Shoreline Types of the Central Texas Coast: Matagorda to Corpus Christi Areas

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EXECUTIVE SUMMARY

The following report describes how the Bureau of Economic Geology (BEG) classified and mapped the shores of the central Texas coast, 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 1997, oblique color slides taken in 1992, and previous field experience. The maps were spot checked in May 1998 from the ground. The Matagorda to Corpus Christi region was selected for the second 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 and other estuarine scrub-shrub wetlands. All of these shoreline types are present along the central Texas coast.

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.

The purpose of this coastal mapping project was to produce a set of large-scale, high-quality maps of shoreline characteristics of the central Texas coast that were suitable for digitization and incorporation into a geographic information system (GIS). The shoreline maps and digital databases represent a significant component 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 Matagorda to Corpus region was selected as the second 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 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 860 miles of shoreline that are represented on 57 topographic quadrangle maps (Figure 1). A list of the quadrangle maps used as base maps is given in Table 1.

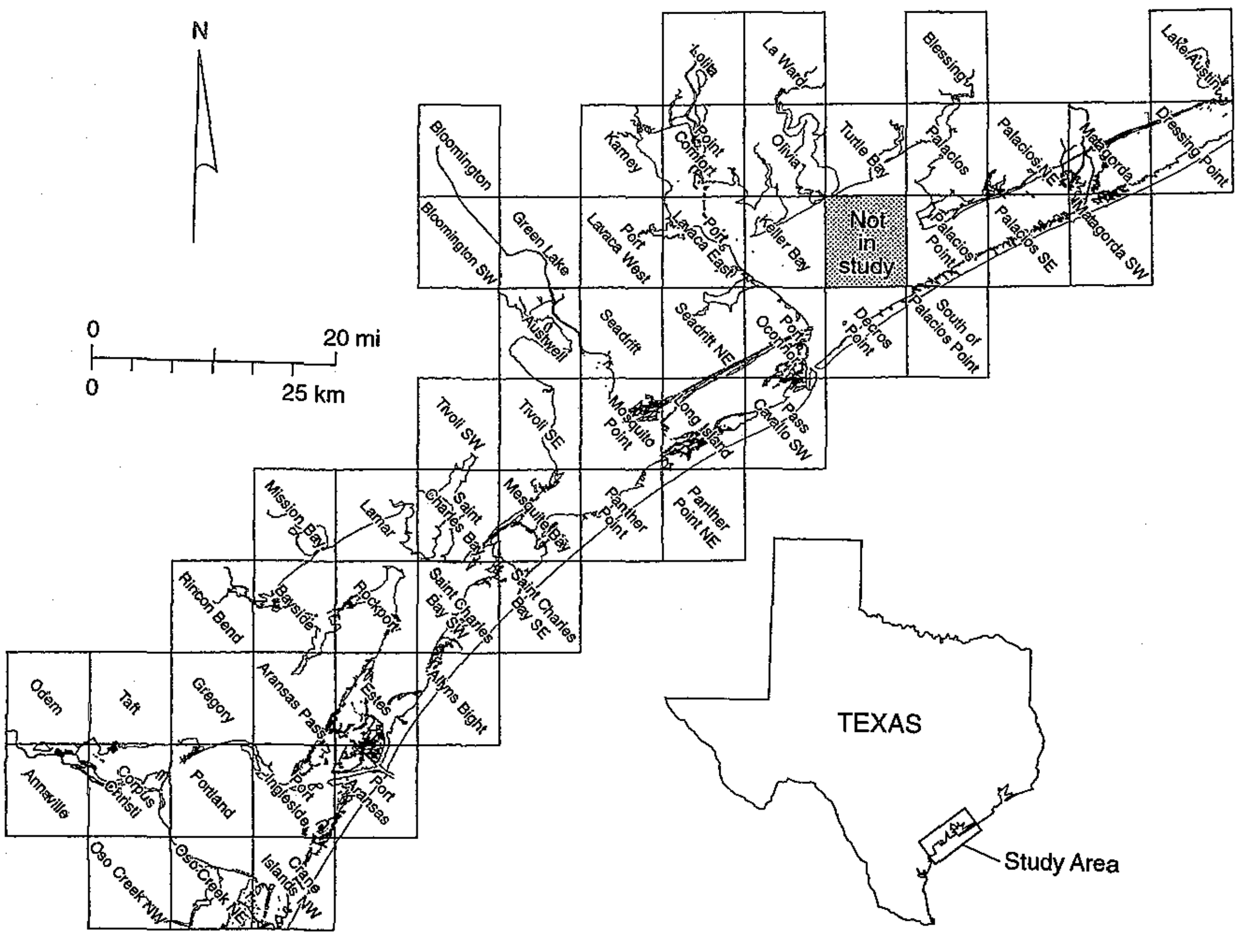

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Figure 1. Index map of the study area showing the locations of 7.5-minute U.S.G.S. topographic maps.

