low and high pressure washing and sandblasting. These techniques were used to cleanup the seawall and revetment at Galveston after the *Alvenus* oil spill in 1984. Oil penetration on vertical walls is limited to surface roughness features and cracks. The reason riprap revetments have a moderately high ESI ranking is the increased surface area and large voids that trap oil between the blocks. Some of the major cleanup concerns regarding coastal structures are logistics and the recovery of treated oil.

## Clay and Sand Scarps and Steep Slopes

The scarp classification (Figure 4) includes ESI Rankings 2A (clay scarps), 3B (sand scarps), and 8C (sheltered scarps). Scarps and steep slopes commonly are created by eroding bluffs that slump and are undercut by waves. They may represent natural shoreline features or they may form along mounds and embankments of dredged material. Scarps and steep slopes normally occur downwind of the prevailing winds where fetch across the bay and wave energy are greatest. Some scarps are fronted by narrow beaches and others are not. Whether or not there is a narrow beach depends on the activity of the bluff. Rapidly eroding bluffs have no beach and those where a major slump occurs may temporarily form a beach reworked from the slump material. A slumping bluff in Galveston Bay is shown in Figure 4a.

High clay bluffs in the Galveston Bay system are found along east Trinity Bay. This bluff shore also includes locally isolated bulkheads, revetments, and piers. Elsewhere, clay scarps occur along west Trinity Bay, at Baytown, Lynchburg, and the Old River sites, along San Jacinto Bay, and West Galveston Bay. The West Galveston Bay bluffs are densely developed by homes that also are fronted by numerous coastal structures and piers.

Some bay shorelines are characterized by relatively steep slopes composed of either clay or sand, that are covered with vegetation. The steep topographic gradient in such areas is manifested by relatively high nearshore elevations, which support upland to transitional vegetation rather than emergent marsh vegetation. Although there may be some fringing marsh along the water's

(a)

(b)

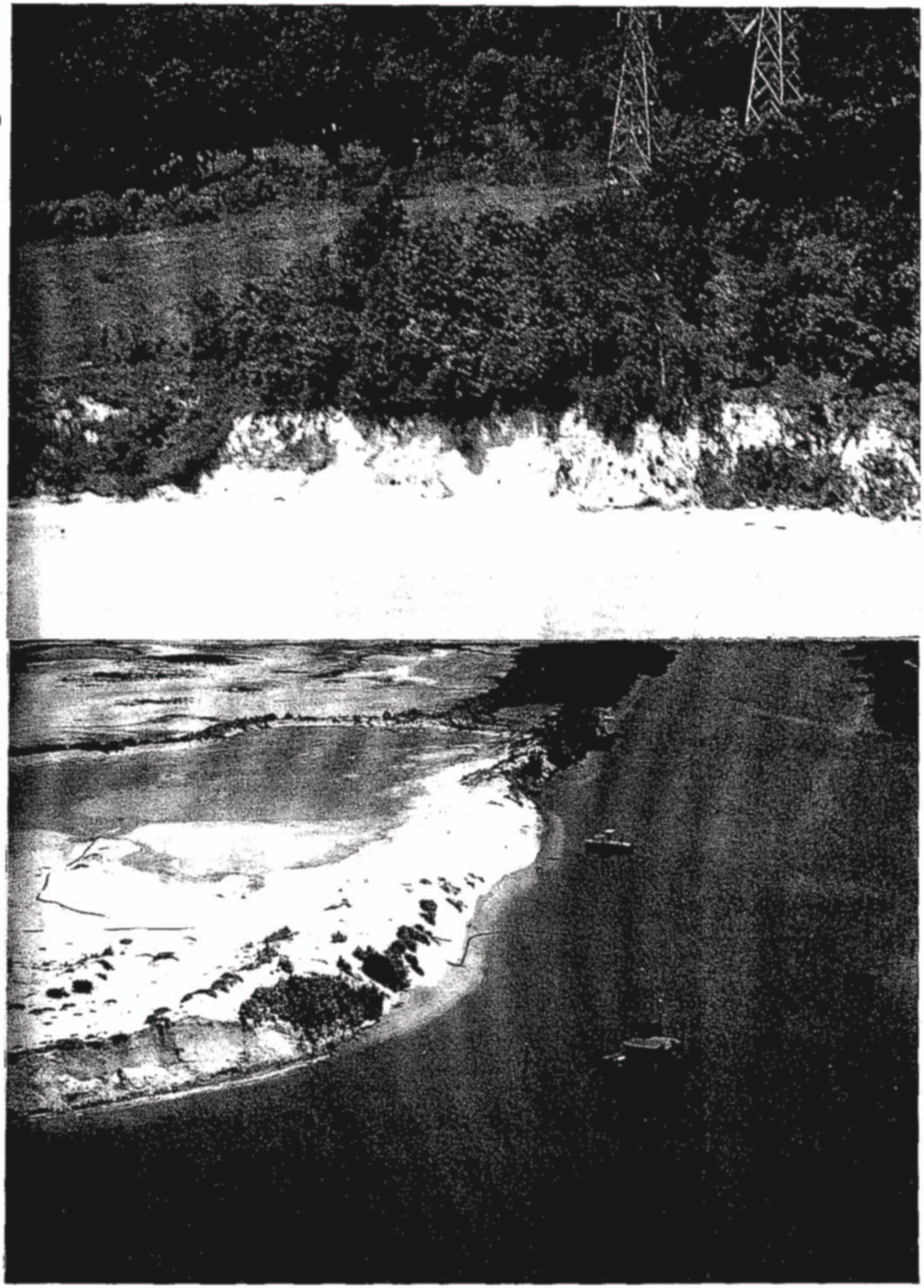


Figure 4. Examples of scarps composed of (a) clay and (b) sand.

edge, it is considered too narrow and not important enough to delineate on the maps. These shorelines were classified as either sheltered scarps (8C), clay scarps and steep slopes (2A), or sand scarps and steep slopes (3B).

