Geological Circular 71-1

RESOURCE CAPABILITY UNITS

Their Utility in Land- and Water-Use Management with Examples from The Texas Coastal Zone

The University of Texas at Austin
Bureau of Economic Geology
W. L. Fisher, Director

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INTRODUCTION

Growing concern over land and water resources, uses, and associated problems of environmental quality is leading toward accelerated Federal and State environmental protection and management legislation. If prudent, fair land- and water-use management policies are to be developed, adequate inventories must be made of these resources, their composition, properties, and natural capacity for a variety of uses. Unfortunately, many current environmental programs are exclusively remedial--aimed at curing or rectifying existing problems. Where severe problems exist, such action is necessary and proper. Environmental programs, however, can also be preventative. If future development and utilization of natural resources--land, water, and biota--are consistent with the natural capabilities and limits of these resources, most environmental problems can be precluded or minimized. Inherent in our industrial society is man's need for and use of resources and the environment. Prudent use is conservation, as opposed to severely limited use or nonuse in the context of strict preservation. Environmental guidelines permitting maximum but wise use of resources, consistent with minimal environmental imbalance, are far more realistic than highly restricted use or total preservation. To develop guidelines consistent with the legitimate resource needs of our society requires an adequate inventory, description, and delineation of these natural units in order that their capability for varied use can be properly evaluated. This leads to the important concept of natural resource capability units.

This report outlines (1) the nature of resource capability units, (2) the basic factors and properties exhibited by the units that define the limits of their use, and (3) the application of resource capability units to environmental management. Specific examples are shown for the 20,000 square miles of the Texas Coastal Zone, where a wide variety of resource units occur in an area of diverse human activities.

DEFINITION OF RESOURCE CAPABILITY UNITS

A resource capability unit is an environmental entity--land, water, area of active process, or biota--defined in terms of the nature, degree of activity, or use it can sustain without losing an acceptable level of environmental quality. Units are established by recognizing elements of first-order environmental significance, whether dominantly physical, biologic, or chemical. These include (1) physical units (geologic substrate and soil units), where physical properties are of primary importance; (2) process units, such as beaches, washover channels, floodplains, escarpments, and dunes where active physical processes are dominant factors; (3) biologic units, such as reefs, marshes, swamps, and grassflats where biologic activity and habitation assume first-order significance; and (4) man-made units such as spoil heaps, dredged channels, canals, and made land where man's activity has resulted in important environmental modification. Capability of water systems is defined by the nature and distribution of sediment substrate, overall salinity patterns, circulation, tidal influence, depth variations, turbidity, fresh-water influx, distribution of biologic communities, and water chemistry.

FACTORS AFFECTING WATER AND LAND CAPABILITY

Factors that affect the capability or capacity of a natural resource unit for specific human activities are diverse and may vary from one area to another. Particularly important to environmental quality are those factors that limit the use of a given land or water unit for specific uses or activities. Examples

include (1) potential for flooding either by hurricane surges or by overbanking rivers; (2) capacity for shrink-swell conditions; (3) tendency for corrosion of pipes and conduits placed in certain substrates; (4) degree of permeability, which determines the extent of transmission of pollutants into groundwater aquifers and nearby surface water bodies; (5) steep slopes, which are susceptible to gravity failure and extreme erosion from runoff; (6) extremely flat lands that are poorly drained and that pond water following excessive rainfall; (7) impermeability, which exaggerates ponding and drainage problems; (8) persistent winds in arid areas, which result in wind erosion and migration of sediments in the form of dunes; (9) tidal flooding of broad, low-lying coastal flats by wind-driven water from bays, lagoons, and estuaries; (10) vegetation over sand substrates, which maintains stability of sediments in high-energy wind and water environments; (11) wave energy dissipated along shorelines with resulting erosion and redistribution of sediments; (12) zones of active or potentially active faulting; (13) tendency for subsidence; and (14) erosional susceptibility of various sediments and soils to wind and water.

RESOURCE USE PRACTICES

Evaluation of natural resource capability units is directly tied to activities that result in some use of these units; capability, of course, can only be defined in terms of use--both present and anticipated. The number of current and potential land- and water-use practices is great, though within any area certain types of practices, exploitation, and modification dominate. Within the Texas Coastal Zone, for example, some important land and water uses by man include (1) waste disposal of solid or liquid wastes on the surface, near the surface, or at depth; (2) disposal of spoil; (3) canal and ditch construction; (4) placement of buried pipelines and cables; (5) construction of buildings; (6) construction of jetties, groins, piers, and seawalls; (7) highway construction; (8) construction of industrial complexes; (9) surficial and subsurface extraction of mineral raw materials; (10) filling and land reclamation; (11) damming of river systems and water impounding; (12) devegetation or alteration of natural vegetation; (13) irrigation; (14) crop cultivation; and (15) grazing.

Evaluation of principal resource use activities in terms of intensity, nature, and distribution establishes criteria necessary to interpret their impact on land and water resources. These criteria can in turn be related to natural capabilities of land and water units to determine either optimum use or negative restraints.

DERIVATION OF RESOURCE CAPABILITY UNITS

The delineation of resource capability units requires an adequate inventory of the nature, grade, and distribution of these resources. Such an inventory can be accomplished only through appropriate mapping and description. Historically, much of our industrial and cultural development has been charted through maps. Maps provide the bases for many decisions involving government, business, trade, land development, and an infinite number of other activities. A variety of maps and mapping programs have been established throughout history as man became aware of their value. For example, topographic mapping provides basic data for slope and terrain analyses; soil maps permit proper agricultural development; geologic maps chart earth materials for use in exploration, mining, and engineering; and other maps are the basic guides for navigation. Growing concentrations of population and industry, their demands for natural resources, and a sense of environmental balance and quality presently require maps that delineate the distribution of natural units, their properties, and their capabilities.

Basic land and water resource maps provide an inventory of natural units that shows the distribution of kinds and grades of resources. These basic map units can be evaluated in terms of current and potential use; the limits of their capability for various uses can be used to develop guidelines that will permit maximum use consistent with minimum environmental degradation. Resource capability maps chart the distribution of natural units; description of these units defines their capabilities.

AN EXAMPLE--RESOURCE CAPABILITY UNITS OF THE TEXAS COASTAL ZONE

An example of the utility and application of resource capability units is drawn from studies of the Texas Coastal Zone. A number of features make this area critical: (1) The Zone embraces a variety of land, water, and biologic units under conditions ranging from a humid upper coast to an arid lower coast; (2) the Zone ranges from a heavily populated and industrialized upper coast to a sparsely populated lower coast; (3) the Zone sustains a high-volume flow of imports and exports through its port cities, and because of the economic differential between cheap ocean transport and more costly land transport, the trend in the region is toward construction of beneficiation, processing, and refining facilities to treat imported raw materials; (4) the Zone embraces land- and water-use competition because of its varied use potential; for example, water bodies are used simultaneously for transportation, for commercial fishing, for sport fishing, for recreation, for shell dredging, for oil and gas well locations, for pipelines, as a source of fill for real estate developments, and as a part of a waste-disposal system; (5) the Zone is a locus of very rapid physical change with earth materials moving in complex erosion-transportation-deposition systems that respond quickly to man's modifications, presenting continued engineering problems; and (6) the Zone includes a fundamental legal boundary where the shore zone commonly is in private ownership and the bays, estuaries, and offshore area are in public ownership. Because the legal boundary is also a high-energy geological boundary, actions taken by one proprietor have an immediate and significant effect on others.

The Bureau of Economic Geology, The University of Texas at Austin, has recently completed a three-year environmental mapping program of the Texas Coastal Zone. As a part of this program, 130 basic environmental units--geologic, process, biologic, and man-made--have been defined, delineated, and mapped. From these basic environmental maps a series of special-use environmental maps has been derived and assembled. These include (1) physical properties maps defining suitability and capability of land units where such characteristics as permeability, transmissibility, compressibility, shrink-swell, plasticity, faulting, and subsidence are important to physical uses such as engineering, construction, and waste disposal; (2) current land- and water-use maps; (3) mineral and energy resource maps; (4) natural environmental and biologic assemblage maps based on vegetation and faunal habitats; (5) active processes maps delineating flood-prone areas and areas of high-energy erosion and deposition; (6) man-made features maps and natural and artificial water-systems maps; (7) climatic maps showing rainfall, discharge, and bay salinities; and (8) topographic-bathymetric maps.

In cooperation with the Division of Planning and Coordination, Office of the Governor, the 130 basic environmental units defined and mapped in the Coastal Zone program have been grouped into 34 major land- and water-capability units (table 1).