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

Allyns Bight	Oso Creek NE
Annaville	Oso Creek NW
Aransas Pass	Palacios
Austwell	Palacios NE
Bayside	Palacios Point
Blessing	Palacios SE
Bloomington	Panther Point
Bloomington SW	Panther Point NE
Corpus Christi	Pass Cavallo SW
Crane Island NW	Point Comfort
Decros Point	Port Aransas
Dressing Point	Port Ingleside
Estes	Port Lavaca East
Green Lake	Port Lavaca West
Gregory	Port O'Connor
Kamey	Portland
Keller Bay	Rincon Bend
La Ward	Rockport
Lake Austin	Seadrift
Lamar	Seadrift NE
Lolita	South of Palacios Point
Long Island	St. Charles Bay
Matagorda	St. Charles Bay SE
Matagorda SW	St. Charles Bay SW
Mesquite Bay	Taft
Mission Bay	Tivoli SE
Mosquito Point	Tivoli SW
Odem	Turtle Bay
Olivia	

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 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 multiyear 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 central 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 1997, the Bureau conducted a study of wetland and aquatic habitats in the Corpus Christi Bay system in support of the Corpus Christi Bay National Estuary Program (White et al., 1998). 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 probable causes of wetland trends including relative sea-level rise and human activities.

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 2-16). 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 by U.S.G.S. topographic map areas (scale 1:24,000) (Table 1) using shoreline positions updated by the Texas General Land Office from U.S. Fish and Wildlife Service National Wetlands Inventory (NWI) maps. Areas that had been modified since NWI mapping were updated where possible using the most recent available aerial photographs and a Bausch and Lomb Zoom Transfer Scope.

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

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 Center for Coastal, Energy, and Environmental Resources (CCEER) (Westphal et al., 1997) and recorded during a cooperative helicopter flight in May of 1997 by staff of the CCEER and BEG. Videotapes were high quality and were accompanied by GPS locations and audio commentaries of shoreline types made by experienced coastal geologists.

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. Available 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 or orthophoto quadrangles taken during the years 1979 through 1995 (Table 4). Shorelines were analyzed using stereoscopes with a magnification of at least 6X.

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 and steep slopes
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 and other estuarine scrub-shrub wetlands

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: Failed bulkhead or breakwater seaward of scarp 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	

Figure 2. Examples of coastal structures (a) exposed seawall in Corpus Christi Bay with riprap, and (b) typical port facilities with bulkheads such as this refinery at Corpus Christi.

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
1979	1:65,000	CIR	NASA	Inland areas northern half of map area
1992	1:65,000	CIR	NASA	Corpus Christi Bay to San Antonio Bay
1994	1:24,000	COLOR	TPWD	Corpus Christi Aransas and Copano Bays
1995	1:12,000	CIR	USGS Orthophoto quads	Matagorda and Palacios quads

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.

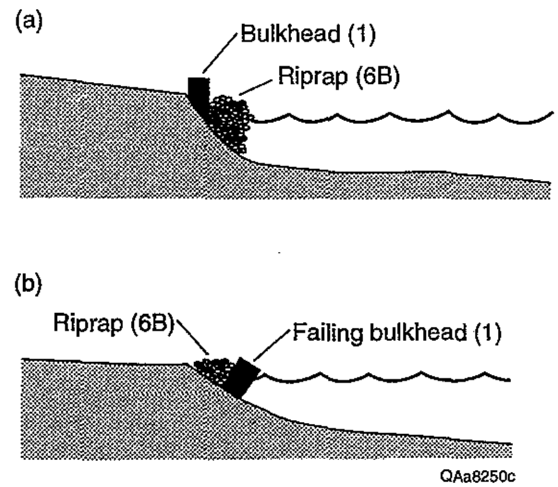

Figure 3. Multiple shoreline types consisting of exposed bulkheads and riprap. The shorelines are classified as 1/6B or 6B/1 depending on whether the bulkhead is landward (a) or seaward (b) of the riprap.