The environmental sensitivity of bluffs and steep slopes is low due to limited plant and animal colonization. Oiling is limited to the lowest elevations because of the steep slopes. Oil typically stains the sediments and the nearshore debris that accumulates at the toe of the slope. The sediment penetration potential is low because of the steep slopes and clay substrates, but penetration potential increases slightly where substrates are composed of sand. Bluffs and steep slopes may be difficult to clean because of poor access and poor trafficability.

## Wave-cut Clay Platforms

The wave-cut clay platform classification (ESI Ranking 2B) describes a shoreline type that forms as a result of exposure to erosive waves generated naturally by wind or artificially by boats. Erosion of muddy substrates along navigation channels, the Gulf shoreline, or bay shores may produce a narrow shelf or platform bordering the water that is sometimes flooded and sometimes exposed depending on water level (Figure 5).

This shoreline type has a very limited areal distribution within the study area. Wave-cut clay platforms along the Texas Gulf shoreline are located in Jefferson County just west of Sabine Pass, in the vicinity of High Island where the washover terraces are located, and at Sargent Beach.

Wave-cut clay platforms generally have a low sensitivity to oil spill impacts and cleanup methods. Oil typically covers the platform near the high water line, but penetration is low because muds have low permeability. However, burrows formed by fiddler crabs in the muddy sediments allow deep oil penetration that is difficult to remove. Most of the wave-cut platforms of the Gulf shore are accessible but they cannot support heavy equipment.

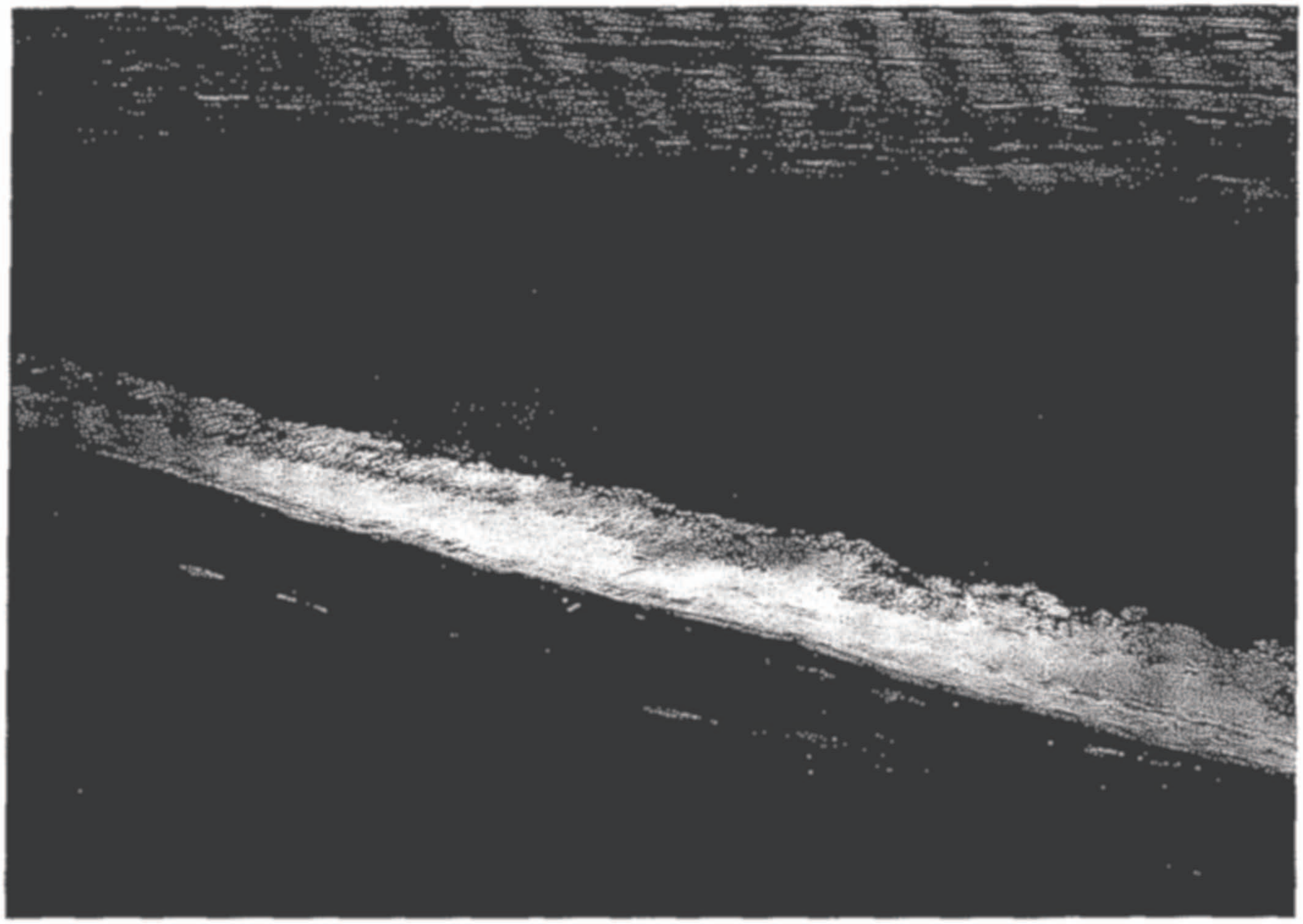


Figure 5. Example of a wave-cut clay platform.