TABLE 1. *Resource capability units, Texas Coastal Zone.*

I. Bays, lagoons, and estuaries
   1. River-influenced bay
   2. Enclosed bay
   3. Oyster reefs and adjacent reef flank and inter-reef areas (living)
   4. Oyster and serpulid reefs and adjacent reef flank and inter-reef areas (dead)
   5. Grassflats
   6. Mobile bay-margin sands
   7. Tidally influenced open bay
   8. Subaqueous spoil
   9. Tidal inlet and tidal delta
   10. Wind-tidal flats

II. Coastal plains
   1. Highly permeable sands
   2. Moderately permeable sands
   3. Impermeable muds
   4. Broad, shallow depressions
   5. Highly forested upland areas
   6. Steep lands
   7. Stabilized (vegetated) dunes and sand flats
   8. Unstabilized (unvegetated) dunes
   9. Fresh-water lakes, ponds, sloughs, playas
   10. Mainland beaches
   11. Areas of active faulting and subsidence

III. Major floodplain systems
   1. Point-bar sands
   2. Overbank muds and silts
   3. Water (including related lakes and sloughs)

IV. Coastal wetlands
   Salt marshes, fresh-water marshes, swamps

V. Made land and spoil

VI. Coastal barriers
   1. Beach and shoreface
   2. Fore-island dunes and vegetated barrier flats
   3. Washover areas
   4. Active dunes (back-island dune fields and blowouts)
   5. Tidal flats
   6. Swales

These units are defined chiefly by negative constraints based on factors that *limit* one or more of the 17 principal human activities that occur within the Coastal Zone (table 2). Capability units occur within six major capability classes: bays, lagoons, and estuaries; major floodplain systems; coastal wetlands; coastal plains; coastal barriers; and made land and spoil.

TABLE 2. *Major activities, Texas Coastal Zone.*

1. Liquid waste disposal
2. Solid waste disposal
3. Gaseous wastes
4. Offshore construction
5. Coastline construction
6. Inland construction
7. Land canals
8. Offshore channels
9. Dredging
10. Excavation (land)
11. Drainage
12. Filling (development)
13. Draining
14. Well development
15. Devegetation
16. Traversing with vehicles
17. Use of herbicides, pesticides, and insecticides

A series of illustrations show the distribution and setting of natural resource capability units described herein. Figure 1 outlines the six major land- and water-capability classes of the Texas Coastal Zone. Figures 2, 3, and 4 are schematic illustrations based on detailed maps of selected areas of the Coastal Zone: Figure 2 illustrates the nature and distribution of natural resource capability units for the upper coast (Galveston-Trinity Bay and environs); figure 3 illustrates units in the Texas Coastal Bend; and figure 4 shows units in the more arid lower Coastal Zone.

The 34 capability units recognized in the Coastal Zone and the 17 principal human activities that dominate within the Zone are compared in table 3, where capability units are evaluated in terms of negative restraints that limit their use within acceptable environmental guidelines. That is, the activity or use is either entirely adverse, or the activity exceeds the natural capacity of the unit to maintain proper environmental balance; only significant limiting uses are indicated. Areas where possible environmental problems are not expected but potentially may arise have also been indicated. The table *does not* consider *effects* of human activities on resource units but only the incapacity of a given resource unit to support a particular activity without environmental damage. Where blanks appear in the table, either a given activity is not applicable to a given resource unit or there is no significant limit on that activity.

Each resource capability unit--land or water--is defined in the following text, along with a notation of limiting use factors and undesirable uses if environmental balance is to be maintained.

RESOURCE CAPABILITY UNITS, TEXAS COASTAL ZONE

BAYS, LAGOONS, AND ESTUARIES

Bays, lagoons, and estuaries are water masses which occupy ancient river valleys and elongate areas between barrier islands and the mainland and are inseparably part of a more complex coastal system including sediment substrate, marginal sources of sediment and fresh water, subaqueous vegetation, benthonic, nektonic, and planktonic organisms, tide- and wind-generated currents and waves, dissolved salts, and suspended colloidal sediment particles. Proper management of the system depends upon a balanced approach which considers all facets of the system as well as its relationship to the terrestrial systems in adjacent areas. Bays and estuaries occupy a position that is physically, biologically, and chemically transitional between the open marine environment and the fluvial system. Shifting and sometimes subtle interfaces exist within the delicately balanced system. Geologically, bays and estuaries are evolving, transient environments which display slow but natural change; biologically, these areas and adjacent marshes are highly productive, delicately balanced ecosystems; and chemically, the water mass is susceptible to external modification resulting from man's activities on the land and in shallow waters. The bay and estuarine system is highly complex, displaying numerous, interdependent subsystems, all of which are capable of reacting either positively or negatively to induced changes. The system naturally evolves, but man can significantly alter the natural processes, resulting in economic, aesthetic, and cultural benefits or losses.

The complexity of the bay and estuary system is not always appreciated primarily because the precise nature of the estuarine environment is poorly understood. Despite absence of extensive biologic,

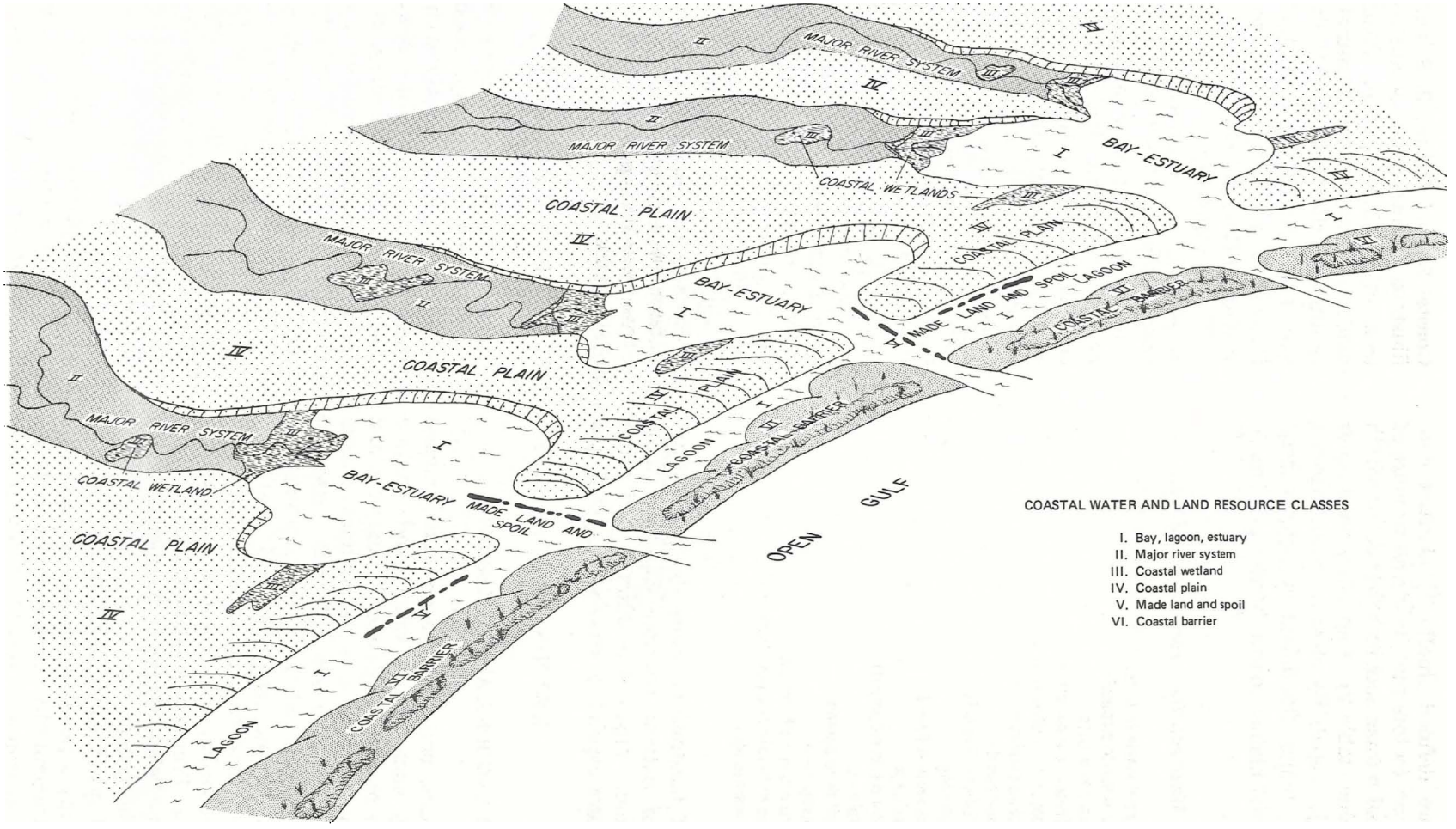

FIG. 1. Schematic map of major land and water resource capability classes, Texas Coastal Zone.

geologic, and chemical data and understanding, general relations between certain human activities and observed impacts on the natural system have been formulated. Cause and apparent effect relations must be investigated, and eventually adequate steps must be taken to prevent permanent environmental damage. In the meantime, empirical, pragmatic caution is warranted in order to preserve the system.

River-Influenced Bay

Definition.--These are low salinity areas (less than 10 ‰) at the heads of bays where rivers discharge fresh water and nutrients. Bottom sediments adjoining river mouths are primarily laminated prodelta muds and sandy muds with mottled mud distal of the prodelta. These areas generally grade into open bay and display a low species diversity.

