ESTABLISHMENT OF OPERATIONAL GUIDELINES FOR TEXAS COASTAL ZONE MANAGEMENT

Final Report on

Resource Capability Units I: Assessment of Locational Effects of Residential, Commercial and Industrial Expansion in the Corpus Christi Area, Texas —Methodology

Bureau of Economic Geology
Division of Natural Resources and Environment
The University of Texas at Austin

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ABSTRACT

A multidisciplinary team has been functioning at The University of Texas at Austin since 1971 to develop, apply, and evaluate methodology for considering environmental and economic effects of alternative Coastal Zone Management policies. The region encompassed by the Coastal Bend Council of Governments served as the test site for this project; special emphasis has been in the area around Corpus Christi Bay--Nueces, San Patricio, Aransas, and Refugio Counties. The principal purpose of the Bureau of Economic Geology task force of the multidisciplinary team was to provide an environmental base line against which to measure the effects of economic and demographic development in the Corpus Christi area and probable differences among several hypothetical management policies. Operational criteria, which form this base line, the systematic approach by which the locational effects of expansion where determined, and examples of the environmental impact of development are contained in this report.

Forty land and water areas have been delineated in the Corpus Christi area each with like capabilities to withstand similar kinds and rates of use or activity without losing an acceptable level of environmental quality. These data have been augmented by: (1) documenting the kinds, rates, and impetus of changes in dynamic shoreline environments; (2) relating engineering test results gathered by public agencies and private firms to physically defined land capability units on the Coastal Plain and in the bays; and (3) determining the distribution, amount, and quality of ground water available in the Corpus Christi area, and possible consequences of withdrawal of the ground water.

Land and water resource data and current (1970) land-use data were digitized for automated processing from maps at a scale of 1:125,000. Environmental assessment is in terms of the kinds, amounts, and relative percentages of land and water resources and land-use types affected by growth in the Corpus Christi area.

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Purpose

A multidisciplinary team consisting of specialists in economics, geography, civil engineering, biology, environmental health engineering, and geology has been functioning at The University of Texas since 1971. The purpose of this group is to develop, apply, and evaluate a methodology for considering the environmental and economic affects of alternative policies for management of the Texas Coastal Zone. Since June 1, 1972, this endeavor has been funded largely by the National Science Foundation through its Research Applied to National Needs (RANN) program (Grant No. 34870X). Additional funding and funding prior to June, 1972 have been from the Office of the Governor of Texas and The University.

The region encompassed by the Coastal Bend Council of Governments has been chosen as the study area for this project. Special emphasis has been placed on the more populous and rapidly developing area around Corpus Christi Bay, Nueces, San Patricio, Refugio, and Aransas Counties. Most of the data gathered and analysed are applicable to these counties.

Specific goals of the multidisciplinary team are to: (1) establish operating criteria specific to the Texas Coastal Zone by which economic and environmental impact of various policy decisions can be assessed; (2) develop a systematic approach for this evaluation so that the consequences of each policy decision can be compared; and, (3) integrate and test the proposed methodology by applying it to several differing, but hypothetical policies and projecting their effects to 1980 and 1990.

Three alternative policies were considered to test the methodology: (1) no change from 1970 public policy--economic and demographic changes will occur, but existing (1970) laws, regulations, technologies, and economic interrelations will remain in effect through projection dates of 1980 and 1990; (2) no development within 1,500 feet of the waterline after 1980--no further development will be allowed after 1980 within 1,500 feet landward or seaward of the mean low waterline of natural bays, estuaries, or lagoons of the Gulf of Mexico, or along existing major public channels and canals. In addition, no new navigation channels will be dug within the 3,000-foot zone; (3) improved waste water treatment--by 1980, waste water discharge will be treated to meet water quality standards possible through application of best available technology, and by 1990 there will be no (zero) discharge of pollutants into streams and coastal water bodies.

During the first year of NSF funding, the first objective was completed and work begun on the second objective. During the second year of funding, operating criteria were refined and the systematic approach developed. Principal effort, however, has been directed toward testing and comparing the three hypothetical policies.

Staff of the Bureau of Economic Geology at The University of Texas comprise the geology task force of the multidisciplinary team. The principal purpose of this group is to provide a base of environmental data against which to measure the consequences of man's activities and future economic development in the Coastal Zone as well as the effects of potential management policies. An interim report on this task force's progress was issued in May 1973. This May 1974 report describes the results of both years of investigation, including the data base, development of a systematic approach, and examples of the documentation of the environmental effects of the three hypothetical policies.

Scope of Investigation

Effective management of the Texas Coastal Zone depends on adequate delineation of the characteristics and distribution of natural and man-made land and water environments. For a management system to be fair, effective, or legally defensible, it must be based on sound scientific data defining properties and inherent carrying capacities of environments and the interrelationships among the environments. Development and use of land and water consistent with their natural capabilities will minimize or preclude many environmental problems. Knowledge of limiting parameters of an environment and its capability to withstand man's impact and serve as a resource to him is essential.

For these reasons, in 1969 the Bureau of Economic Geology began a comprehensive inventory of the Texas Coastal Zone (Fisher and others 1972; 1973a). Based on experience and knowledge gained in completing the Environmental Geologic Atlas of the Texas Coastal Zone, a concept of mapping units with different environmental significance developed. The basic premise of this concept is that land and water areas can be delineated with like capabilities to withstand similar kinds and rates of use or activity without losing acceptable environmental quality, thus allowing their continuing use as resources for man (Brown and others, 1971). These environmental entities, or resource capability units, are defined by elements of primary environmental significance, considering (1) geology, soils, and substrate, (2) biology, (3) hydrology, (4) physical properties, (5) chemistry, and (6) natural processes involved. Description of the process of resource capability analysis is contained in the following section.

Mapping of natural capability units is a necessary first step in considering capability, but basic data needed for defining capability for land- and water-use management include more than qualitative mapping of surface and near surface environments. Among the additional data needed are: (1) delineation of the subsurface extent of and relationships among certain of the different capability units; (2) quantification of physical and hydrologic parameters of the units, particularly those related to construction, waste disposal, and use of ground water; (3) documentation of the kinds, rates, and causes of change in the dynamic units along the coastline; and, (4) inventorying of the economically valuable mineral and fossil-fuel resources of the area.