## Fine-grained Sand Beaches

The fine-grained sand beaches classification (ESI Ranking 3A) describes beaches that have low slopes and an average grain size of 0.0625 to 0.25 mm (Figure 6). Generally these beaches also contain a small percentage of shell or shell hash. In Texas, the fine-grained sand beaches of the Gulf shore are 50 to 100 m wide, whereas in the bays, fine sand beaches are about 15 m wide.

Fine-grained sand beaches occur along most of the Texas Gulf shoreline. This shoreline type makes up most of the Texas barrier islands and peninsulas including Follets Island, West Beach of Galveston Island west of the seawall, East Beach of Galveston Island between the seawall and

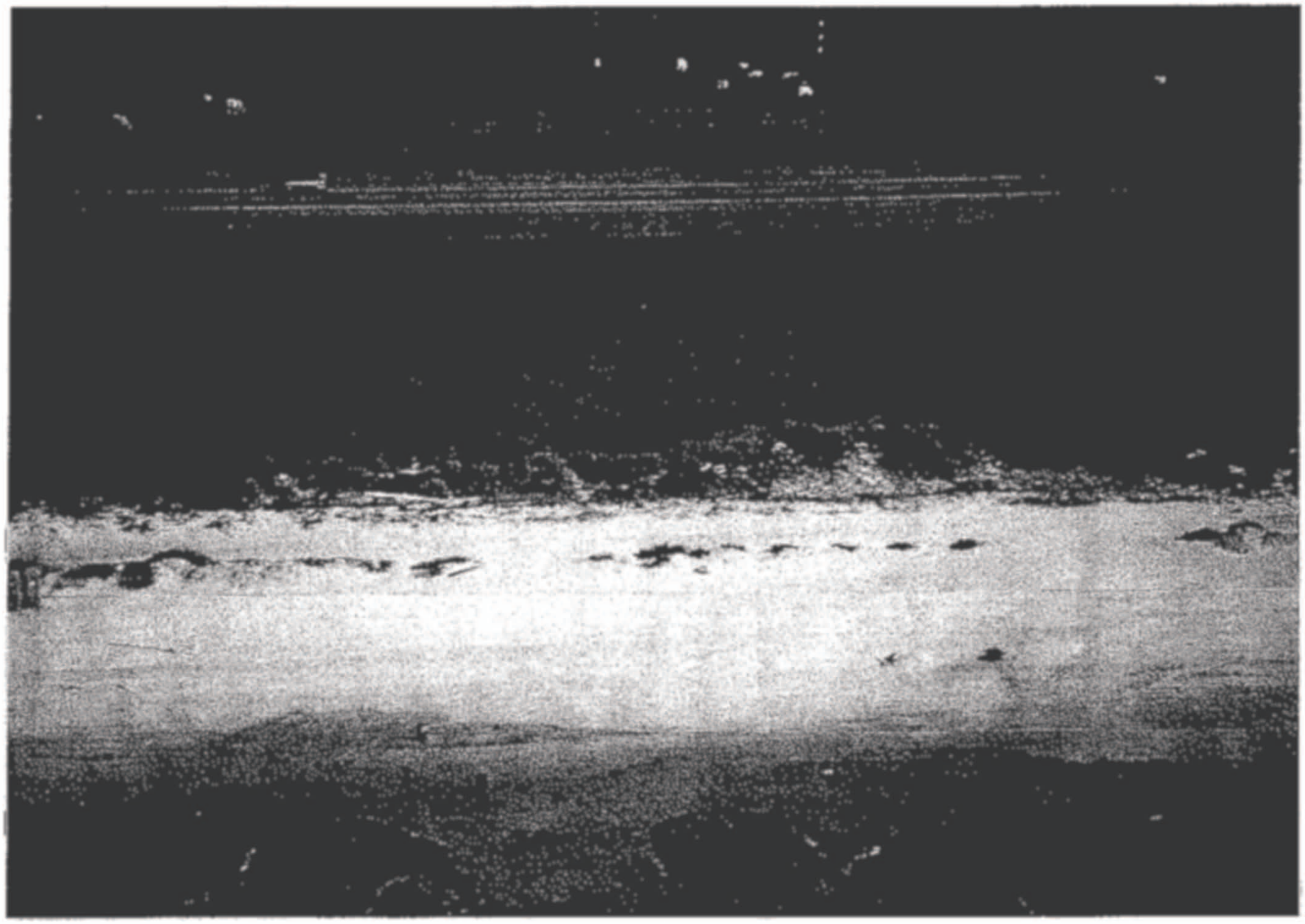


Figure 6. Example of a fine-grained sand beach.

south jetty, and Bolivar Peninsula. The Gulf shores of the Brazos Delta and the Gulf shore in the vicinity of Sea Rim State Park also are composed of fine-grained sand beaches.

Fine-grained sand beaches within the Galveston Bay system are located along south Galveston Bay and include reworked material dredged from the Gulf Intracoastal Waterway. Elsewhere fine-grained sand beaches are located along East Bay and around the large spoil islands of the Houston Ship Channel.

Fine-grained sand beaches generally have a low sensitivity to oil spill impacts and cleanup methods. Oil typically stains and covers the beach near the high water line, but penetration is low to moderate depending on the water table and the position of oil on the shoreline. A major environmental concern during beach cleanup is the protection of the dune habitat from the cleanup operations and the removal of sand from eroding beaches. Large volumes of stained sand and debris can be generated by cleanup of fine sand beaches. This occurred on West Beach of Galveston Island after the Alvenus oil spill. Most of the fine-grained sand beaches of the Gulf shore are accessible and can support heavy equipment. In the bays they are generally inaccessible and trafficability is limited.