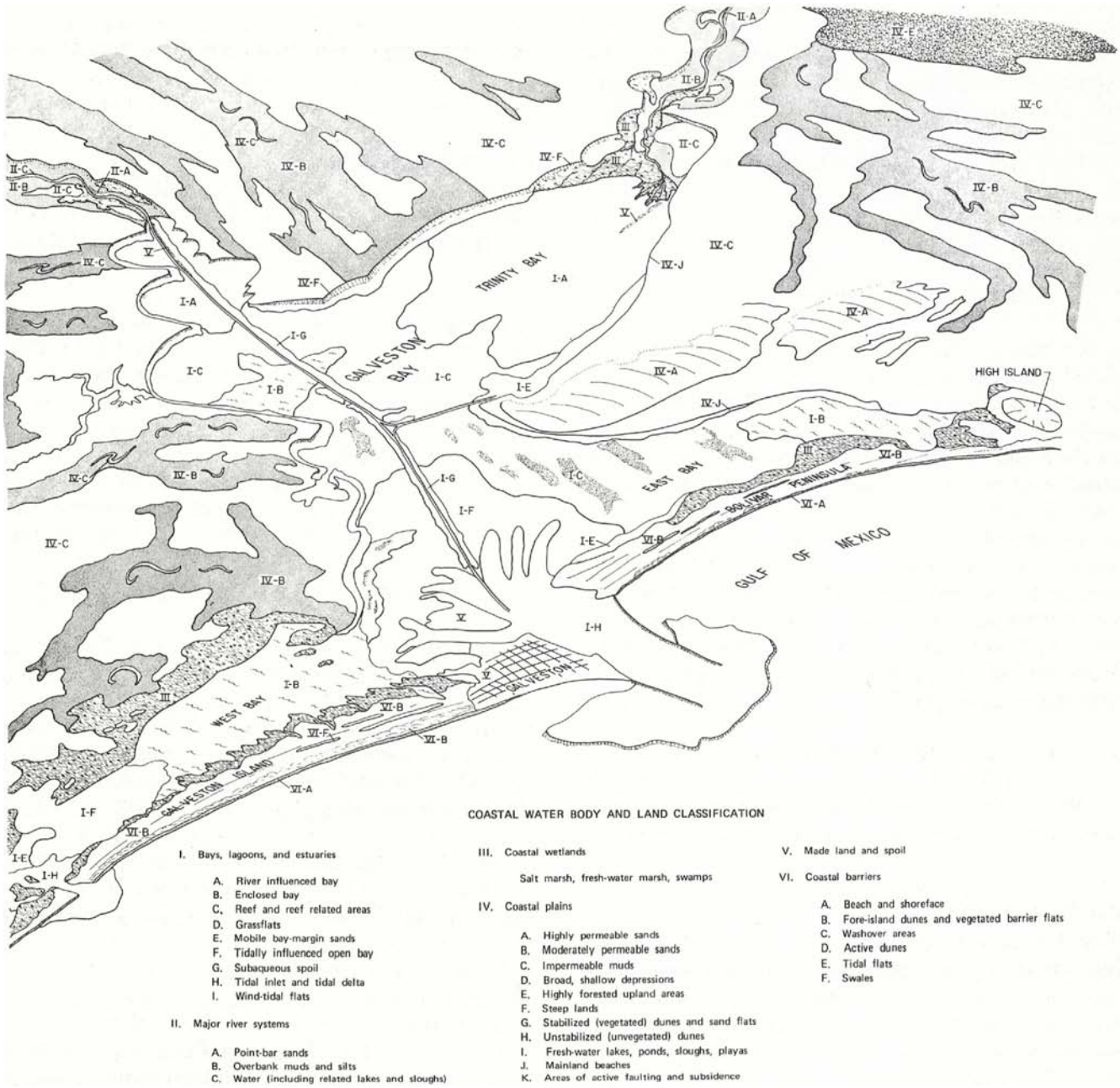

FIG. 2. Schematic map of land and water resource capability units, moderately humid upper Texas Coastal Zone.

Common clams include *Rangia*, *Palymesoda*, and *Macoma*. The snail *Littordina* is common in some localities. Crustaceans include *Callinectes* and *Marcobrachium*. Ostracods are abundant on the soft, muddy, organic-rich bottoms. Foraminifers are not abundant in this zone, but a few, including *Candona*, *Darwinula*, and *Physocypria*, are characteristic of the prodelta subfacies in some bays. The brown shrimp *(Penaeus aztecus)* and white shrimp *(P. setiferus)* use these areas (along with the associated marsh) for development through the juvenile stages. Destruction of these upper bay shallows or significant changes in the quality of the fresh-water discharge, particularly changes in temperature or the introduction of toxins, could promote extinction of valuable commercial and recreational species.

Depths in these upper bay areas range from 3 to 7 feet. Turbid waters entering these areas from the associated rivers cause a decrease in light penetration and thus a lower level of photosynthetic activity. These fresh waters are usually high in humic acids from upstream runoff. Turbidity, low salinity, and low pH values from humic acids preclude significant growth of oysters and other sessile benthonic shellfish.

Limiting use factors.--Submergence precludes most uses except after highly undesirable filling. The value of these areas (along with associated marsh) as nursing grounds for about 85 percent of the commercially valuable species should not be ignored.

Undesirable uses.--Undesirable uses include any activities, such as filling, disposal of solid and/or liquid wastes, and restriction of circulation by construction of hurricane barriers, which tend to make the area unusable by or inaccessible to postlarval and juvenile shrimp, crabs, fish, and other organisms.

Enclosed Bay

Definition.--These are bay areas (3 to 8 feet in depth) away from tidal or river influence which display generally poor circulation, an abundance of fine sediment, low species diversity, and large numbers of individual organisms. Benthonic organisms are mainly infaunal deposit feeders which burrow through and churn the sediments to produce mottled, organic-rich muds. Some bay areas (*i.e.*, Baffin Bay), however, display a very low species diversity and a small number of individual organisms due in part to hypersaline conditions. In these areas, the fine bottom sediments have not been bioturbated and thin (1 to 4 mm) undisturbed laminae remain intact.

Since enclosed bay areas are characterized by poor circulation, high or low salinity extremes are often reached. Areas of poor circulation near heads of bays sometimes display brackish water conditions (less than 35‰). Restricted bays, such as Baffin Bay, along the arid South Texas coast, however, are hypersaline much of the year due to the high evaporation rate, low rainfall, and the resultant concentration of dissolved solids in the remaining water. Poor circulation causes deficiency in dissolved oxygen content in many enclosed bay areas with consequent reducing conditions near the sediment-water interface. High salinities and concentration of organic acids (due to reducing conditions) contribute to the low pH of these areas.

Common living species include the clams *Mulinia* and *Nuculana*. Hypersaline enclosed bays and lagoons (*i.e.*, Baffin Bay and parts of Laguna Madre) are thickly populated by the clams *Anomalocardia*, *Mulinia*, and *Tellina*. The snail *Cerithium* is also common in these areas.

Limiting use factors.--Placement of structures is hampered by the unstable ooze which floors these areas. Poor circulation makes these areas highly unsuitable for waste disposal, since pollutants tend to pond and saturate bottom sediments. Restricted bays are poorly flushed by tidal or flood action, resulting in low water exchange with the open Gulf.

Undesirable uses.--Undesirable uses would include (a) placement of structures without pilings or other stabilizing foundations and (b) any disposal of solid and/or liquid waste materials.

Oyster Reefs and Adjacent Reef Flank and Inter-Reef Areas (Living)

Definition.--These submerged mounds, elongate ridges, and adjacent flanking areas (up to several miles in length) of the colonial oyster *Crassostrea virginica* and associated reef organisms occur in varying concentration in all major bays with the exception of Laguna Madre and Baffin Bay. Reefs are ridged structures which locally baffle or restrict circulation and commonly exhibit orientation perpendicular to prevailing currents. Reef crests may grow to the water surface and may be exposed during low tide.

The bulk of a reef is composed of the shells of dead oysters and other organisms, but epifaunal, nektonic, and some vagrant benthonic organisms inhabit the living reef surface. Along with the oysters are many associated molluscs including