Each of these tasks was addressed during the two years over which this phase of study was carried out. Resource capability mapping of the four-county area around Corpus Christi and the entire 13-county area of the COG was completed; many of the physically defined capability units were quantified, ground water availability was determined, kinds and rates of shoreline changes were documented, progress was made on determining the three dimensional character and mineral and energy resource potential of the capability units, and the environmental effects of implementing certain management policies in the Coastal Zone were determined. This report contains (1) descriptions and mode of derivation of land and water resource units in the four-county Corpus Christi area; (2) summaries of physical and hydrogeological character of the capability units, shoreline changes, and mineral and energy resource potential of the region; and (3) the method and results of assessing the environmental impact of projected development in the Corpus Christi area. A companion report will contain (1) description of the land resources of the entire Coastal Bend Region, and (2) details of the investigations of the physical and hydrogeological character of the capability units, historical monitoring of shoreline changes, subsurface configuration of the capability units, and mineral and energy resources available in the area.

DERIVATION OF LAND AND WATER CAPABILITY UNITS

Resource capability units are environmental entities--land, water, area of active process, or biota--defined in terms of the nature and degree of activity or use they can sustain without losing an acceptable level of environmental quality. Units are established by recognizing elements of primary environmental significance, whether dominantly physical, biological, or chemical. Analysis of resource capability considers basic facets of the land--geology, pedology, biology, and current land use as it pertains to the capability of land and water areas to sustain present and potential use. The net result of this analysis is delineation of areas with like natural ability to withstand similar kinds and rates of use without deteriorating environmentally beyond an acceptable level and recognition of areas that are subject to natural processes such as flooding and erosion that are potentially troublesome to human activity.

As such, resource capability analysis provides an environmental base line against which to measure the consequences of man's activities, assuming no engineering improvements are made to the land. Carrying capacity can be enhanced by proper engineering modifications, of course, but knowledge of natural capability provides a measure of the extent and the scope of modifications needed to make a particular land or water area suitable for a given use.

Factors that determine natural capability or carrying capacity are many and diverse. Factors that limit the use of a land or water area for specific activities are particularly important. Included in consideration of capability are: (1) potential for flooding by hurricane-driven tides and surges and by overbanking rivers; (2) erosional and depositional action by wind and water; (3) occurrence of dynamic equilibria; (4) physical properties of soils and substrates such as shrink-swell potential, corrosion tendency, and permeability; (5) slope and relief; (6) biotic habitation, activity and tolerances; (7) vegetation stabilization; (8) natural water movements and quality; and, (9) active or potentially active faulting and subsidence.

Evaluation of natural capability units is also tied to the types and intensity of activities that take place on the land and in/on the water. Present and anticipated land and water uses are varied, but certain activities serve as examples (Table 1). These are: (1) solid and liquid waste disposal; (2) channelization, ditching, and draining;

RESOURCE CAPABILITY UNITS		ACTIVITIES: Liquid Waste Disposal			Solid Waste Disposal		Coastal Construction			Inland Construction											
		Surface Disposal of Untreated Liquid Wastes	Disposal of Untreated Liquid Wastes, Subsurface, Shallow	Maintenance of Feed Lots	Disposal of Solid Waste Materials	Construction of Offshore and Bay Platforms	Construction of Jetties, Groins, Piers	Construction of Storm Barriers and/or Seawalls	Placement of Pipelines and/or Subsurface Cables ▲	Light Construction	Construction of Highways	Heavy 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			
	Swales	X	X		X					X	X	X		X	X	X	X		X		X
Man-Made	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

Table 1
Coastal Zone Land and Water (Resource) Units--Use and Capabilities
(After Brown and Others, 1971)

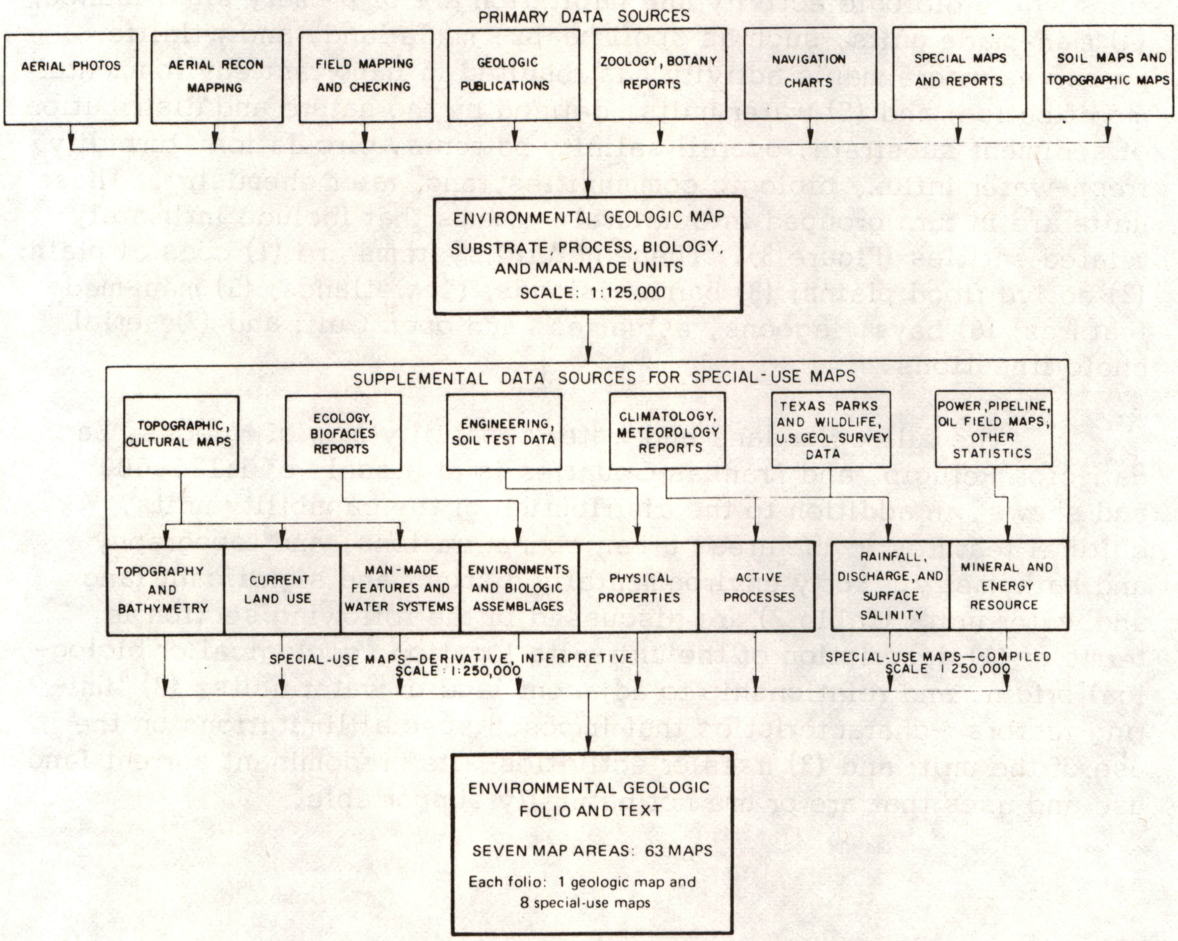
(3) construction of buildings, highways, light and heavy industry, jetties, groins, piers, and seawalls; (4) surface and subsurface extraction of raw materials; (5) filling and land reclamation; (6) devegetation and other alteration of natural flora; (7) farming and grazing; (8) use of herbicides, pesticides, and insecticides; and, (9) impounding of surface water for future use or storage of wastes. Thus, the natural characteristics and carrying capacities of different areas are related to the kinds and rates of activities that they may be called on to support.