## Coarse-grained Sand Beaches

The coarse-grained sand beaches classification (ESI Ranking 4) describes beaches that have moderate to steep slopes and an average grain size of 0.5 to 2.00 mm. Generally coarse-grained beaches are composed mostly of small shells or broken shells that form a shell hash. In Texas, coarse-grained sand beaches are located mostly in the bays and their distribution is limited. They commonly occur around mounds of dredged material that are reworked by waves. Coarse-grained sand beaches were not identified separately on the shoreline type maps because they almost always occur in conjunction with mixed sand and gravel (shell) beaches (ESI 5).

Coarse-grained sand beaches within the Galveston Bay system are located along south Galveston Bay and include reworked material dredged from the Gulf Intracoastal Waterway. Elsewhere coarse-grained sand beaches are located along East Bay and around the large spoil islands of the Houston Ship Channel.

Coarse-grained sand beaches generally have a moderate sensitivity to oil spill impacts and cleanup methods. Oil typically stains and covers the beach near the high water line, and penetration is moderate depending on the water table and the position of oil on the shoreline. A major environmental concern during beach cleanup is the potential for deep penetration and possible burial of oil making cleanup difficult. Large volumes of stained sand and debris can be generated by cleanup of coarse-grained sand beaches. Most of the coarse-grained sand beaches of the Gulf shore are accessible, but they are soft and can not support heavy equipment. In the bays they are generally inaccessible and trafficability is limited.

## Mixed Sand and Gravel (Shell) Beaches

The mixed sand and gravel (shell) beach classification (ESI Ranking 5) includes those beaches composed mostly of fine-grained sand that also contain a moderately high percentage of shell (Figure 7). These beaches occur on Bolivar Peninsula between Crystal Beach and Rollover Pass, between High Island and Sea Rim State Park, and along spoil islands in East and West Bays and Galveston Bay.

Figure 7. Example of a mixed sand and gravel (shell) beach.

In Texas, the environmental sensitivity of mixed sand and shell beaches is moderate due to the presence of relatively coarse material. Oil typically coats and covers the sediment and penetration potential is moderate because of the abundant shell. This shoreline type is characterized by poor trafficability. Mixed sand and gravel (shell) beaches are accessible where they occur along the Gulf shore but they generally are only accessible by boat in the bays.

## Gravel (Shell) Beaches

The gravel (shell) beach classification (ESI Ranking 6A) is used to describe shores that are composed almost entirely of shell (Figure 8). The shell material may be in the form of shell hash or whole shells. The sources for the shells include the nearshore zone or the bays. Shell beaches form steep beach faces because of the coarse shell fragments and whole shells making up the shore.

Beaches of the Gulf shore containing high concentrations of gravel (shell) are located at Sargent Beach, at San Luis Pass, and east of High Island. Only a short segment of the Gulf shore east of Sea Rim State Park was mapped as a gravel (shell) beach, all of the other gravel (shell)-rich segments were mapped as ESI Ranking 5 because they are composed of mixed sand and gravel (shell). In the bays, gravel (shell) beaches are common along shores near oyster reefs such as in East and West Bays, and along spoil islands where waves and currents rework spoil material and concentrate shells in steep berms and beaches.

The environmental sensitivity of gravel (shell) beaches is moderate due to the use of this shore type by estuarine organisms and extensive washover terrace development. Oil typically stains and coats the shell hash and whole shells composing the beach. Oil penetration is high due to the porous beach character created by the shell material. This beach type quickly turns into an asphalt pavement under heavy oiling conditions. Shell beaches have poor trafficability due to the low bearing strength and steep beach face. Accessibility to shell beaches in Texas is variable

(a)

(b)