TABLE 3. *Coastal Zone resource units—use and capabilities.*

ACTIVITIES / RESOURCE CAPABILITY UNITS			Liquid Waste Disposal: Surface Disposal of Untreated Liquid Wastes	Liquid Waste Disposal: Disposal of Untreated Liquid Wastes Subsurface Shallow	Liquid Waste Disposal: Maintenance of Feed Lots	Solid Waste Disposal: Disposal of Solid Waste Materials	Construction of Offshore and Bay Platforms	Coastal Construction: Construction of Jetties, Groins, Piers	Coastal Construction: Construction of Storm Barriers and/or Seawalls	Coastal Construction: Placement of Pipelines and/or Subsurface Cables ▲	Inland Construction: Light Construction	Inland Construction: Construction of Highways	Inland Construction: Heavy Construction	Inland Construction: Flooding (through dam construction)	Dredging of Canals and Channels and Spoil Disposal ★	Excavation (includes extraction of natural materials)	Filling for Development	Draining of Wetlands	Well Development	Devegetation	Transversing with Vehicles (marsh buggies, air boats dune buggies, motorcycles)	Use of Herbicides Pesticides Insecticides
WATER CAPABILITY UNITS	Bays Estuaries, and Lagoons	River Influenced Bay Areas Including Prodelta and Delta Front	X	X		X	O	O	X	O					X		X		O			
		Enclosed Bay Areas	X	X		X	O		X	O					O		O		O			
		Living Oyster Reefs and Related Areas	X	X		X	X	X	X	X					X		X		X			
		Dead Oyster and Serpulid Reefs and Related Areas	X	X		X	O	O	X	O					X		X		O			
		Grassflats	X	X		X	X	X	X	X					X		X		X			
		Mobile Bay Margin Sand Areas	X	X		X	X	X	X	X					X		X		O			
		Tidally Influenced Open Bay Areas	X	X		X	O	O	X	O					X		X		O			
		Subaqueous Spoil Areas	X	X		X	O	O		O							O		O			
		Inlet and Tidal Delta Areas	X	X		X	X	X	X	X					X		X		O			
		Tidal Flats	X	X		X			X	X	X	X	X		O	X	X		O			
LAND CAPABILITY UNITS	Coastal Wetlands	Salt Water Marsh	X			X	X		X	X	X	X	X	X	X	X	X	X	O	X	X	X
		Fresh Water Marsh	X			X			X	O	X	X	X	X	X	X	X	X	O	X	X	X
		Swamps	X			X				O	X	X	X	X	O	O	X	X	O	X	O	X
	Coastal Barriers	Beach and Shoreface	X	X		X		X	O		X	X	X		X	X			X		O	
		Fore Island Dunes and Vegetated Barrier Flats	X	X	X	X			X		+	+	+		X	X			O	X	X	X
		Washover Areas	X	X	X	X		X	X	X	X	X	X		X		X		X			
		Blowouts and Back Island Dune Fields	X	X		X				O	X	X	X		X				X			
		Wind Tidal Flats	X	X		X					X	X	X		O		X		O			
	Man Made	Swales	X	X		X					X	X	X		X	X	X	X		X		X
		Made Land and Spoil	X	X	X	X							O							X		
	Coastal Plains	Highly Permeable Sands	X	X	X	X									O	X			O	X		X
		Moderately Permeable Sands	X	X	X	X									O	X			O	X		X
		Impermeable Muds	O							O	O	O	O						O			O
		Broad Shallow Depressions *	O								X	O	X						O			O
		Highly Forested Upland Areas *												X					O	X		X
		Steep Lands, Locally High Relief	X			X					O		O			X				X		O
		Stabilized Dunes	X	X	X	X						O			X	X			O	X	X	X
		Unstabilized, Unvegetated Dunes	X	X		X				O	X	X	X		X				X			
		Fresh Water Lakes, Ponds, Sloughs, Playas	X			X									X		X	X	O			X
		Mainland Beaches	X	X		X		X	X		X	X	X		X	X	X		X	O		
		Areas of Active Faulting and Subsidence	O	O		O				X	O	O	X						O			
	Major Floodplain Systems	Point Bar Sands	X	X	X	X					O				X				O	X		X
		Overbank Muds and Silts	X	X	X	X				O	O	O	O	O								O
		Water	X			X								O	X							X

X Undesirable (will require special planning and engineering)
O Possible problem(s)
\+ Barrier Flat only (no construction on dunes)
* Substrate variable
▲ Also occurs in Offshore Construction
★ Also occurs in Offshore Canals and Dredging

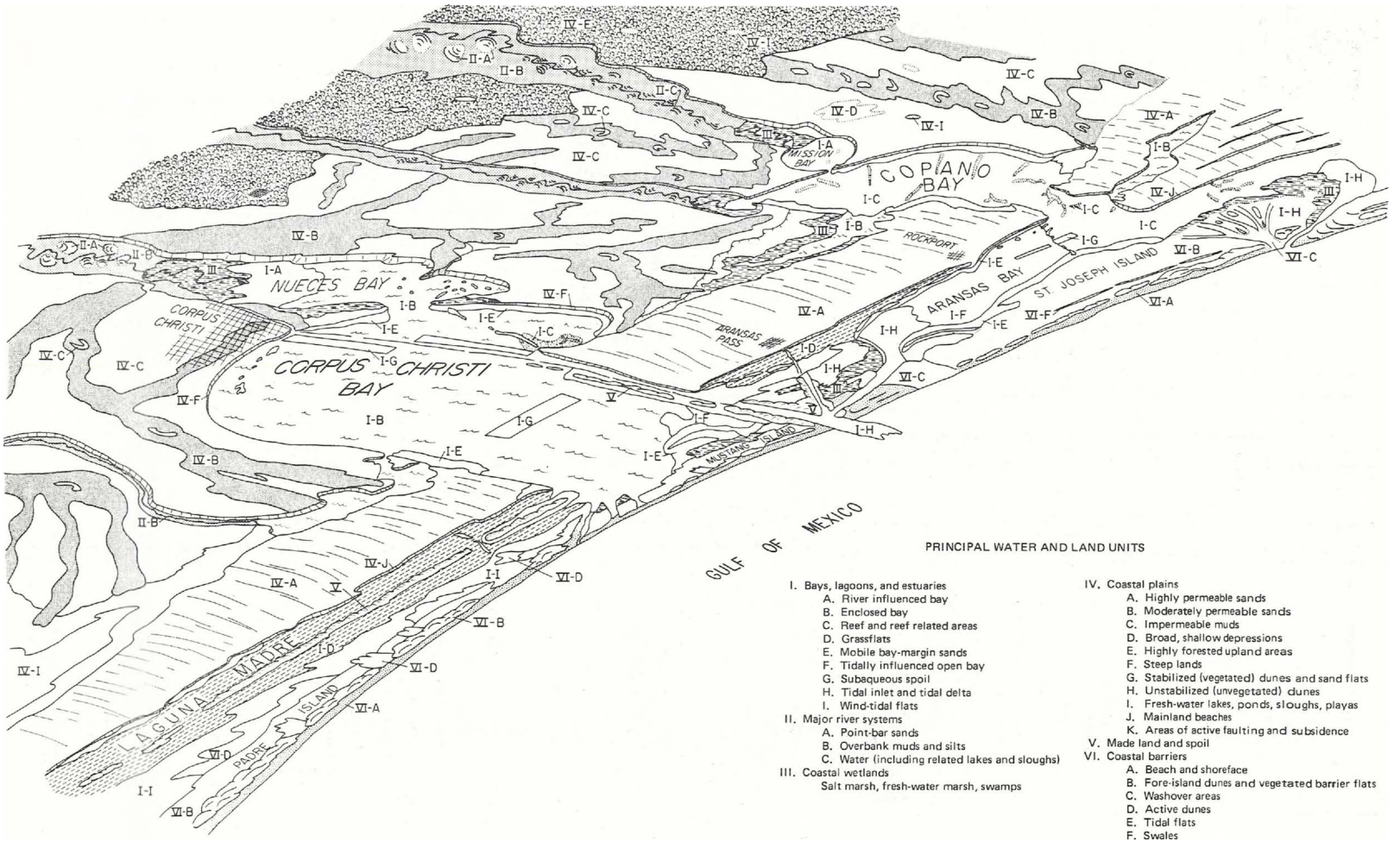

FIG. 3. Schematic map of land and water resource capability units, coastal bend region, Texas Coastal Zone.

Anomia, Anachis, Mitrella; several epizoans including barnacles *(Balanas)* and *Brachidontes;* and several varieties of coral and bryozoans. Normal oyster reef salinities range from 10 to 30 ‰ with water depths up to 8 feet. Oysters can live and grow in normal marine salinities of 30 to 35 ‰, but under these conditions several oyster predators, including the oyster drills *Thais* and *Urosalpinx*, also flourish. High salinity oyster reefs contain *Ostrea equestris.*

Reef flank areas are composed of shell debris dislodged during storms, along with lesser numbers of living oysters. Some sand and mud may be mixed with shell debris during hurricanes. Epizoans are fewer in this less favorable environment, and scavengers subsist on organic debris derived from the adjacent reef.

Inter-reef areas are relatively flat, subaqueous plains (at about 6 feet in depth) within a reef complex where some individual clumps or small oyster colonies occur, growing upward from a sandy or muddy shell substrate. New reefs originate where these colonies flourish, and they grow to become shoal areas. Significant vertical growth is principally controlled by the ability of the bottom strata to support the growing reef mass. Compaction and subsidence of sediment may eventually be stabilized and provide the foundation for a new reef. Vagrant and infaunal (burrowing) benthonic organisms predominate within the inter-reef areas.

Oyster reefs and associated reef areas serve as valuable feeding grounds for many varieties of commercial and game fish and crabs. These are productive environments economically and constitute one of the major resource areas of the bay ecosystem.

Limiting use factors.--Submergence precludes most uses. The high productive capability of these areas should limit any destructive uses.

Undesirable uses.--Any activity which disrupts the natural ecology of live oyster reefs (such as dredging, dumping of spoil, discharge of waste, restriction of bay circulation patterns, and construction in reef areas) is undesirable and should be avoided in a balanced bay-estuary management program.

Oyster and Serpulid Reefs and Adjacent Reef Flank and Inter-Reef Areas (dead)

Definition.--These dormant reefs may be expressed as submerged mounds and elongate ridges or they may be buried at shallow depths beneath the sediment-water interface. They are composed principally of *Crassostrea virginica* shells, but Baffin Bay reefs are exclusively serpulid (Annelida) mounds up to 130 feet long. Serpulid reefs in Baffin Bay are now dead, possibly the result of a recent increase in salinity in this restricted bay. Serpulid reefs, like oyster reefs, are composed of calcium carbonate secreted by the organism. Other invertebrates and some vertebrate organisms inhabit abandoned reefs and compose an ecologic assemblage adapted to this protective reef structure. These reef masses are slowly disintegrated by storm waves and slowly overlapped by reef flank and inter-reef sediment, especially in areas where poorly compacted substrate allows continued subsidence. The assemblage of organisms inhabiting reef-flank and areas between dormant reefs slowly changes as the character of the reef is modified. Dead reef areas may shoal during low water and are often navigational hazards.

Limiting use factors.--Submergence precludes most uses of this unit. Activities such as dredging of shell should be limited by the fact that circulation patterns can be drastically altered, turbidity can be increased, and biotic communities (both proximal and distal) can be irreparably damaged. Reefs may also provide a baffle to hurricane surge.