All available information was used in evaluating land and water capability in the Corpus Christi area including published and unpublished reports, maps, and observations. It is impossible to credit each idea and fact to a specific source. Major references used are the Interim Report on Resource Capability (Fisher and others, 1973b) prepared for NSF-RANN and the Office of the Governor of Texas, the conceptual reports on the management of bay and estuarine systems in the Texas Coastal Zone (Fruh and others, 1971, 1973) prepared for Office of the Governor of Texas, and basic documents on environmental geology and resource capability analysis (Brown and others, 1971, Fisher and others, 1972, 1973a) prepared at the Bureau of Economic Geology. These reports contain extensive bibliographies not duplicated here.

Principal source of map data is environmental geologic mapping for the Corpus Christi (Brown and others, in progress) and Port Lavaca (McGowen and others, in progress) sheets of the Bureau of Economic Geology's Environmental Geologic Atlas of the Texas Coastal Zone. Environmental geologic units were interpreted from 7.5-minute Edgar Tobin Aerial Surveys photomosaics and corresponding U.S. Geological Survey topographic maps, both at a scale of 1:24,000, or approximately 2.5 inches per mile. Interpretation and mapping of environmental geologic units were based on genetic grouping of the major natural and man-made features of the Coastal Zone. In addition to aerial photo interpretation, mapping involved extensive field work, aerial reconnaissance, and utilization of available published data for the region. General sources and flow of data are shown in Figure 1.

By considering basic map data and the affects that all environmentally significant factors--physical, chemical, and biological, active and passive--as well as current and potential land use have upon a given area in the four principal counties of the Coastal Bend COG, the natural carrying capacities of land and water in the Corpus Christi area was assessed. Constant reassessment of each factor,

Figure 1
Sources and Flow of Data for the Environmental Geologic Atlas
of the Texas Coastal Zone
(After Fisher and Others, 1972)