Locally, as many as three shoreline types may be recognized in an alpha-numeric sequence, such as 8C/10A/2B, which details a shoreline that progresses from a sheltered scarp to a salt/ brackish marsh perched on a wave-cut clay platform.

Delineation of Wetlands Using NWI Data

U.S. Fish and Wildlife Service National Wetlands Inventory (NWI) data were used 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).

Field Verification and Modifications

The Environmental Sensitivity Index rankings and boundaries of selected shoreline units mapped by the BEG were checked on the ground at some sites 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 armored shorelines such as along the landward margin of Laguna Madre and at the junction of the GIWW and the Colorado River, 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 BEG were responsible for field checking and completing original work maps during post-mapping surveys. Maps were field

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) (Needle-leaved deciduous) (Needle-leaved evergreen)	E2SS 1, 2, &4
10D Mangroves	Estuarine Intertidal Scrub/Shrub Wetland (Broad-leaved evergreen)	E2SS3

checked to ensure completeness and accuracy of shoreline designations. Completed and field checked maps were then digitized and entered into a Geographic Information System (GIS). The BEG 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. BEG 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.

SHORELINE TYPES OF THE CENTRAL 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 central 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 central 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, where it is landlocked, 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. 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 central Texas coast include three sets of paired jetties. Long jetties constructed of large granite blocks are located at each of the major ship channels: Matagorda Ship channel, which crosses Matagorda Peninsula, and Corpus Christi Ship channel entrance, which coincides with Aransas Pass. Short jetties also constructed of granite blocks are located in Mustang Island State Park at the entrance to the Fish Pass, which has closed naturally by shoaling sand.

Most of the coastal structures within East Matagorda Bay are along short stretches of the GIWW such as at Chinquapin Landing near the mouth of Live Oak Bayou and Lake Austin. Major coastal structures within the San Antonio 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 Copano Bay system are associated with housing developments and small marinas at Copano Village, Hannibal Point, and Bayside. 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.

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. 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 Nueces Bay is shown in Figure 4a.

High clay bluffs in the Matagorda-Lavaca Bay system are found along the southwest shore near Alamo Beach. This bluff shore also includes bulkheads, revetments, and piers. Elsewhere, clay scarps occur along bluffs of Nueces Bay and Corpus Christi Bay, and some bluffs at Portland and along Ocean Drive of Corpus Christi are densely developed by homes that also are fronted by numerous coastal structures and piers.