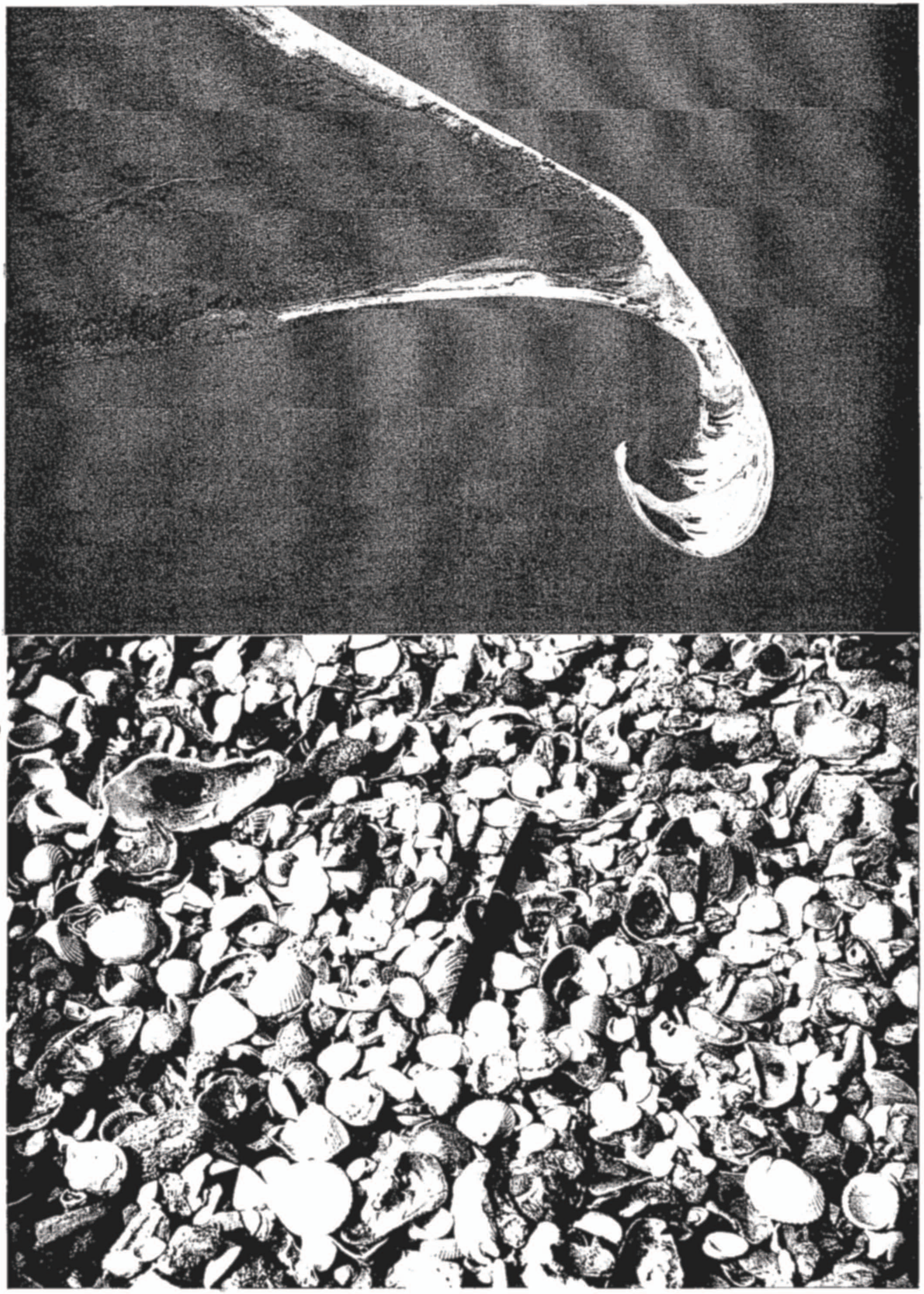


Figure 8. Example of gravel (shell) beaches (a) aerial view and (b) ground view.

depending on location. On the Gulf shore they are easily accessible but shell beaches in the bays are generally inaccessible except by boat.

## Exposed Tidal Flats

The exposed tidal flat classification (ESI Ranking 7) is used to describe broad intertidal areas normally consisting of fine sand and minor amounts of shell. The mean grain size ranges between 0.0625 and 0.200 mm. Exposed tidal flats are typically found in association with barrier islands (Figure 9) and tidal inlet systems. In Texas, tidal flats can be either submerged or exposed depending on water level, wind strength, and wind direction. Due to the low flat gradient, slight changes in water levels can produce significant changes in position where the water meets the shore. Salt marsh vegetation often develops along the upper intertidal areas of the exposed flats.

Figure 9. Example of an exposed tidal flat.

The only extensive sandy tidal flats along the Texas Gulf shoreline are found at the southwestern tip of Bolivar Peninsula where sand has been trapped by the north jetty. Sandy tidal flats within the Galveston Bay system are located on Galveston Island at San Luis Pass, at Big Reef on the margin of the Galveston-Houston Ship Channel, and on parts of Pelican Island where it has not been leveed to receive dredged material. The sandy flats of Pelican Island are also intermixed with salt marshes and the unit was mapped as marshes because of the higher environmental sensitivity of marshes relative to flats. Local sandy shoals, such as in Rollover Bay, were classified as exposed tidal flats.

The environmental sensitivity of sandy tidal flats is moderate due to the presence of abundant infauna. Oil tends to be transported across the flat and accumulate at the high-tide line. The oil penetration potential is low to moderate depending on the water level and location of the oil deposits. The trafficability is highly variable depending on substrate character. In Texas, many of the sandy tidal flats associated with backbarrier environments have poor trafficability and will not support heavy equipment. Access to exposed tidal flats in Texas is generally poor except by boat.

## Sheltered Tidal Flats

The sheltered tidal flat classification (ESI Ranking 9) is used to describe broad intertidal areas (Figure 10) normally consisting of mud and minor amounts of shell hash. The grain size of these shores typically is less than 0.0625 mm. Sheltered tidal flats are typically associated with prograding river mouths or eroding Gulf shores. Recently deposited muddy tidal flats are soft and dynamic shores rich in newly developed habitat. Older muddy flats are firm and exhibit a stable marsh vegetation. The amount of exposed mud flat decreases as the density of marsh vegetation increases until eventually little exposed mud flat remains. In some areas, ESI 9 was used to denote sand flats (common on barrier islands) that are sheltered from wave energy by their slightly higher elevations. These flats are not effected by the daily tidal cycle but are subject

Figure 10. Example of a sheltered tidal flat.

to inundation by wind-generated tides. Because of the infrequent inundation of the flats, oil that covers sediment and vegetation remains on the surface and is not removed by tidal action.

Sheltered tidal flats in Sabine Lake are associated with the Sabine River delta and in the Galveston Bay system, they are located along some bayous and creeks at the head of Galveston Bay. Sandy sheltered tidal flats are also common along the bay shore of west Galveston Island.

The environmental sensitivity of muddy tidal flats is high due to their high utilization by infauna and difficulty of cleanup. Oil does not adhere to the wet muddy substrates, but can penetrate into burrows. A major environmental concern associated with muddy tidal flats is the damage done by cleanup operations. Both access and trafficability of muddy tidal flats are poor.

## Salt- and Brackish-water Marsh

The salt- and brackish-water marsh classification (ESI Ranking 10A) describes the wet grasslands vegetated by plant species that tolerate salt and brackish water. The sediments of salt- and brackish-water marshes commonly are highly organic and muddy except on the margins of barrier islands where sand is abundant. Salt- and brackish-water marshes are extensive around the margins of the bays in Texas (Figure 11).

Figure 11. Example of a salt- and brackish-water marsh.