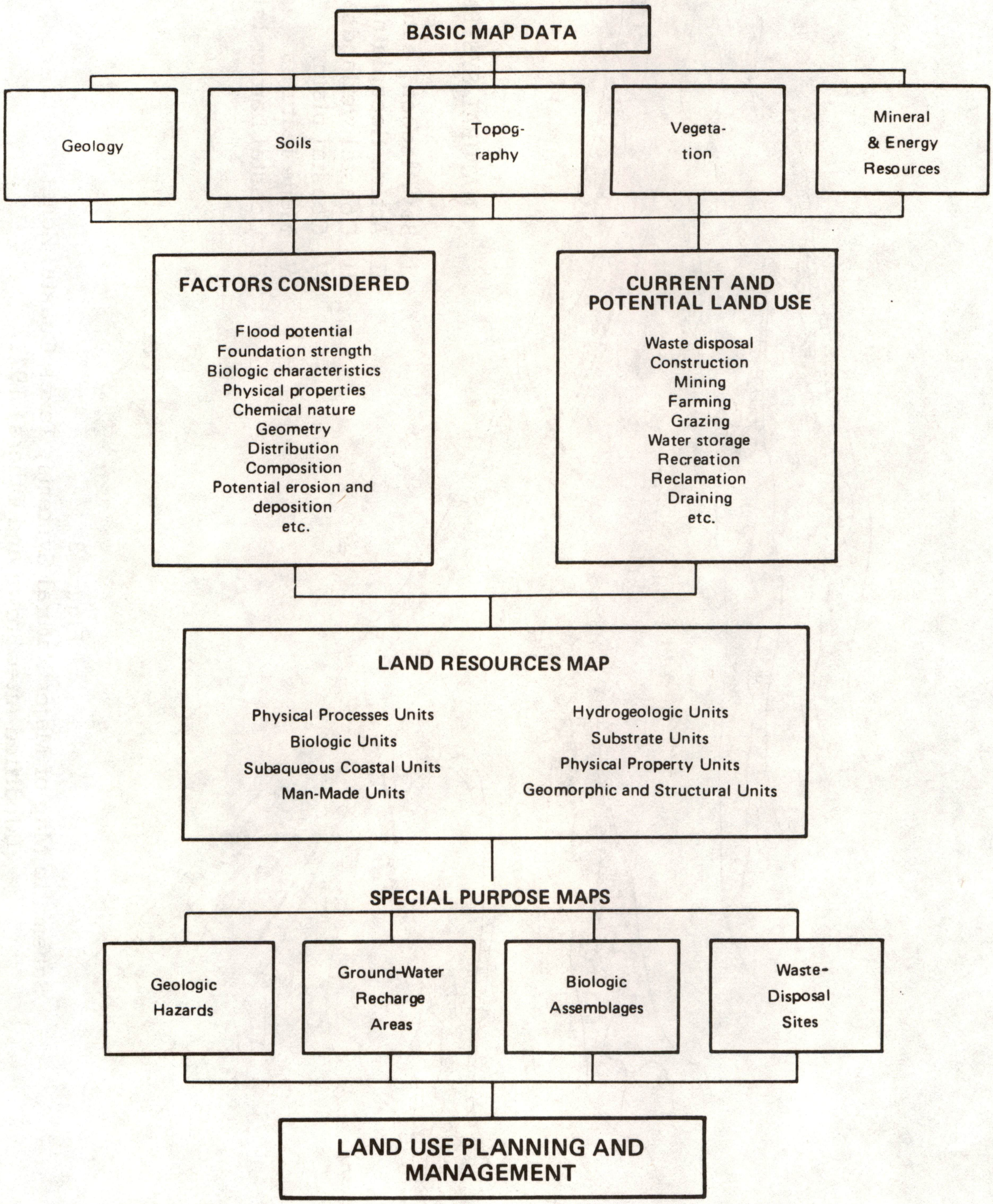


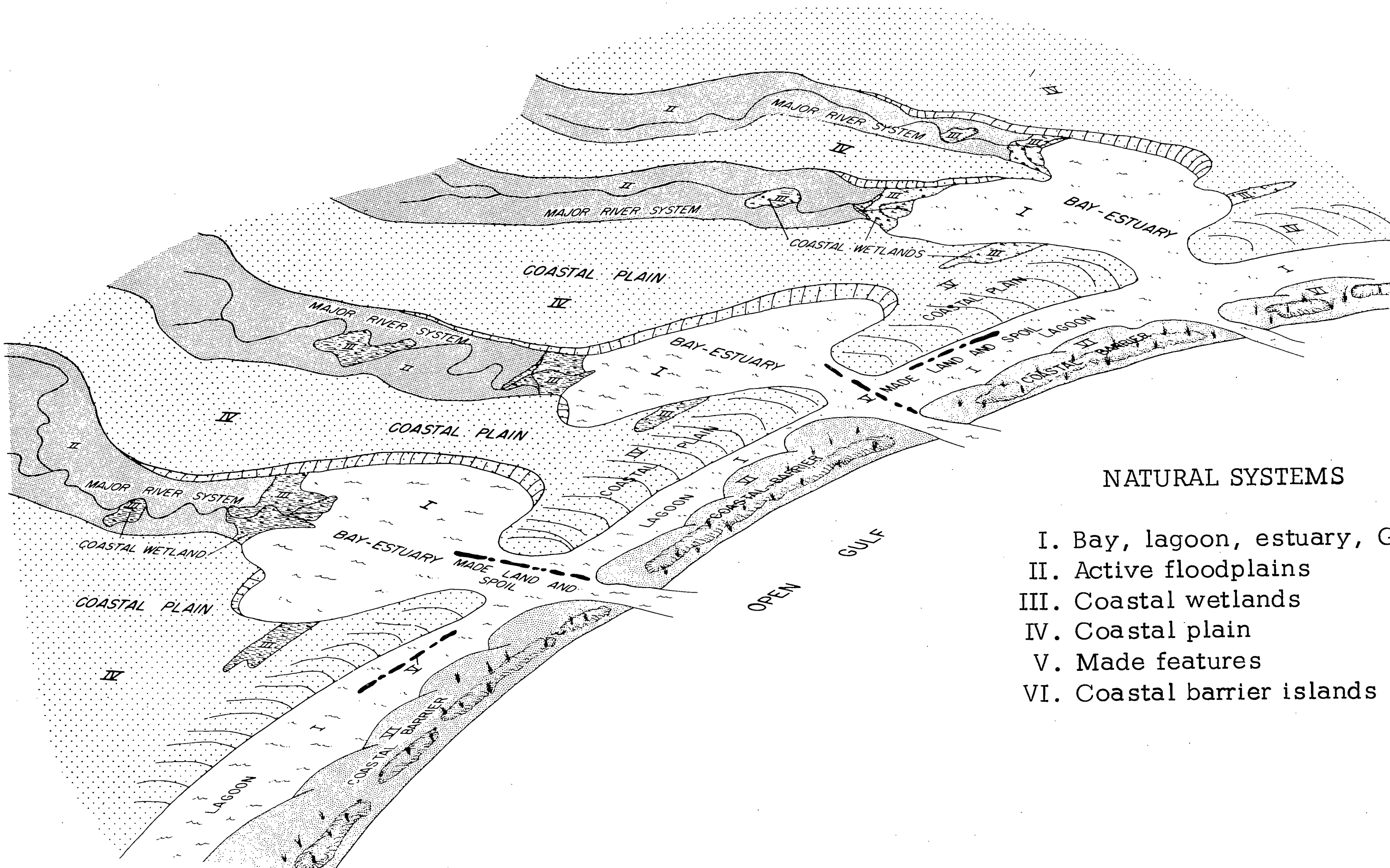
use, and piece of map information assures completeness and consistency. A flow diagram illustrating the process of resource capability evaluation is presented in Figure 2.

Basic units defined in the Corpus Christi area by this process and shown on the land and water capability map (in pocket) accompanying this report include: (1) physical units (geologic substrate and soils units); (2) process units, such as tidal inlets, hurricane surge channels, and flood plains; (3) biologic units such as reefs, marshes, and grass flats where biologic activity and habitation are of primary significance; (4) man-made units, such as spoil heaps, made land, and wildlife preserves where man's activity has resulted in important environmental modification; and (5) water units, defined by the nature and distribution of sediment substrate, overall salinity patterns, circulation, turbidity, fresh-water influx, biologic communities, and water chemistry. These units are in turn grouped into natural systems that include intimately related entities (Figure 3). These natural systems are (1) coastal plain; (2) active flood plains; (3) barrier islands; (4) wetlands; (5) man-made features; (6) bays, lagoons, estuaries, and open Gulf; and (7) aerial photo lineations.