Undesirable uses.--Undesirable uses include removal of shell material, which severely alters water circulation patterns and increases turbidity, thus potentially changing the estuarine environment. Navigation through these areas is limited, especially during low-water periods. Removal of baffling effects of reef may also increase the impact of hurricane surge in upper bay-estuary areas.

Grassflats

Definition.--These are shallow subaqueous flats (1 to 5 feet in depth) principally along the margins of bays and lagoons, although grassflats extend across the entire shallow northern Laguna Madre bottom.

Grassflats are composed of moderate to dense growths of *Ruppia, Thalassia,* and *Diplanthera* marine grasses. A calcareous green alga, *Acetabularia,* is common in these areas. Temperatures may vary considerably, but the dense grass aids in maintenance of satisfactory ranges for many organisms. Such flats have salinities ranging from 20 to 35 ‰ and are characterized by a diverse mollusc assemblage including grazing and carnivorous snails

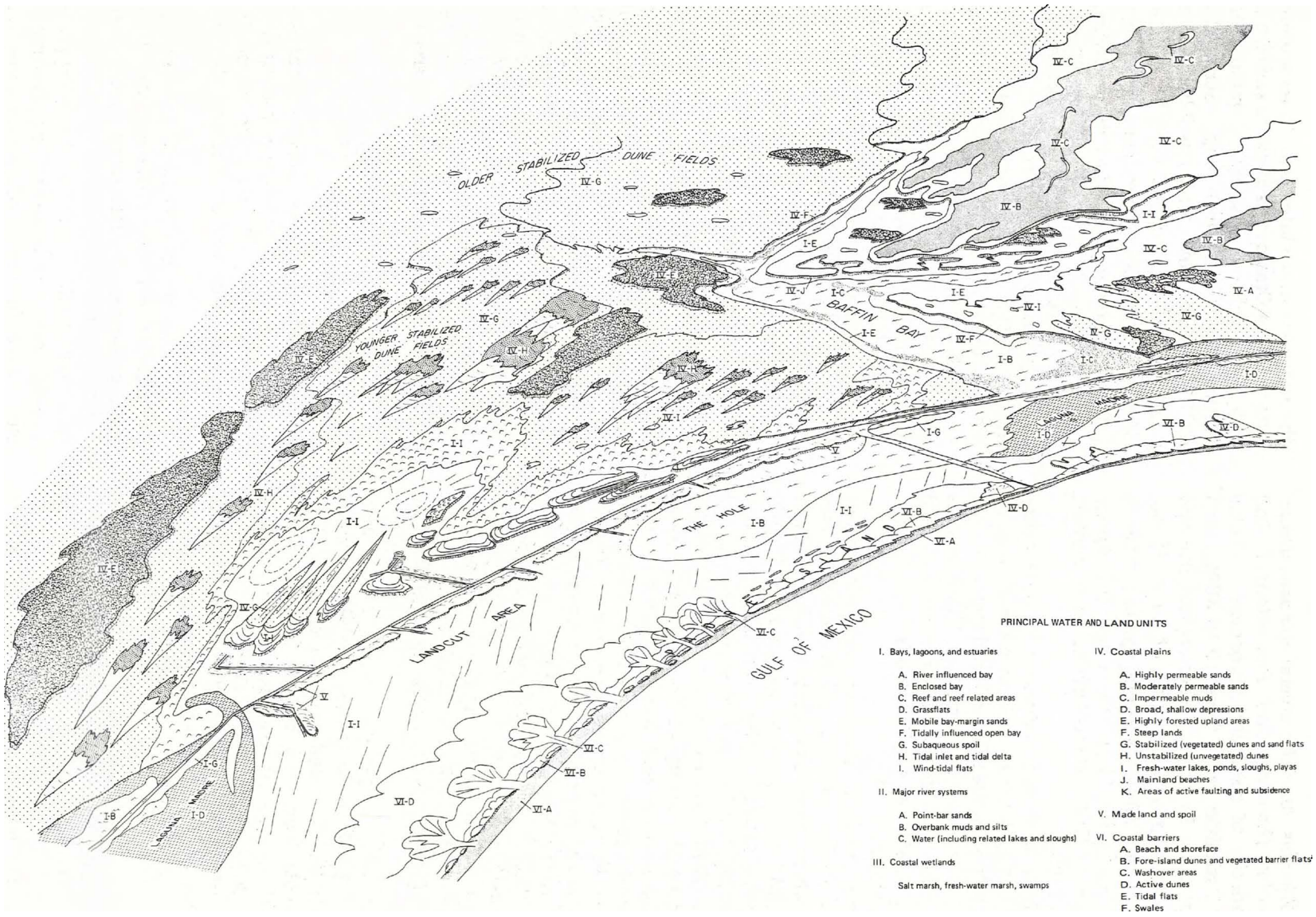

FIG. 4. Schematic map of land and water resource capability units, arid south Texas Coastal Zone.

Cerithium, *Cerithidea*, *Modulus*, *Vermicularia*, and *Melampus*. Common clams include *Atrina*, *Tagelus*, *Laevicardium*, *Cyrtopleura*, *Tellina*, and *Amygdalum*. Grassflats are feeding and spawning grounds for numerous aquatic animals including many commercial and game fish.

Grassflats are physically "low-energy" environments where currents are baffled and the sand and muddy sand substrate is stabilized by rooted vegetation. Spotted concentrations of shell debris in these zones are due partly to the shell-cracking feeding habits of the Black Drum *(Pogonias cromis)* and other bottom-feeding fishes. Grassflats are extensive from Copano Bay south to Mexico and constitute a most important, highly productive ecological unit.

Limiting use factors.--Submergence precludes any land use except after highly undesirable filling with spoil. The high biologic productivity of these areas should be a principal limiting factor.

Undesirable uses.--Destruction of natural biologic communities through dredging, dumping of spoil, and dumping of solid and liquid wastes is very undesirable. Grassflat areas are indispensable to the natural bay and estuarine ecosystem and should be maintained.

Mobile Bay-margin Sands

Definition.--These shallow bay-margin areas (depth to 6 feet) of high current activity and rapid sand transport are sites of significant deposition. The sand supply is predominantly from eroded flood tidal deltas, storm washover fans, and older eroded coastal plain sediments incised by bay waves. These marginal areas support locally sparse marine grasses *(Thalassia, Diplanthera)* and display variable temperatures and salinities. The rather diverse pelecypod fauna includes *Aequipecten*, *Trachycardium*, *Mercenaria*, *Chione*, *Curtopleura*, *Tagelus*, and *Ensis*. The two clams, *Mulinia* and *Anomalocardia*, inhabit these shallow sandy areas in Baffin Bay. Many carnivorous and grazing snails, such as *Thais* and *Busycon*, are also present. Crustaceans including isopods, ostracodes *(Cytherura, Paradoxostoma, Perissocytheridea)*, mud shrimp *(Callianassa)*, and a variety of crabs, including *Calinectes*, inhabit these shoal areas. Fish, such as Black Drum *(Pogonias cromis)*, feed here on molluscs. Species diversity increases near tidal inlets where there is greater mixing of bay waters with the more normal marine waters of the Gulf.

Great seasonal variation exists in the composition of these shallow, bay-margin assemblages. There is marked migration of many of the epifaunal and mobile invertebrates into deeper water during periods of extreme high or low temperatures and/or salinities.

Included within this unit are sand *spits*, which are elongate depositional features developed locally on the back sides of barrier islands and on mainland shores. Here currents are controlled by local bathymetry and shoreline configuration. Spits are areas of very rapid shoreline accretion.

Limiting use factors.--Limiting factors include (a) strong current activity, (b) rapid sand transport and deposition, and (c) high wave energy during storms.

Undesirable uses.--Undesirable uses include restriction of natural sand movement by construction of jetties, groins, piers, and offshore platforms, which tends to cause local erosion and restriction of sand nourishment to other environments along the bay-estuarine shoreline.

Tidally Influenced Open Bay

Definition.--These areas (6 to 12 feet in depth) encompass the lower ends of bays where tidal influence is great and salinities range from 20 to 35 $^{o}/_{oo}$. They display good circulation and the substrates generally are mottled mud. Species diversity is relatively high. The number of species increases and the number of individuals of each species decreases as the salinity increases. In some bays a few species of Foraminifera make up large percentages of the bottom sediment. Benthonic filter feeders and burrowers (deposit and filter feeders) are important organisms in this estuarine area, and bottom sediments are strongly bioturbated. Common infaunal deposit feeders include the clams *Nuculana*, *Mulinia*, and *Abra*. *Nassarius*, *Polinices*, and *Retusa* are probably the most abundant snails in open bays.

Limiting use factors.--This is an area of fairly thick soft mud accumulation which gives poor support to structures. Structures (platforms) placed here would need pilings or thick shell pads, and they would tend to restrict circulation in these physically dynamic areas. Normal salinity (35 $^{o}/_{oo}$) sea water circulates through this environment to reach other estuarine areas.

Undesirable uses.--Undesirable uses include placement of platforms or other structures (hurricane barriers) without special preparation.