The only extensive salt-water marshes within the upper Texas coastal plain are located in Jefferson County just west of Sabine Pass. A smaller area of salt-water marsh is located at the southern tip of Bolivar Peninsula in the sheltered area between the north jetty and the peninsula. Salt- and brackish-water marshes within Sabine Lake are located at Sabine Pass and the lower alluvial valleys and deltas of the Sabine and Neches River. Within the Galveston Bay system, extensive salt- and brackish-water marshes are located on Follets Island, Galveston Island, and Bolivar Peninsula, and around Dollar Bay, Greens Lake, Chocolate Bay, and West Bay-Bastrop Bay and on the Trinity River delta at the head of Trinity Bay. The West Bay-Bastrop Bay marshes also are intermixed locally with sandy tidal flat and perched sand and shell beaches. The largest continuous expanse of brackish-water marsh on the Texas coastal plain is located between Sabine Pass and East Bay and includes parts of Jefferson and Galveston Counties.

The environmental sensitivity of salt- and brackish-water marshes is high because of the presence of wetland habitat. Oil typically stains and covers both sediment and vegetation. The oil penetration is low due to the high water table and the muddy composition of the sediments. A major environmental concern about salt- and brackish-water marsh is that the cleanup may be more damaging than the oil itself. In Texas, the access and trafficability of salt- and brackish-water marshes are generally poor due to the muddy sediment.

## Fresh-water Marsh

The fresh-water marsh classification (ESI Ranking 10B) is used to describe the densely vegetated coastal interior that is not inundated by salt water and the sediments typically are highly organic and muddy. Fresh-water marshes are characterized by high biodiversity and rich wetland habitat. This shoreline type is found within the river valleys and along the uplands at elevations higher than the tidal range (Figure 12).

Fresh-water marshes occur predominantly upstream of the brackish-water marshes in the alluvial valleys of major rivers and along inland stretches of tributary bayous and creeks. The only extensive fresh-water marshes within Sabine Lake are found on the Sabine River delta and

Figure 12. Example of a fresh-water marsh.

inland along the Neches River. Within the Galveston Bay system, extensive fresh-water marshes are located inland of the Trinity River delta.

The environmental sensitivity of fresh-water marsh is also high for the same basic reasons as those given for salt- and brackish-water marshes. Oil tends to coat the above-ground vegetation. The oil penetration is low due to the high water table and the muddy composition of the sediments, except in burrows. A major environmental concern about fresh-water marsh is that the cleanup may be more damaging than the oil itself. In Texas, the access and trafficability of fresh-water marshes are generally poor due to the muddy sediment.

## Fresh-water Swamps

The fresh-water swamp classification (ESI Ranking 10C) describes shores that consist of shrubs and hardwood forested wetlands (Figure 13). This shoreline type, which is essentially a flooded forest, is common in the river valleys of the upper Texas coast. The sediments within the interior swamps tend to be silty clay and contain a large amount of organic debris.

Figure 13. Example of a fresh-water swamp.

Forested swamps within the Sabine Lake area are located in the valleys of the Sabine and Neches Rivers. Within the Galveston Bay system, swamps are located upstream of the coast in the valleys of the Trinity River and San Jacinto River.

The environmental sensitivity is high for swamps because of the ecological value of the swamps, presence of oil-sensitive organisms, and difficulty of cleanup. Oil usually coats vegetation and can heavily contaminate accumulated debris. The sediment penetration is low due to the high water table and the muddy composition of the sediments. A major environmental concern is that the cleanup may be more damaging than the oil itself. The access and trafficability of swamps are poor due to the soft sediment and the presence of dense tree growth.

## EXAMPLES OF MULTIPLE SHORELINE TYPES AND THEIR ESI RANKINGS

Many of the bay shores and some of the Gulf shore segments exhibit several different types of shorelines that are juxtaposed. Because the adjacent shoreline types are vulnerable to spilled oil, they are mapped as combined shoreline types with an emphasis on the shoreline type closest to the water. The following sections briefly describe some of the most common multiple shoreline types found in the Sabine to Sargent region.

### Tree-Lined Marshes (10B/10C)

In some areas along rivers, bayous, and artificial channels of the upper Texas coast, bald cypress trees line the shores of marsh habitats. In places, the stand of trees is several trees wide. Locally, however, only a single, continuous line of closely spaced trees is present. The presence of the trees is considered significant and an important part of the overall habitat setting and its sensitivity to oiling and cleanup activities. The classification of these shorelines (10B/10C) documents both the marsh and the line of trees that border the marsh and channel (Figure 14).

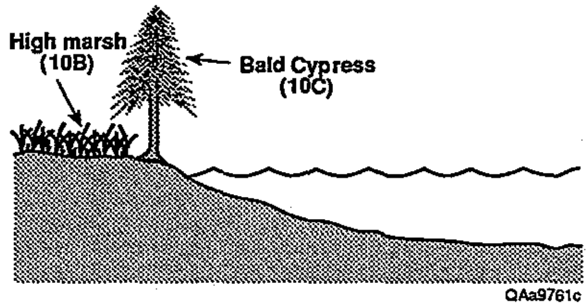



Figure 14. Multiple shoreline types consisting of fresh-water marsh and wetland trees lining the shore. These shorelines are classified as 10B/10C.

## Marshes Bordered by Low Wave-Cut Clay Scarps (10A/2A)

In some areas, shorelines are undergoing erosion and are characterized by a high marsh along the seaward margin of which is a low wave-cut clay scarp. If the clay scarp is considered significant and could provide the marsh some protection, both the scarp and the marsh are mapped. A classification of 10A/2A in such cases indicates that the clay scarp is seaward of the marsh. Locally, narrow or fringing bands of intertidal or topographically low marsh front clay scarps in which case the designation is reversed, 2A/10A, indicating that a higher clay platform is landward of the fringing marsh (Figure 15a). If a topographically high marsh is landward of the clay scarp, then a 10A/2A/10A designation is used to indicate a sequence consisting of a landward high marsh, succeeded by a clay scarp, followed by a seaward low fringing marsh. These multiple types of shorelines are occasionally mapped along the mainland shores of East and West Galveston bays. In some sheltered areas, shorelines are locally characterized by marshes fringing sheltered scarps and are designated as 8C/10A.