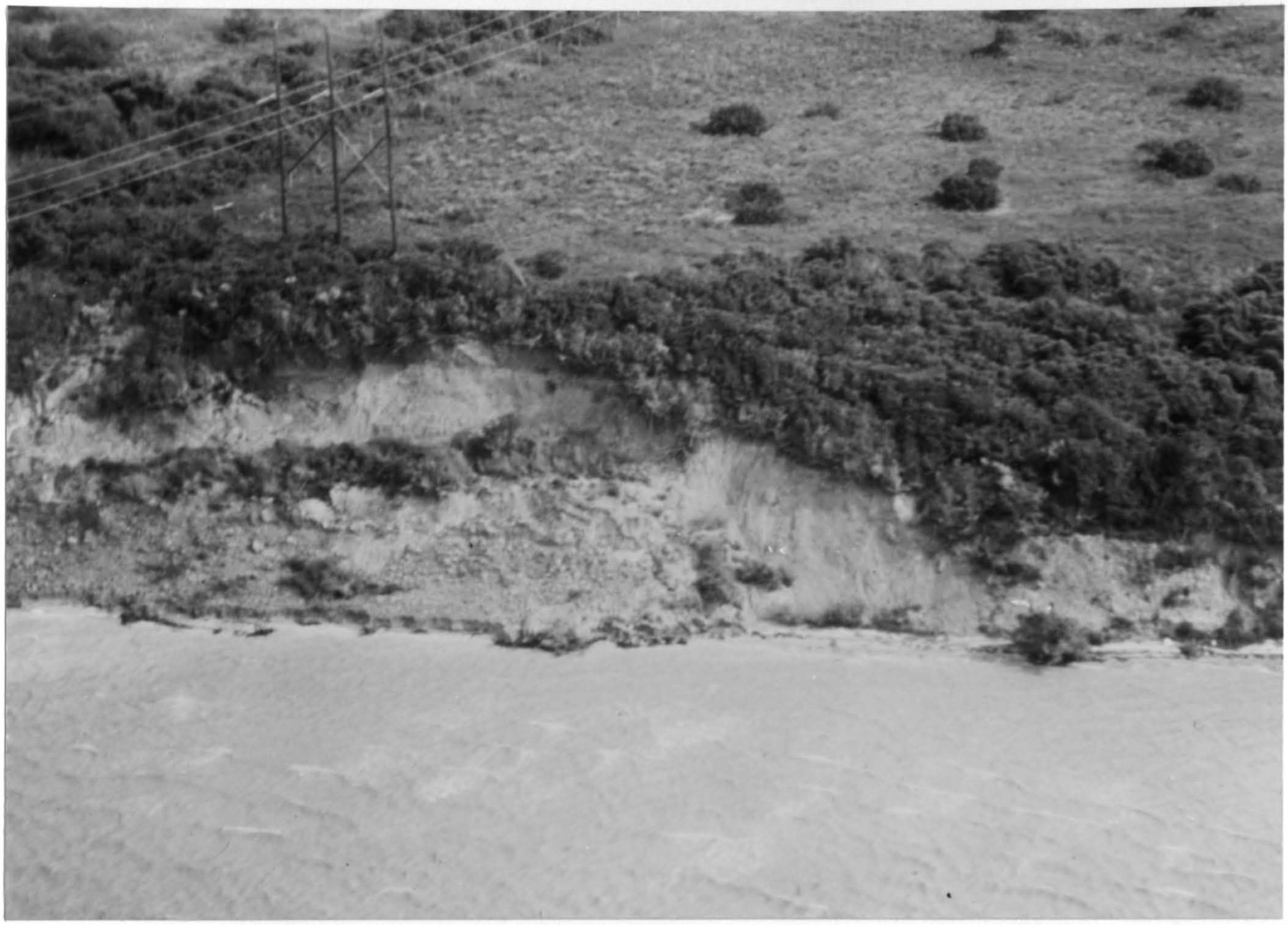

Figure 4a. Examples of scarps composed of clay.

Some bay shorelines are characterized by relatively steep slopes composed of either clay or sand, that are covered with vegetation (Figure 4b). 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 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.

Figure 4b. Examples of scarps composed of sand.

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. There are no wave-cut platforms of the Gulf shore in the Central Texas coast map area, however a clay platform is located at the head of Lavaca Bay.

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.

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 5). 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.

Examples of fine-grained sand beaches occur along most of the Gulf shoreline of the central Texas coast. This shoreline type makes up most of the Texas barrier islands and peninsulas including Matagorda Island, San Jose Island, and Mustang Island.

Fine-grained sand beaches within the Lavaca-Matagorda Bay system are located along the northern side of Matagorda Peninsula near the Ship Channel and within the Corpus Christi-Aransas Bay system along the Pleistocene barrier strandplain near Ingleside and Rockport.

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

Figure 5. Example of a fine-grained sand beach.

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. 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 and all of the shell-rich beaches were mapped as either ESI 5 or 6A.

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 6). These beaches occur on segments of Matagorda Peninsula west of the Colorado River entrance.

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.

Figure 6. Example of a mixed sand and gravel (shell) beach.

Gravel (Shell) Beaches

The gravel (shell) beach classification (ESI Ranking 6A) is used to describe shores that are composed almost entirely of shell (Figure 7). 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 mapped as ESI Ranking 5 because they are composed of mixed sand and gravel (shell). In the

Figure 7. Example of gravel (shell) beaches (a) aerial view and (b) ground view.

bays, gravel (shell) beaches are common around Shamrock Island, along the margins of erosional shorelines on Matagorda Peninsula, on the southwestern shores of Matagorda Bay, 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 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 8) 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.