The full-color land and water capability map of Nueces, San Patricio, Refugio, and Aransas Counties is at a scale of 1:125,000, and shows, in addition to the distribution of the capability units, cultural features in the area, urban concentrations, and topography and bathymetry. Forty environmentally distinct and significant land and water units (Table 2) are discussed in the following section in terms of (1) description of the unit--its location, geological or biological origin, and relationship to adjacent land or water units, (2) limiting factors--characteristics that imposed special limitations on the use of the unit; and (3) uses or activities--its predominant current land use and uses that are or are not naturally supportable.

Figure 2
Flow Diagram Illustrating the Process of Resource Capability Analysis
(After Kier, 1974)





NATURAL SYSTEMS

I. Bay, lagoon, estuary, Gulf
II. Active floodplains
III. Coastal wetlands
IV. Coastal plain
V. Made features
VI. Coastal barrier islands

Figure 3
Schematic Map of Major Natural Systems, Texas Coastal Zone
(Modified After Brown and Others, 1971)

Table 2
Land and Water Resource Units, Nueces, San Patricio, Aransas, and Refugio Counties, Texas

A. Coastal Plain
1. Highly permeable recharge sand
2. Moderately to highly permeable recharge sand
3. Moderately permeable sand and silt
4. Mud veneered, moderately to highly permeable sand
5. Mud veneered, moderately permeable sand and silt
6. Low to moderately permeable sandy mud with moderately permeable sand veneer
7. Sand veneered, low permeability mud
8. Low permeability mud
9. Mixed mud and sand with local mud-filled channels
10. Mud-filled channels, beach swales, and topographic lows
11. Calichified sand
12. Lakes, ponds, sloughs, and streams
13. Ephemeral lakes, ponds, and sloughs

B. Active Floodplains
1. Highly permeable sand and gravel
2. Low to moderate permeability mud and silt
3. Elevated natural levees
4. Small active streams or stream alluvium

C. Barrier Islands
1. Beach
2. Fore-island dunes and vegetation-stabilized barrier flats
3. Active dunes and sand blowouts
4. Storm washover areas
5. Tidal flats

D. Wetlands
1. Brackish- to salt-water marsh
2. Fresh-water marsh
3. Swamps

E. Man-made Features
1. Made land and spoil
2. Subaqueous spoil
3. Aransas National Wildlife Refuge

Table 2 (continued)

F. Bays, Lagoons, Estuaries, and Open Gulf

1. River-influenced bay
2. Enclosed and/or restricted bay
3. Open bay
4. Tidally influenced open bay
5. Tidal inlets and subaqueous tidal deltas
6. Bay-margin sand and muddy sand
7. Oyster reef, adjacent reef flank, and interreef areas
8. Grassflats
9. Upper shoreface
10. Lower shoreface and open Gulf
11. Local sand and shell beaches and berms

G. Aerial Photo Lineations

CAPABILITY UNITS

Coastal Plain (A)

The Coastal Plain in the Corpus Christi area is a flat to gently rolling surface inclined slightly seaward at an average gradient of 4 to 5 1/2 ft/mi (feet/mile) and having a maximum elevation of 200 feet at the western border of San Patricio County.

The Nueces, Aransas, and Mission Rivers transect the Coastal Plain in the Corpus Christi area. The San Antonio River, joined by the Guadalupe River about 10 miles upstream from San Antonio Bay, flows along the northern boundary of Refugio County. All the modern streams are more or less entrenched into the soft Coastal Plain sediments. Average incision is about 15 to 20 feet; maximum incision is up to 80 feet along the Nueces River where it enters the Corpus Christi area.

Numerous creeks also cross the Coastal Plain: Oso, Chiltipin, Blanco, Melon, Copano, and Artesian Creeks and several others. Many of these creeks also have cut into the Coastal Plain and nearly all are actively extending their courses in a headward direction.

Most sediments that comprise the Coastal Plain accumulated in Pleistocene and Holocene age rivers, deltas, and coastal barriers or in shoreline environments. During one or more of the interglacial periods of the Pleistocene, rivers transported large quantities of sand, silt, and clay from the interior of Texas to deltas and embayments in the ancient Gulf shoreline. Long narrow barrier islands or shoreline sedimentary bodies were also present along the ancient shoreline. The varying processes in effect during deposition of the sediments resulted in a variety of kinds of deposits, each with unique characteristics. Natural carrying capacity is primarily determined by the physical, hydrological, and biological aspects of the different land and water areas.

Dryland farming is the dominant use of land in Nueces and San Patricio Counties where muddy soils predominate. In the western half of San Patricio County and to a lesser extent in northwestern Nueces County some of the farmland is irrigated, principally with ground water. In Aransas and Refugio Counties most of the land is underlain by sand or muddy sand and is used as range-pastureland. Locally, muddy soils that are sufficiently well drained are cultivated.

Little natural vegetation remains on the Nueces and San Patricio farmland. The original prairie grass was plowed under to make fields. Natural vegetation on the rangeland in Aransas and Refugio Counties is mesquite, mesquite-oak, oak, oak-prairie, and prairie. Small stands of willows are found along streams and topographic lows that frequently pond water following rainstorms. Extensive land areas of Aransas County are salt- and fresh-water marsh, particularly around Port Bay.

Thirteen land and water resource units have been delineated on the Coastal Plain.

A1. Highly permeable recharge sand

Land composed of loose, highly permeable sand lies along the entire mainland coast in the Corpus Christi area. Accumulation occurred as Pleistocene age barrier islands and/or related shoreline deposits. These sands are 2 to 6 miles wide in the Corpus Christi area, cover approximately 139 square miles, and reach a maximum thickness of about 50 feet.

Ridge-and-swale topography dominates the land northeast of Copano Bay in the Aransas National Wildlife Refuge. Numerous marshes, tidal creeks, and mud-filled depressions occur in the swales. (These lands are discussed further under separate headings.) Dominant vegetation types are scrub brush, prairie grass, and oak trees.

Southward from Copano Bay, wind action has modified the land surface eliminating almost all depressions except those filled with water. This increasing effectiveness of wind action is associated with decreasing rainfall and decreasing abundance of trees. Precipitation between Copano Bay and Corpus Christi Bay is still sufficient to maintain scattered stands of oak, but south of Corpus Christi Bay few natural stands of trees remain.