Marshes Bordered by Perched Beaches and Clay Platforms (10A/5/2B)

A perched beach forms where a thin deposit of sand and shell overlies a fresh or salt marsh with an eroded marsh platform outcropping in the surf zone (Figure 15b). Perched sand and shell beaches can occur as a continuous straight shoreline or as a series of pocket beaches.

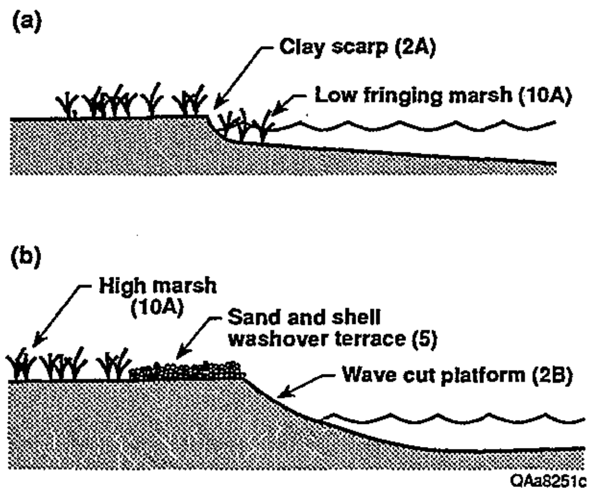



Figure 15. Multiple shoreline types consisting of marshes, a clay scarp, perched beach, and a wave-cut platform. These shorelines are classified as (a) 2A/10A, and (b) 10A/5/2B.

Perched sand and shell beaches deposited as washover terraces are the principal shoreline type at Sargent Beach, near High Island, and in Jefferson County just west of Sabine Pass. These perched sand and shell beaches are also typically associated with muddy wave-cut platforms. In the Galveston Bay system, wave-cut clay platforms with perched sand and shell beaches can form anywhere salt marshes are the predominant shore type. These storm deposits are prominent on West Galveston Island and at Gangs Bayou.

Shell Berms, Clay Scarps, and Marshes (10A/6A/2A)

Along some bay shorelines where oysters are abundant it is common to have oyster shells reworked by waves and currents and deposited alongshore. In most instances these shores consist of shell berms (6A). If the shell is deposited on the seaward side of an erosional clay bluff or scarp, then the shore is classified as 2A/6A. Locally the shell is reworked during storms and deposited as a washover terrace on a marshy clay platform landward of the clay scarp. These shorelines are classified as 6A/2A to reflect a shell terrace landward of the scarp. Where the shell has been deposited on a marsh, it is designated 10A/6A to recognize the marsh that lies landward of the shell washover terrace. Locally, all three types are recognized (10A/6A/2A)(Figure 16). Examples of these types occur on the mainland shore of East Galveston Bay.

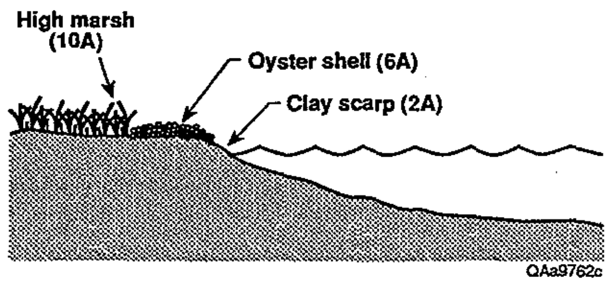



Figure 16. Multiple shoreline types consisting of a marsh, shell berm, and clay scarp. These shorelines are classified as 10A/6A/2A.

Sandy Washover Terraces and Marshes (10A/3A)

Along the western shore of West Bay and Chocolate Bay, sand has been deposited on the margins of marsh habitat by storm waves forming sandy washover terraces or aprons. These shorelines are designated 10A/3A (Figure 17) or 3A/10A depending on whether the sand lies seaward or landward of the marsh.

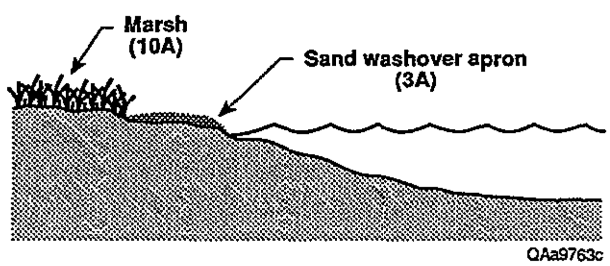



Figure 17. Multiple shoreline types consisting of a marsh and sand washover deposit. These shorelines are classified as 10A/3A.

Scarps Lined by Bulkheads and Riprap (2A/1 and 3B/1)

Along some shores, failed bulkheads lie offshore from erosional clay or sand scarps. These areas are mapped as 2A/1 (Figure 18) and 3B/1 along wave exposed shorelines to reflect both the scarp and bulkhead.

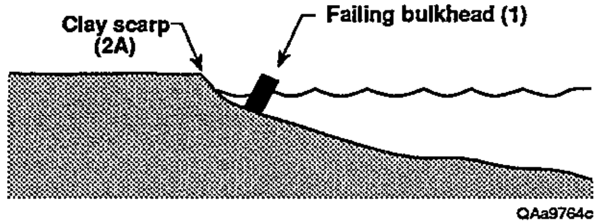



Figure 18. Multiple shoreline types consisting of a clay scarp and failing bulkhead. These shorelines are classified as 2A/1.