Subaqueous Spoil Areas

Definition.--These are areas of man-made, mixed substrate along dredged channels and near dredged oyster shell areas. Sediments are commonly poorly sorted sand, silt, shell, and some mud, with a biologic assemblage depending upon age and position of the spoil within the bay. Shallow subaqueous spoil areas and subaerial spoil mounds and ridges along dredged channels tend to compartmentalize bays and estuaries by restricting natural circulation patterns. This causes many of the natural bay-estuary environments to become locally enclosed, restricted basins with low pH and high anaerofiosis and with consequent lowering of their productivities. Spoil areas supply vast amounts of sediment to the bay-estuarine sediment disposal system and expose poorly consolidated sediment to the effects of storm waves. Suspension of winnowed fine sediments results in turbid conditions, locally effecting photosynthesis and dissolved oxygen content.

Limiting use factors.--Further disturbance of these areas only adds to turbidity and increases compartmentalization and restriction of natural estuarine systems.

Undesirable uses.--Undesirable uses would include further dredging and any other activity, such as disposal of waste materials, which would lead to increased instability of these areas.

Tidal Inlet and Tidal Delta

Definition.--Tidal inlets or passes are channel areas of sediment transport with intense current energy connecting the bays with the open Gulf. Associated with the inlets are depositional areas termed ebb and flood tidal deltas occurring at the Gulf and bay ends of tidal passes, respectively. Inlets are channel areas of sediment transport with shifting, localized erosion and deposition where sediments are mostly winnowed sand and shell detritus. A diverse faunal assemblage characterizes the inlet environment including the molluscs *Crassinella, Lucina, Tellidora, Anachis, Polinices,* and others. Common echinoderms include *Luidia, Mellita,* and *Ophiolepis.* Many small encrusting epifauna, such as corals and bryozoans, live attached to the various molluscs. Clams and snails alike are often attacked by the boring clionid sponges.

Species diversity decreases on the shoal water (to 10 feet) tidal delta areas which are dominated by shallow infaunal species and echinoderms, such as *Mellita.* Here the southern flounder, *Paralichthys lethostigma,* also lives and feeds in abundance. Flood tidal deltas are subaqueous and emergent, marsh-covered sand areas where deposition occurs when tidal-induced currents wane within the adjacent bay. Ebb and flow tidal channels lace through the ebb deltas exchanging water and nutrients daily. Salt marshes on ebb deltas are areas of high productivity. Ebb tidal deltas on the Texas Gulf coast are subaqueous and are poorly developed because sand temporarily deposited at the Gulf end of the tidal inlet is rapidly dispersed along the barrier islands by long-shore currents.

Passes or inlets provide communication between the open Gulf and bays or lagoons for fish migration and water exchange. Large schools of mullet *(Mugil)* pass through this zone on the way to their spawning grounds in the Gulf. During tropical storms and hurricanes, as well as during mainland floods, extensive exchange of marine and fresh water, respectively, occurs through these passes. Under normal tidal conditions, however, water exchange is minimal. Natural water depths in these passes range up to 40 feet, but most of these areas are maintained by dredging for navigation purposes. Salinities range from 10 to 40$^{o}/_{oo}$, depending upon current flow conditions; normal salinities for these areas lie in the 30 to 35$^{o}/_{oo}$ range.

Limiting use factors.--Limiting factors include (a) high current energy, especially during storms, and (b) excessive erosion and deposition. A very important factor is the exchange of waters which occurs through these areas, allowing flushing of bay pollutants and natural migration of organisms.

Undesirable uses.--Undesirable uses include (a) obstruction of natural circulation and sediment transport through construction and (b) liquid waste disposal in these areas, prohibiting fish and shrimp migration.

Wind-Tidal Flats

Definition.--These extensive flats (greater than 100 square miles) occur on the back side of barrier islands south of St. Joseph Island and on the landward side of Laguna Madre from mean sea level to about plus 3 feet. Extensive, vegetated, windward accreting clay and sand islands (Rincons, Potreros) occur on the landward flats in the landcut area south of Baffin Bay and on the abandoned portions of the Rio Grande delta. Flats are flooded by wind-driven lagoon and bay water either during northers or by persistent southeasterly spring and summer winds. These areas are dominantly sand, although

they become muddy in depressed areas in the "landcut" portion of the coast immediately south of Baffin Bay. Algal blooms during intermittent inundation result in thin algal mats which bind the sediment into a tough substrate; gypsum and other salts are common in the more depressed and/or restricted areas. High temperatures in the thin sheet of water on the tidal flats restrict biologic activity.

Limiting use factors.--Limiting factors include (a) frequent tidal and hurricane flooding and (b) moderate permeability.

Undesirable uses.--Undesirable uses include (a) waste disposal, (b) construction, because of frequent tidal flooding and potential hurricane damage, and (c) excessive channeling and canalization which block tidal circulation.

COASTAL PLAINS

Coastal plains are flat uplands which occur landward from bays, lagoons, or open Gulf and extend from sea level to an elevation of approximately 100 feet; they display a slight coastward inclination and are underlain predominantly by ancient deltaic, fluvial, and barrier-strandplain sediments. Local relief is produced by headward-eroding streams and salt domes. In most areas, the coastal plain is traversed by elongate sand belts with very slight topographic relief. Coastal plains are cut by several major river systems; some, like the Trinity and Nueces, are deeply incised, while the Brazos and Colorado systems flow within broad, shallow valleys. Other sandy belts up to 3 miles wide are oriented approximately parallel to the present coastline and represent ancient sand barriers and strandplains. Much of the more arid South Texas coastal plain consists of an extensive windblown sand sheet.

Highly Permeable Sands

Definition.--These sand belts are oriented parallel or subparallel to the coastline and represent ancient barrier islands or strandplain deposits. These clean, highly permeable sand belts, which are 2 to 8 miles wide and 20 to 40 feet thick, occur intermittently from the Louisiana border to Baffin Bay, the sands being locally absent where crossed by major river systems. These ancient barrier sand bodies are surrounded by impermeable muds and are important fresh-water aquifers.

Limiting use factors.--Limiting factors include (a) high permeability, (b) high erosion potential (water and/or wind), and (c) importance as a source of fresh water.

Undesirable land uses.--Land uses which may result in undesirable environmental effects include (a) liquid waste disposal, (b) solid waste disposal, (c) disposal in surface holding ponds (brine, sludge), (d) development of feed lots, (e) septic tank use except with careful monitoring, (f) extensive excavation (such as drainage canals, developments, and landcuts) and development of steep slopes in these noncoherent sediments, which accelerate erosion, and (g) devegetation in the area south of Corpus Christi, which results in wind erosion and dune development.

Moderately Permeable Sands

Definition.--These moderately permeable sand deposits from 20 to 100 feet thick occur in higher elevations of the coastal plain and locally extend coastward in narrow belts from 1 to 5 miles wide. These sands represent ancient river and deltaic deposits, and they commonly overlie and are flanked by impermeable muds; they are significant shallow, ground-water aquifers.

Limiting use factors.--Limiting factors include (a) moderate permeability, (b) moderate erosion potential (wind and water), and (c) importance as a local source of fresh water.

Undesirable land uses.--Undesirable land uses are the same as those for highly permeable sand, but the effects are generally less severe.

Impermeable Muds

Definition.--Extensive, impermeable mud prairies extend inland from marshlands to thick sand belts. The muds were deposited on ancient deltas and along ancient rivers. This unit comprises 60 to 70 percent of the coastal plain and includes most agricultural areas.

Limiting use factors.--Limiting factors include (a) impermeability which results in poor internal drainage, (b) high shrink-swell potential, (c) high corrosion potential, (d) unstable steep slopes, especially when wet, and (e) low shear-strengths resulting in foundation problems.

Undesirable land uses.--Undesirable land uses include (a) construction, which is limited by severe shrink-swell problems, (b) burial of pipes and cables that are subject to corrosion, (c) development without proper drainage systems, (d) construction on steep slopes in upper coastal areas that are sub-

ject to failure, and (e) use of muds for fill without prior stabilization treatment.

Broad, Shallow Depressions

Definition.--These low-lying areas adjacent to river courses occupy abandoned and partially filled ancient stream channels and other low, depressed areas such as ancient floodplain lakes. They may result from local subsidence or damming by man-made features such as highways and railroad rights-of-way.

Limiting use factors.--These areas are (a) frequently flooded and (b) are subject to many of the same problems described for impermeable muds.

Undesirable land uses.--Land-use limitation includes development or agriculture without proper drainage systems.

Highly Forested Upland Areas

Definition.--These wide belts of pine and hardwoods occur predominantly on ancient fluvial sands and muds north and east of Houston. South and west of Houston, in areas of lesser rainfall, forests are dominantly hardwoods on ancient fluvial sands with live-oaks concentrated on ancient barrier sands and older wind deposits. In more arid coastal areas, forests are restricted to thicker ancient sand deposits. Forested areas are concentrated on thick, permeable, well-drained sand substrate.

Limiting use factors.--This unit generally coincides with and has land-use limitations similar to those of highly permeable sands. Devegetation aggravates these problems, especially as it affects erosion.

Undesirable land uses.--Excessive deforestation results in (a) water erosion, (b) increased runoff resulting in decreased ground-water recharge, and (c) extensive wind erosion in south coastal areas.

Steep Lands

Definition.--These lands occur as erosional bluffs and steep slopes along stream valleys and bay margins. Steep eroded lands are commonly developed on muds and sandy muds with some development on sand deposits. Storm-wave erosion along bay margins and erosional-slope retreat are significant geological processes.

Limiting use factors.--Limiting factors include (a) critical need for vegetation, (b) slopes from 5 to 75 degrees, and (c) potential for slump failure.