Current use of this land is varied. The area north of Copano Bay is maintained as a wildlife habitat. Much of the land area south of Copano Bay is occupied by urban, residential, and recreational development, contributing to the loss of trees. The rest of the land is used predominantly for grazing. Low moisture retention by the sandy soils makes the land generally unsuited for cultivation.

Very high porosity and permeability of the loose sand make direct recharge of ground water possible. North of Corpus Christi Bay local residents use water from this aquifer, and there are numerous shallow wells. Impermeable mud occurs beneath and adjacent to much of the sand, isolating the aquifer from other Coastal Zone aquifers.

Pollution or alteration of this perched aquifer is easily possible from improperly designed and maintained disposal or holding sites for solid or untreated liquid waste, brines, sludges, and heated fluids, from extensive use of septic tanks or seepage pits, or from development of feed lots. Lateral migration of pollutants to water supply wells and adjacent bays, lagoons, and marshes is probable before the contaminants are sufficiently diluted. Disposal or cooling ponds should be sealed or allowed to seal naturally and carefully monitored to guard against leakage.

The high water table found in this sand unit, as evidenced by water well records and the occurrence of numerous ponds, may limit construction that would require deep excavations or that would be harmed by having footings constantly submerged in ground water. High ground water levels most certainly reduce the effectiveness of septic tanks. Significant amounts of precipitation can raise the water table nearly to the land surface, above the level of filtration fields. Effluent trapped in septic tank laterals may back up into indoor plumbing or spread over the land surface. Constant immersion of unprotected pipes and cables in ground water that is occasionally slightly saline after severe storms and during droughts can induce corrosion. Low density grazing and most recreation will not pollute the ground water supply nor cause excessive devegetation.

Foundation strength of the loose sand is generally good, although heavy structures will probably have to be placed on piers driven into the sand and road beds may have to be stabilized to prevent buckling. Lack of clay and silt in the sand render it incohesive and it fails readily in steep sided excavations; it is highly susceptible to wind and water erosion, particularly where devegetated. Other properties of the sand--low shrink-swell potential, plasticity and compressibility, and high foundation strength--present few problems in construction of highways and buildings.

<u>A2. Moderately to highly permeable recharge sand</u>

Loose, unconsolidated, moderately to highly permeable sand comprises about 199 square miles of land in the northwestern part of the Corpus Christi area between Chiltipin and Melon Creeks. Deposition occurred in an ancient river system in which medium- to coarse-grained sand was relatively abundant with respect to finer grained sediments. This sand-dominated river system produced a widespread network of vertically and laterally interconnected elongate sand bodies and associated mud (A-7) and mixed mud and sand (A-9) deposits. Lenses and pockets of mud and sandy mud, too small to map, occur within the sand bodies also. Most of this land supports sparse to dense growths of mesquite, scrub brush, and scattered oaks. Locally some of the land has been cleared and is grass covered, or has been cleared except for oak mottes. Grazing is the dominant land use.

The high permeability of this sand allows direct recharge to the coastal aquifer system. Precipitation quickly soaks into the ground and few streams originate within the area. Ground water in this sand is abundant and is generally within U.S. Public Health Service standards for drinking water. This is one of the best shallow aquifers in the Corpus Christi area.

Because of the high permeability, however, waste-disposal leachate, brines, sludges, septic tank effluent, and feed lot runoff can easily percolate downward to the water table contaminating the fresh ground water. Furthermore, cooling ponds may leak unless lined or allowed to seal with very fine sediment.

Low moisture retention by the sandy soils developed on the recharge sand means that farming is generally not possible and grazing is the best agricultural land use. The loose, incohesive nature of the porous sand also makes it highly susceptible to wind and water erosion, particularly if devegetated.

Although the sandy soil is easily excavated, slope stability is poor. The abundance of through-flowing water and presence of muddy lenses tend to create a battery effect, accelerating deterioration of metal pipes and cables buried in the sand. Other than poor slope stability and high corrosion potential, few problems should be encountered in construction of buildings and highways. The low amount of clay and silt with the sand means low shrink-swell potential, low plasticity, low compressibility, and high foundation strength. Internal drainage is very high, and foundation footings will probably not have to endure extended periods of soaking. Fill excavated from these lands generally requires no special stabilization, provided it is not placed on steep slopes where it might fail or be eroded.

A3. Moderately permeable sand and silt

Moderately permeable sand and silt deposits 20 to 100 feet thick occur on about 624 square miles of the Coastal Plain in the Corpus

Christi area in belts 1 to 5 miles wide that are oriented approximately perpendicular to the coastline. These sediments accumulated during the Pleistocene as deltaic distributary channels and deltaic margins, and in river systems.

Two different modes of moderately permeable sand and silt occur in the Corpus Christi area. In Refugio County sand and silt deposits are dominant and few muddy areas can be found. There the sand and silt are very similar to the permeable sand (A-2) previously described, but differ in having a greater silt and mud content, and being somewhat less permeable and less densely vegetated. Locally, unmapped veneers of mud may occur and are reflected by relatively open areas with oak mottes. Moisture retention by soils developed on the sand and silt is generally low and most of the area is used for rangeland.

In the southern part of the Corpus Christi area, narrow belts of moderately permeable sand and silt overlie and are flanked by widespread low permeability mud (A-8). Moisture retention by soils on these narrow sand belts is higher than on the sand and silt to the north. Most of the land area has been cleared, leaving little natural vegetation, and the sand and silt is cultivated, principally dryland cotton.

These sands and silts are a significant part of the Coastal Zone aquifer system, and are a source of shallow ground water. Water quality in the northeastern occurrence of moderately permeable sand and silt is nearly as good as in the moderately to highly permeable recharge sand (A-2), and there is nearly as much ground water available. In the sourthern part of the area, ground water movement is largely confined to the deposits of sand and silt, and water quality is not as good as to the north. Total dissolved solids and chloride content are generally too high to meet Public Health Service standards for drinking water, although the water is still used to a limited extent.