The only extensive sandy tidal flats along the Texas Gulf shoreline are found at the southwestern tip of Matagorda Peninsula where sand is being deposited on the margin of pass Cavallo. Sandy tidal flats within the Corpus Christi Bay system are located on Mustang Island and North Padre Island. In many areas the sandy flats are also intermixed with salt marshes and the unit was mapped as marshes because of the higher environmental sensitivity of marshes

Figure 8. Example of an exposed tidal flat.

relative to flats. Local sandy shoals on barrier islands that appeared to be frequently flooded were classified as exposed tidal flats. Other examples of exposed tidal flats are on the Nueces River delta, in Laguna Madre, and Oso Bay.

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 9) normally consisting of mud, sandy mud, muddy sand, and minor amounts of shell hash. The grain size of theses shores typically is less than 0.0625 mm. Sheltered tidal flats are typically associated with prograding river mouths. 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

Figure 9. Example of a sheltered tidal flat.

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 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 on the margins of Mustang Island and Harbor Island are associated with the Corpus Christi Bay system, they are located at the head of Oso Bay and along Oso Creek. Sandy sheltered tidal flats are also common along the bay shore of North Padre 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 10). In all the bays, extensive salt- and brackish-water marshes are located on the margins of barrier islands and bayhead deltas. Salt marshes also are intermixed locally with sandy tidal flat and perched sand and shell beaches.

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.

Figure 10. Example of a salt- and brackish-water marsh.

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 11). 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 most extensive fresh-water marshes within the map area are found on the Guadalupe River delta and inland along the Guadalupe River.

Figure 11. Example of a fresh-water marsh.

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 12). This shoreline type, which is essentially a flooded forest, is not common but does occur locally in the river valleys of the central Texas coast. The sediments within the interior swamps tend to be silty clay and contain a large amount of organic debris. Forested swamps within the map area are located in the valleys of the Nueces River. Within the Palacios Bay system, swamps are located upstream of the coast in the valley of Tres Palacios Creek.

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

Figure 12. Example of a fresh-water swamp.

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 Matagorda to Corpus Christi region.

Mangrove-Lined Marshes (10A/10D)

On some estuarine islands mixtures of salt marshes and black mangrove shrubs are common. Where salt marsh vegetation is lined with mangroves, the classification is 10A/10D (Figure 13), and where marshes are seaward of the mangroves, this order is reversed. These classifications are common in the Harbor Island/Redfish Bay area and near Pass Cavallo at the northeastern end of Espiritu Santo Bay.

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 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 (Figure 14). This multiple type of shoreline is occasionally mapped along channels in deltaic marshes such as in the Nueces River delta. In some sheltered areas, shorelines are locally characterized by marshes fringing sheltered scarps and are designated as 8C/10A.

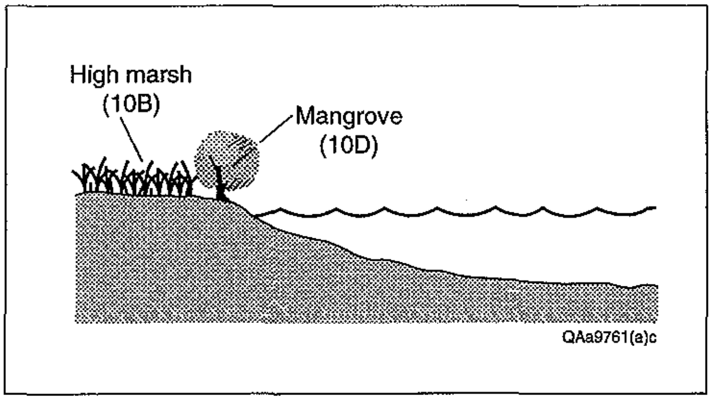

Figure 13. Multiple shoreline types consisting of fresh-water marsh and wetland trees lining the shore. These shorelines are classified as 10B/10D.