Undesirable land uses.--Undesirable practices include (a) over-steepening of slopes, which will accelerate erosion and slump, (b) devegetation, which will accelerate erosion, and (c) construction that is limited by potential slump failure, especially in higher rainfall areas of the upper coast.

Stabilized, Vegetated Dunes and Sand Flats

Definition.--Densely vegetated, stabilized dunes and associated sand flats covered by live-oaks *(Quercus virginiana)*, mesquite *(Prosopis reptans* and other species), or more rarely grasses and associated plants, occur between Baffin Bay and Arroyo Colorado from the landward side of Laguna Madre inland for more than 50 miles. These dunes have local relief up to 30 or 40 feet and consist of highly permeable sands locally cemented by caliche. These old dune fields are characterized by a locally high ground-water table.

Limiting use factors.--Limiting factors include (a) high permeability, (b) critical need for vegetation, and (c) susceptibility to wind erosion.

Undesirable land uses.--Undesirable practices include (a) solid waste disposal, (b) liquid waste disposal, (c) construction of surface waste ponds, (d) devegetation, which accelerates wind erosion, and (e) road construction or other excavation without adequate revegetation.

Unstabilized, Unvegetated Dunes

Definition.--These are broad areas of active wind-driven dunes migrating inland between Baffin Bay and Arroyo Colorado. Until stabilized by adequate vegetation, dunes may move northwestward up to tens of feet per year. Dune orientation is essentially parallel with the prevailing southeasterly winds. The dunes are highly permeable sands with local relief up to 30 or 40 feet. Depth of wind erosion is controlled by the height of the ground-water table as well as by the nature of subjacent material. Dune migration becomes more active with drought conditions.

Limiting use factors.--Limiting factors include (a) high permeability, (b) dune movement, and (c) wind erosion.

Undesirable land uses.--Undesirable practices include (a) construction on or downwind from dunes, (b) the waste-disposal limitations as for stabilized dunes, and (c) road construction through dunes,

resulting in excavation and maintenance problems.

Fresh-Water Lakes, Ponds, Sloughs, Playas

Definition.--Lakes, ponds, and sloughs, which represent ancient river cut-offs and abandoned channels, are concentrated on ancient fluvial deposits. Sloughs occupy ancient abandoned channel courses, while lakes and ponds are commonly ancient flood basins and meander cut-offs. Playas are restricted to arid regions south of Corpus Christi where there is insufficient rainfall to maintain permanent lakes. Alternate wet and dry conditions result in playa salt deposits and associated clay dunes.

Limiting use factors.--The primary limiting factor is the value of fresh-water storage in these reservoirs, both as surface supply and ground-water recharge.

Undesirable land uses.--Undesirable use involves any (a) filling of the reservoir with consequent elimination of this important local water supply and (b) development adjacent to these reservoirs of improper disposal facilities that would pollute the fresh water.

Mainland Beaches

Definition.--These low-energy beaches along mainland sides of bays are composed of sand, shell, and caliche fragments. Storm berms composed of bay molluscs are common, particularly along marshy shorelines. There is a minimum of sand transport along these beaches, and beach deposits are normally thin and overlie older muds and muddy sands of the coastal plain.

Limiting use factors.--Limitations include (a) erosional susceptibility and (b) daily tidal activity.

Undesirable land uses.--Undesirable uses include any modification of natural sediment-dispersal processes through construction and/or excavation.

Area of Active Faulting and Subsidence

Definition.--Faults in the coastal region are linear features along the coastal plain commonly oriented parallel to subparallel to the shoreline along which some vertical displacement has occurred. Faults may be currently active (displacement in inches per 10 years) or may be temporarily inactive. Faulting is principally the result of compaction of thick wedges of ancient, water-saturated deltaic muds. Fault movement is along a curved surface that commonly extends thousands of feet into coastal sediments. Areas of unusually rapid *subsidence* normally result from extensive withdrawal of ground water. These areas may be several miles in diameter, and subsidence may also activate faults in the area. Withdrawal of oil and gas may also result in land subsidence. The only coastal plain area of significant subsidence at the present is near Houston, where withdrawal of ground water has resulted in 4 or 5 feet of subsidence southeast of Houston.

Limiting use factors.--The limiting problems are: (a) potential damage to foundations or other structures by fault movement or subsidence and (b) potential flooding of subsided areas during hurricanes and tropical storms or gradual flooding by marine water if the subsidence occurs along the shoreline.

Undesirable land uses.--Undesirable uses involve (a) construction of any sort (buildings, pipelines, cables, streets, and railroads) across faults without special design and maintenance and (b) construction within any subsiding area without proper drainage.

MAJOR FLOODPLAIN SYSTEMS

Major floodplain systems include through-flowing streams and associated lakes and sloughs, point-bar sands, and overbank or floodplain muds and silts; excluded are headward-eroding streams which originate within the coastal plain. These major river systems have extensive inland drainage basins and have been active for thousands of years. Each system incised its present valley during the last low sea-level stand (ice age), and filling began about 18,000 years ago when sea level began to rise. Valleys are filled with point-bar sands and floodplain muds and silts. Except for the Colorado, Brazos, and Rio Grande, these incised valleys have not been entirely filled by alluvial sediments. Bays and estuaries are segments of the drowned valleys which have not been filled, although small estuarine deltas, such as the Trinity, Nueces, and Guadalupe, have been building slowly into the estuaries for the past 5,000 years.

Point-Bar Sands

Definition.--These are bodies of highly permeable sand that are currently being deposited by lateral accretion on the convex bank of modern stream meanders and similar sand bodies that were deposited by earlier streams within the same valleys.

These lens-like sand bodies normally grade abruptly into muds. Coarser and more highly permeable sand and gravel occur near the base of point bars. These bodies are normally charged with fresh water. Older exposed point bars are vegetated primarily by willows, oaks, and other water-tolerant hardwoods.

Limiting use factors.--Limiting factors include (a) high permeability, (b) erosional susceptibility to running water, (c) the need to maintain the fresh water within these aquifers, and (d) susceptibility to flooding.

Undesirable land uses.--Undesirable uses include (a) liquid and solid waste disposal, (b) construction of surface holding ponds for brine or sludge, (c) development of feed lots, (d) placement of septic tanks except with careful monitoring of aquifer, (e) extensive excavation and development of steep slopes which accelerate erosion, and (f) devegetation which permits erosion of these sands.

Overbank Muds and Silts

Definition.--These units are sheet-like bodies of impermeable to moderately permeable sediment that were deposited on modern floodplains during flood stage. Valley fill also contains similar sediments deposited in earlier stages of development of the river system. The upper surfaces of modern floodplains slope gently away from levees flanking the rivers. Valleys are filled by lenses of point-bar sands dispersed within the less permeable deposits. Vegetation is primarily water-tolerant hardwoods in northern coastal areas; less vegetation occurs south of Corpus Christi.

Limiting use factors.--Limiting factors include (a) impermeability resulting in poor drainage, (b) high shrink-swell potential, (c) moderate corrosion potential, (d) moderate to low shear-strengths resulting in foundation problems, and (e) unstable steep slopes, especially when wet.

Undesirable land uses.--Undesirable land use includes (a) construction of any kind which is affected by shrink-swell problems such as cracking of foundations, (b) burial of pipes and cables that are subject to corrosion, (c) use of mud from these areas as fill without proper stabilization treatment, and (d) holding ponds that may be inundated during flood stage.

Water

Definition.--Through-flowing streams and their water discharge, dissolved solids, suspended load, and bed load are controlled by the size and substrate of the drainage basin, agricultural practices, climate, pollutants introduced into the drainage basin, and the presence of artificial reservoirs. This unit includes water within lakes, channel cut-offs, and abandoned stream courses, which occur within the floodplain system.

Limiting use factors.--See definition, above.

Undesirable land uses.--Undesirable uses include (a) waste disposal, especially chemical wastes and poorly treated sewage discharge, (b) excessive dredging and straightening of natural channels, and (c) restriction of sufficient flow to maintain river and deltaic accretionary processes, as well as nutrients and fresh water for maintenance of normal bay-estuarine systems.

COASTAL WETLANDS

Definition.--Wetlands include salt-water marsh, fresh-water marsh, and swamp. *Salt marsh* is flooded daily by tidal action and contains plants such as cordgrass *(Spartina alterniflora)*, grasswort *(Salicornia perennis)*, maritime saltwort *(Batis maritima)*, seepweed *(Suaeda* sp.*)*, and sea-oxeye *(Borrichia frutescens)*, inland from the shoreline to higher marsh areas, respectively. Along the Texas coast, salt marsh commonly occurs on the back sides of barrier islands north of Baffin Bay, along the margins of ancient deltas of the coastal plain, and on modern, presently active deltas.

Fresh-water marsh is maintained by a permanently high water table and/or high rainfall, and it is characterized by plants such as coastal sacahuista *(Spartina spartinae)*, marshy cordgrass *(Spartina patens)*, big cordgrass *(Spartina cynosuroides)*, bullrush *(Scirpus* sp.*)*, cattail *(Typha* sp.*)*, and rushes *(Juncus* sp.*)*. Fresh-water marsh occurs in the lower portions of river valleys, in swales on the modern barrier islands, in some abandoned stream channels, surrounding some coastal lakes, and inland from salt marsh on modern deltas and bay margins.