Because of the permeability of the sand and silt, effluent or leachate from improperly sited and maintained waste-disposal sites, holding ponds, feed lots, and household waste treatment systems can penetrate downward to the ground water. Transmission of these undesirable fluids coastward would contaminate wells and possibly lead to discharge of some of the pollutants into coastal water bodies.

In addition to the above sensitivity, the sand and silt land is moderately susceptible to erosion and has a high corrosion potential. Lack of clay renders the sediments somewhat incohesive and susceptible to erosion by wind and water, particularly if vegetation is removed. Close proximity of different kinds of deposits, however, can set up an electric potential along pipes and cables, greatly accelerating their corrosion.

The limited amount of clay in the sand and silt also means low shrink-swell potential, low plasticity and compressibility, generally high foundation strength, and easy excavation--characteristics favorable for construction of heavy structures and roads. Care should be exercised, though, that footings are not unwittingly founded in clay with poor engineering properties, possibly subjecting constructed works to damaging torques. In general, fill material composed of the sand and silt may be used without further stabilization.

A4. Mud veneered, moderately to highly permeable sand

Mud veneered, permeable sand occurs in the same area as the moderately to highly permeable sand (A-2) and is similar to it except for being overlain by a generally thin cover of mud. The origin of the mud veneer is not well understood, but it is either an erosional remnant of a once more extensive clay-rich deposit that accumulated approximately at the same time as the Pleistocene age elongate sand bodies or the mud was transported onto the ancient sand deposits more recently. There are about 70 square miles of mud veneered, moderately to highly permeable sand in the Corpus Christi area.

Most of the land has been cleared leaving only the prairie grass cover and it is now used for pasture. Locally the mud cover is sufficiently thick and retains enough moisture to be suitable for agriculture. Nowhere is the mud cover thick enough, however, to significantly retard downward percolation of ground water.

Because of the moderate to high permeability, particularly below the surface cover of mud, leakage or runoff from waste disposal sites, holding ponds, septic tanks, and feed lots could reach underlying ground water. To prevent pollution of the ground water, only sites determined to be secure by careful investigation and/or completion of necessary engineering modifications should be used.

The mixed nature of this land, consisting of separate layers of sand and mud, presents some problems in construction of highways and buildings. Because of the close conjunction of sand and mud and ground water, potential to corrode buried pipes and cables is high. In places, the mud cover is thick enough that its moderate to high shrink-swell potential, moderate to high plasticity and compressibility, and low to moderate foundation strength can affect construction. The sand beneath the mud veneer provides a firm foundation and excavation to the sand is easy to moderate, but variations in the thickness of mud cover and consequent differences in engineering properties of the land at any given depth can still result in differences in foundation strength from place to place. In addition, steep sided excavations are unstable and are easily eroded. Fill should be adequately stable without further stabilization, particularly if the upper mud layer and underlying sand are mixed.

A5. Mud veneered, moderately permeable sand and silt

Mud veneered, moderately permeable sand and silt covering about 62 square miles occurs near the mainland coast north of Copano Bay and south of Corpus Christi Bay. It is similar to the moderately permeable sand and silt (A-3) with the exception of being overlain by a thin cover of low permeability mud. Deposition of the sand and silt occurred in Pleistocene age deltas and marine reworked delta margins. Much of the mud cover probably was washed fairly recently onto the sand and silt. Some mud may also be erosional remnants of ancient clay-rich deposits that accumulated on top of the sand and silt.

Few trees grow on the mud-covered sand and silt and most of it is used for pasture. Locally the mud is sufficiently thick and retains enough moisture to be farmed.

Use characteristics of the mud veneered sand and silt are similar to those of the mud-veneered, moderately to highly permeable sand (A-4) with the exception that overall permeability is less. Ground water lies only a few feet below the ground surface, and despite reduced permeability there is probably some recharge through the mud covered sand and silt. Contaminants from improperly designed and maintained waste disposal sites, feed lots, holding ponds, and septic tank systems, could move the short distance downward to the water table. Although the ground water is briny and used very little, pollutants entering the aquifer may be discharged into adjacent streams or coastal water bodies before there is sufficient attentuation to lessen impact on water quality. Well designed and maintained disposal or holding sites could prevent the problem, of course.

Because of the clay layer, shrink-swell potential, plasticity, and compressibility may be moderate to high, and foundation strength may be only moderate. Where the underlying sand is sufficiently close to the surface, conditions are more favorable for construction; placing footings in the sand where possible will eliminate many problems associated with construction on mud. Corrosion potential is very high, however, owing to through-flowing water and close conjunction of sand and mud. Slope stability is generally low to moderate, but excavation is moderately easy and fill generally needs no additional stabilization.

A6. Low to moderately permeable sandy mud with moderately permeable sand veneer

About 100 square miles of sand veneered sandy mud is associated with the northern occurrence of the moderately permeable sand and silt (A-3). Accumulation probably occurred in the cut-off channels of ancient rivers and between the distributaries of sand-dominated deltas. Subsequent erosion and redistribution of sediment has apparently transported sand from the adjacent sandy areas onto sandy mud. This sand veneer is highly variable in thickness.

Most of the sand covered land is used for rangeland. It is a fairly open prairie with a few scattered stands of oaks. Only locally is moisture retention capacity (low to moderate) of the sandy soil sufficient to allow farming. Drainage is a minor problem and some drainage ditches have been dug. When the sandy soil dries out however, it becomes incohesive and susceptible to wind and water erosion, particularly if devegetated.

This land is among the most tolerant to man's use in the Corpus Christi area. Some recharge of the subjacent aquifer probably occurs where the sandy mud is moderately permeable, but the land should be readily adaptable for solid and liquid waste disposal sites, brine and sludge holding ponds, cooling ponds, and feed lots after performance of engineering modifications necessary to insure security of the site. The sandy mud easily handles household septic tanks or seepage pits, without special modifications.

Moderate shrink-swell potential, low to moderate plasticity and compressibility, and generally moderate but variable foundation strength should present few problems for construction. Excavation is moderately easy, slope stability is good, and minimal stabilization of fill should be needed. Close proximity of sand and mud may set up a battery effect, however, accelerating corrosion of unprotected pipes and cables.