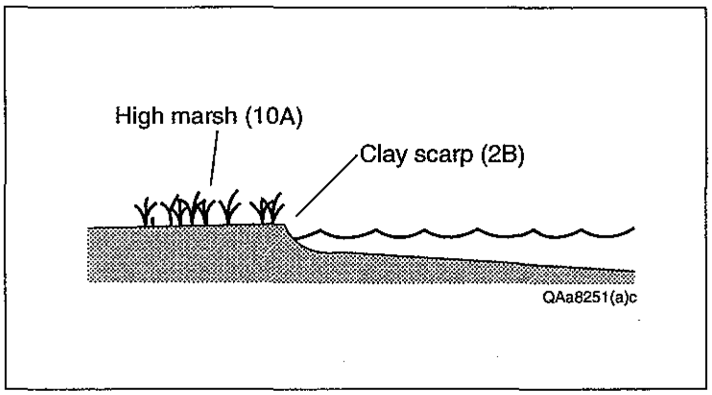

Figure 14. Multiple shoreline types consisting of marshes and a clay scarp. These shorelines are classified as 10A/2B.

Clay Scarps Bordered by Eroding Marshes and Clay Platforms (8C/10A/2B)

Along some stretches of bay shoreline such as at the head of Lavaca Bay, marshes and associated clay substrates have developed bayward of erosional Pleistocene scarps. As the marsh and substrate erodes, a perched clay platform develops seaward of the marsh and clay scarp. Because the Pleistocene clay scarp is protected or sheltered by the marsh, it is classified as a sheltered scarp. This type of shoreline is designated as 8C/10A/2B, indicating a sequence progressing from a sheltered scarp, to salt marsh, to perched clay platform.

Shell Berms and Marshes (10A/6A)

One of the most common shoreline designations occurs along bay shorelines where oysters are abundant and the shells have been reworked by waves and currents and deposited alongshore. In most instances these shores consist of shell berms (6A). Where the shell has been deposited on a marsh, it is designated 10A/6A to recognize the marsh that lies landward of the shell berm (Figure 15). Examples of these types occur on the bay shore of Matagorda Peninsula.

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 16) and 3B/1 along wave exposed shorelines to reflect both the scarp and bulkhead.

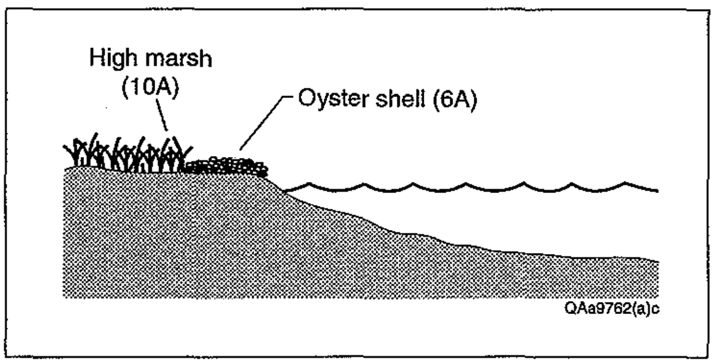

Figure 15. Multiple shoreline types consisting of a marsh and shell berm. These shorelines are classified as 10A/6A.

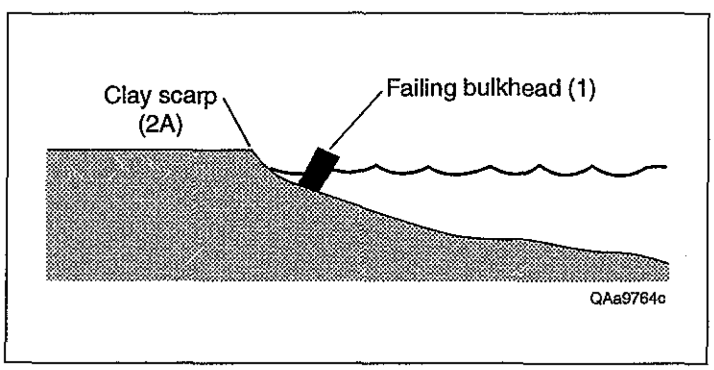

Figure 16. Multiple shoreline types consisting of a clay scarp and failing bulkhead. These shorelines are classified as 2A/1.

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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., 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.

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.

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.

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., 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.

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., , and Garner, L. E., 1997, Aerial videotape survey of coastal Texas and Louisiana: Center for Coastal, Energy, and Environmental Resources, Louisiana State University, Coastal Geology Map Series No. .

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., 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, 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., Tremblay, T. A., Hinson, J., and Moulton, D. W., Smith, E. H., and Jenkins, K., 1998, Current status and historical trends of selected estuarine and coastal habitats in the Corpus Christi Bay National Estuary Program study area: Report prepared for the Corpus Christi Bay National Estuary Program, 120 p.