ACKNOWLEDGMENTS

This project partly fulfills requirements stipulated in Section 4107 of the Texas Natural Resources Code. The work was supported primarily by funding from the Texas Natural Resources Inventory Program (NRI) through Interagency Contract IAC 94-0198. The NRI Program is a coordinated effort among the State's natural resource trustees (Texas General Land Office, Texas Natural Resource Conservation Commission, and Texas Parks and Wildlife Department). Funding for this project meets all requirements as provided in Oil Spill Prevention and Response Act of 1990. Additional funding was provided by the U.S. Geological Survey Coastal Geology Program that partly supported preliminary geomorphologic mapping, field reconnaissance work, and the video survey of shoreline types. Funding from the Minerals Management Service through the Louisiana State University Coastal Marine Institute supported shoreline type mapping along the coast between the tidal inlets at San Luis Pass and East Matagorda Bay (Brown Cedar Cut).

## REFERENCES


Fisher, W. L., Brown, L. F., Jr., McGowen, J. H., and Groat, C. G., 1973, Environmental geologic atlas of the Texas coastal zone, Beaumont–Port Arthur area: The University of Texas at Austin, Bureau of Economic Geology, 93 p.

Fisher, W. L., McGowen, J. H., Brown, L. F., Jr., and Groat, C. G., 1972, Environmental geologic atlas of the Texas coastal zone, Galveston–Houston area: The University of Texas at Austin, Bureau of Economic Geology, 91 p.

Gundlach, E. R., and Hayes, M. O., 1978, Vulnerability of coastal environments to oil spill impacts: Marine Technology Society Journal, v. 12, p. 18–27.

Gundlach, E. R., Finklestein, K. J., and Sadd, J. L., 1981, Impact and persistence of Ixtoc I oil on the south Texas coast: Proceedings of the 1981 Oil Spill Conference American Petroleum Institute, Washington, D.C., p. 477–485.

Hayes, M. O., Gundlach, E. R., and Getter, C. D., 1980, Sensitivity ranking of energy port shorelines, in Proc. Specialty Conference, American Society of Civil Engineers, New York, N.Y., p. 697–709.

Hayes, M. O., Michel, J., and Brown, P. J., 1976, Coastal geomorphology and sedimentation, Lower Cook Inlet, Alaska: Tech. Report. No. 12-CRD, Dept. of Geology, Univ. of South Carolina, Columbia, 107 p.

Michel, J., and Dahlin, D., 1993, Guidelines for developing digital environmental sensitivity index atlases and databases: Research Planning Inc., report prepared for the National Oceanic and Atmospheric Administration, Hazardous Materials Response and Assessment Division, 43 p.

Michel, J., and Hayes, M. O., 1992, An introduction to coastal habitats and biological resources for oil spill response: National Oceanic and Atmospheric Administration, Hazardous Materials Response and Assessment Division, Report No. HMRAD 92-4, 83 p.

Michel, J., Hayes, M. O., and Brown, P. J., 1978, Application of an oil spill sensitivity index to the shoreline of lower Cook Inlet Alaska: Environmental Geology, v. 2, p. 107–117.

Morton, R. A., 1974, Shoreline changes on Galveston Island (Bolivar Roads to San Luis Pass): The University of Texas at Austin, Bureau of Economic Geology Geological Circular 74-2, 34 p.

Morton, R. A., 1975, Shoreline changes between Sabine Pass and Bolivar Roads: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 75-6, 43 p.

Morton, R. A., and Pieper, M. J., 1975, Shoreline changes in the vicinity of the Brazos River delta: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 75-4, 47 p.

Paine, J. G., and Morton, R. A., 1986, Historical shoreline changes in Trinity, Galveston, East, and West Bays, Texas Gulf Coast: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 86-3, 58 p.

Paine, J. G., and Morton, R. A., 1989, Shoreline and vegetation-line movement, Texas Gulf Coast, 1974 to 1982: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 89-1, 50 p.

Texas Water Commission, 1989, Spill Response Map Series Coastal Region: Austin, Texas.

Westphal, K. A., Penland, S., Seal, R. W., and Morton, R. A., 1992, Aerial videotape survey of coastal Texas and Louisiana: Center for Coastal, Energy, and Environmental Resources, Louisiana State University, Coastal Geology Map Series No. 13, 210 p.

White, W. A., Calnan, T. R., Morton, R. A., Kimble, R. S., Littleton, T. G., McGowen, J. H., and Nance, H. S., 1987, Submerged lands of Texas, Beaumont-Port Arthur area: sediments, geochemistry, benthic macroinvertebrates, and associated wetlands: The University of Texas at Austin, Bureau of Economic Geology, 110 p.

White, W. A., Calnan, T. R., Morton, R. A., Kimble, R. S., Littleton, T. G., McGowen, J. H., and Nance, H. S., 1988, Submerged lands of Texas, Bay City–Freeport area: sediments, geochemistry, benthic macroinvertebrates, and associated wetlands: The University of Texas at Austin, Bureau of Economic Geology, 130 p.

White, W. A., Calnan, T. R., Morton, R. A., Kimble, R. S., Littleton, T. G., McGowen, J. H., Nance, H. S., and Schmedes, K. E., 1985, Submerged lands of Texas, Galveston-Houston area: sediments, geochemistry, benthic macroinvertebrates, and associated wetlands: The University of Texas at Austin, Bureau of Economic Geology, 145 p.

White, W. A., Tremblay, T. A., Wermund, E. G., and Handley, L. R., 1993, Trends and status of wetland and aquatic habitats in the Galveston Bay system, Texas: Galveston Bay