Swamps are areas of entirely fresh water and are maintained by rainfall and a high water table. They occur in active stream valleys inland from fresh-water areas and locally in ancient stream channels and cut-offs. Swamps are characterized by dwarf palmetto *(Sabal minor)*, cypress *(Cupressus)*, elm *(Ulmus)*, bay, mulberry, water oak *(Quercus nigra)*, gum, grapevine *(Vitis)*, and yaupon

(Ilex vomitoria).

Limiting use factors.--Limiting factors include (a) standing water and frequent storm flooding, (b) need to maintain local ground-water recharge by fresh-water marsh and swamps, and (c) the importance of the vegetation and physical environment for survival of many marine and terrestrial organisms, principally because of the extremely high plant productivity.

Undesirable land uses.--Undesirable land uses include (a) unnecessary dredging and/or construction of excessive canals or channels, (b) unnecessary filling of wetland areas and/or blocking of tidal channels that connect wetlands with the bay-estuary environment, (c) waste disposal in wetlands or in adjacent areas draining into wetlands, (d) flooding and, therefore, destruction of wetlands by construction of artificial reservoirs, (e) excessive traverses by marsh buggies and by air boats, (f) unnecessary devegetation of wetland areas, which decreases productivity and alters the food chain, and (g) draining of wetlands.

MADE LAND AND SPOIL

Definition.--Made land includes areas composed of dredged bay, barrier, marsh, and deltaic sediments (sand, mud, and shell) used to fill shallow bay areas and wetlands for development and industrial purposes. Permeability of this fill material is highly variable, as are its other physical properties. *Spoil* is waste sand, mud, and shell dumped into the bay or on adjacent lowlands during channel and canal dredging and oyster-shell production. In most bays, spoil occurs as circular to elongate islands which protrude up to 20 feet above sea level. Most spoil-disposal areas parallel adjacent dredged channels. Margins of spoil islands may be highly reworked by wave and current activity, concentrating shell and transporting finer sediment into adjacent bay-bottom environments, such as subaqueous grassflats.

Limiting use factors.--Limiting factors include (a) commonly high permeability and (b) erosional susceptibility to running water and waves or currents.

Undesirable land uses.--Liquid and/or solid waste disposal.

COASTAL BARRIERS

These highly permeable sand bodies are elongate parallel to the shoreline and are separated from the mainland by lagoons and estuaries. Local relief of the islands is from sea level to 50 feet; width is from ½ mile to 3 miles. Barriers are composed of a variety of wind, vegetational, and storm units.

Beach and Shoreface

Definition.--This is an area of high wave and current energy along the Gulf side of barrier islands characterized by sand and shell. Shoreface extends from low tide to 30 feet in depth. The lower shoreface is an area of strong biological activity characterized by abundant burrowing animals (crustaceans, molluscs, worms, echinoderms) and by minor sand transport. This zone displays an upward increase in sand content from muddy deposits at the toe of the shoreface to clean beach sands above. The upper shoreface is a zone of very active sediment transport with shifting bars 2 to 4 feet high. The beach extends from low tide inland to the vegetation line and is characterized by clean, highly permeable sand and shell. The lower beach is subjected to daily swash and backwash. The upper beach is subjected to inundation by spring tides and storm tides and to modification by wind activity. Upper beaches supply sand for maintenance of fore-island dunes.

Limiting use factors.--Limiting factors include (a) high permeability, (b) potential storm damage and continuously high physical energy, (c) tidal inundation, and (d) erosional susceptibility (wind, waves), with some beaches displaying erosion and other deposition.

Undesirable land uses.--Undesirable uses include (a) waste disposal (solid and/or liquid), (b) construction on beaches, because of potential loss of life and property during hurricanes, (c) construction of piers, groins, and jetties on erosional beaches where they may be undercut, resulting in recreational hazards as well as locally accelerating erosion, and (d) excavation or mining of sand which reduces the local sand budget and provides potential storm washover sites.

Fore-Island Dunes and Vegetated Barrier Flats

Definition.--These units are grass-covered, stabilized dunes (from 5 to 50 feet high) and sand flats between the beach and bay-side marshes or tidal flats. This area includes most of the exposed barrier island. Low rainfall and persistent wind prohibit growth of stabilizing grasses on central and

southern Padre Island. Fore-island dunes are also absent to poorly developed on Matagorda Peninsula where the beach and barrier flat are in juxtaposition. Stabilized blowouts occur behind fore-island dunes, producing a hummocky ramp-like surface. Vegetation consists of salt-tolerant grasses, rare mesquite *(Prosopis)*, and live-oak *(Quercus virginiana)* trees.

Limiting use factors.--Limiting factors include (a) critical need for stabilizing vegetation, (b) erosional susceptibility (wind, storm tides), (c) high permeability, (d) potential for loss of life and property during hurricanes, and (e) local, isolated fresh-water aquifer which is easily contaminated.

Undesirable land uses.--Undesirable uses include (a) devegetation, which accelerates wind and water erosion, (b) excavation of sand, (c) proliferation of access roads through fore-island dunes, (d) solid and/or liquid waste disposal, (e) surface sludge or brine pits, (f) modification of, or construction on, fore-island dunes, and (g) overgrazing, especially during drought years.

Washover Areas

Definition.--These are local areas from ¼ mile to 3 miles wide which channel hurricane flood tides across the barrier islands into bay areas. Many washovers occupy sites of abandoned tidal channels; others are caused by storm tides where fore-island dunes are poorly developed or weakened by blowouts. During major storms, these are areas of intense current activity with scour of large volumes of sand on the seaward side of the island and deposition in the channels and/or on the back side of the island.

Limiting use factors.--Limiting factors include (a) intense hurricane flooding and high current energy, (b) high permeability, and (c) erosional susceptibility.

Undesirable land uses.--Undesirable uses include (a) construction of any sort, because these are sites of intense hurricane activity and (b) solid waste disposal, because materials are excavated and washed back into lagoons and bays by storm currents.

Active Dunes

Definition.--These are areas of actively moving sand resulting from devegetation or storm breach of *fore-island dune-ridge.* On Padre Island, *blowouts* supply sand to back-island areas, resulting in dune fields 2 or 3 miles wide and tens of miles long. *Back-island dunes* eventually migrate into bay and lagoonal areas; blowouts are eventually revegetated and stabilized. Dunes and blowouts are aligned with prevailing southeasterly winds and are composed of highly permeable sand.

Limiting use factors.--Limiting factors include (a) erosional susceptibility to wind and water, (b) high permeability, and (c) movement of dune sands with prevailing winds.

Undesirable land uses.--Undesirable uses include (a) construction on or downwind from dunes, (b) solid waste disposal, and (c) proliferation of roads and highways through dune areas.

Tidal Flats

Definition.--These are flat areas subject to daily inundation by astronomical tides. They occur predominantly in the area of Sabine Pass, where mudflats rather than sandy beaches front the Gulf of Mexico. This area of relatively low wave activity is a shallow submerged flat occupied by a prolific burrowing fauna of molluscs, worms, crustaceans, and other organisms.

Limiting use factors.--The principal limiting use is the daily tidal inundation.

Undesirable land uses.--The principal undesirable use is construction of any sort, for daily tidal inundation precludes almost all land-use activities.

Swales

Definition.--These features are narrow, elongate troughs oriented parallel or subparallel to the strandline; they are from 10 to 100 feet wide and up to several miles long. The troughs are mud lined and may contain fresh water and a marsh flora. They occur between ancient or recently formed sand-beach ridges; local relief from the top of adjacent ridges is up to 5 feet.

Limiting use factors.--The only limiting factor is the need to preserve these swales as natural holding basins for fresh-water recharge of permeable sand beneath the mud floor.

Undesirable land uses.--Undesirable uses include (a) filling, (b) disposal of liquid and/or solid wastes, and (c) drainage.

APPLICATION TO MANAGEMENT PROGRAMS

Proper management of land and water resources, whether through voluntary or regulatory programs,

lies somewhere between strict preservation or highly restricted use and rampant exploitation. Determining the capability or tolerance of varied land and water units under man's use and activity will permit maximum use with minimum environmental destruction.

Natural units of land and water have different capabilities and tolerances. For example, a highly permeable sand is a very poor host for solid waste disposal simply because of its capability for transmitting wastes to aquifer systems; a relatively impermeable clay unit provides a secure host without aquifer pollution. A brackish marsh not only can tolerate but is in fact defined on its capacity to accommodate changes in salinity; a salt-water marsh, by contrast, can tolerate little fresh-water influx. A washover channel is a natural outlet for hurricane surges; it is an exceedingly poor site for construction. Many land and water resource units and their capability for particular uses are obvious; others are more subtle.

Resource capability units comparable to those outlined for the Texas Coastal Zone and described in this report can be delineated through adequate environmental geologic mapping elsewhere within the State. Of critical importance are areas within and adjacent to the larger metropolitan centers where highly concentrated population and industry exist with accompanying extensive use of land and water resources. Other critical areas are those adjacent to inland water bodies where current or potential development exists. All areas where large-scale construction projects are anticipated should be evaluated in terms of resource capability. Further, additional detailed studies are needed to define quantitatively these resource capability units.

Another important element in land- and water-use management is adequate inventory of the nature, degree, and distribution of man's activities throughout the State and the environmental stresses these activities create. These stresses can be evaluated and balanced with the capability of specific resource units and, when considered in terms of consequent economic impact, give a firm, logical, and just basis for environmental management and decision-making.

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