A7. Sand veneered, low permeability mud

Small areas of sand veneered low permeability mud occur along the margins of the moderately to highly permeable recharge sand (A-2) northwest of Copano and Corpus Christi Bays. The underlying mud is similar to low permeability mud (A-8) described next. The thin cover of loose sand apparently was washed or blown fairly recently off adjacent sand deposits. Dryland farming and grazing are the dominant present-day land uses. There are about 38 square miles of sand veneered low permeability mud in the Corpus Christi area.

Important characteristics of the sand veneered mud are: (1) low permeability, (2) moderate to high shrink-swell potential, plasticity and compressibility, (3) low to moderate foundation strength, (4) very high corrosion potential, (5) instability of steep slopes, especially when wet, and (6) the presence of loose surface material.

Low permeability results in slow internal drainage; a large percentage of precipitation falling on this unit runs off without percolating into the ground. This is advantageous to locating liquid and solid waste disposal sites, brine and sludge holding ponds, and feed lots on the sand veneered mud. Careful on-site investigation should quickly delineate localities that are truly secure and which with repeated inspection and maintenance will prevent ponding on or near the sites or migration of effluents or waste products onto adjacent permeable areas. Use of the sandy upper layer without modification as final cover for landfills or dikes around holding ponds may allow leakage into or from the sites, however.

In contrast, low permeability may present problems in the use of septic tanks. As in the situation with the low permeability mud without a sand veneer (A-8), effluent is not easily absorbed. When dry, the mud is extremely impermeable and the chief means of effluent escape are by evaporation and by movement into desiccation cracks. When saturated, the mud drains slowly at best and will not absorb additional fluids. Thus, effluent may run out on the surface or be trapped in septic tanks. Properly designed absorption fields or seepage pits can largely overcome these difficulties, particularly where the sand veneer is more than a few feet thick, but frequent inspections will be necessary to insure that the effectiveness of the field is not impaired with age or overuse.

Low foundation strength and moderate to high shrink-swell potential, with associated high absorption pressure and tendency for cracking, can present severe problems to construction of buildings, bridges, and highways. Post-tensioned slabs or pier and beam foundations may be required. The sand veneer probably reduces shrink-swell potential only slightly by inhibiting drying of the upper surface of the clay, although locally the sand veneer may be thick enough to improve foundation conditions. Potential to corrode buried metal is very high due to the close proximity of sand and the acidic nature of the muds.

In addition, poor internal drainage of the mud may allow ponding of water in and adjacent to structures, causing damage from wetness and perhaps weakening concrete footings. Slope stability of the dry soil is low, and is reduced further when the mud becomes saturated. Shear strength is decreased and plasticity increased with increasing saturation, causing failure on seemingly low slopes. The loose, incohesive sand veneer is highly susceptible to erosion, especially if the plant cover is removed.

A8. Low permeability mud

Low permeability mud that accumulated in ancient deltas between sand-filled distributaries and along ancient rivers, is widespread in the southern half of the Corpus Christi area. It is the most extensive capability unit present covering approximately 791 square miles. Locally, unmapped clay-sand dunes that are mostly stabilized and have somewhat different properties also occur. Topographically, the land surface is very flat and it is poorly drained. This factor, coupled with the lack of permeability, commonly results in temporary ponding of rainwater and concomittant damage to crops and man-made structures. Construction of numerous drainage canals has alleviated this problem, but has not eliminated it.

Prairie grass was the dominant natural vegetation on the mud but most of the grass has been plowed under to make fields for farming, mostly dry-land cotton. Locally, some of the land is irrigated. Moderate to high moisture retention capacity of soils developed on the mud render it highly suitable for farming, but severe cracking can develop as the soil dries and shrinks.

The impermeable nature of the mud makes it inherently the most secure substrate on which to locate feed lots, solid and liquid waste disposal sites, and holding ponds for brines, sludges, and other contaminating or heated fluids. Pre-use engineering modifications should be minimal, other than insuring that precipitation drains away from disposal or holding sites. Continued monitoring and perhaps maintenance of the sites may, of course, be necessary, but, excluding the original price of land, overall costs of a properly designed and operated facility should be less than for any other capability unit in the Coastal Zone. Only locally derived final cover for landfill material may have to be stabilized to prevent swelling and cracking from alternate wetting and drying. Clay-sand dunes should be avoided because they are more permeable and susceptible to erosion.

The same factors that make this land suitable for disposal or holding solid and liquid wastes or other noxious fluids can lead to problems with the use of septic tanks. Because of impermeability, effluent commonly cannot be absorbed and runs out on the ground surface or is trapped in the tanks, particularly during times when the soil is extremely dry or extremely wet. Properly designed absorption fields or seepage pits may alleviate the problem, but continued inspection probably will be necessary to insure that the initial design was adequate and that effectiveness of the field has not been affected with age and use.

Very high shrink-swell potential, high to very high plasticity and compressibility, low foundation strength, very high corrosion potential, and slope instability present construction problems that may require expensive solutions. These problems are similar to those of the sand veneered low permeability mud (A-7), but may be even more severe. Ground surface movements associated with alternate wetting and drying of the soil produce strong, often differential, lateral and vertical pressures on foundations. Foundation strength is reduced even more when the soil becomes saturated and very plastic. Excavations that are steep-sided may need to be supported. Such characteristics also put severe strains on buried pipes and cables, which, because of natural acidity of the mud, will also quickly corrode if left unprotected. Dry soil becomes very hard and cracks severely, becoming difficult to excavate. Fill material generally requires stabilization treatment to bear loads or be graded to a steep slope.

A9. Mixed mud and sand with local mud-filled channels

Mixed mud and sand in local channel fills occurs in about 77 square miles of the northern half of the Corpus Christi area and are associated primarily with moderately to highly permeable recharge sand (A-2) and moderately permeable sand and silt (A-3). The organic-rich mud and sand were deposited in abandoned channels of the ancient rivers and deltas. In many places, however, the mud- and sand-filled channels are too numerous to distinguish individually and several channels have been lumped together along with some adjacent permeable sand and silt. In other places the channels are simply a thin veneer on the permeable sand and were not mapped.

The predominant land use is grazing. Although moisture retention of the soil is probably sufficiently high to favor use as farmland, most mud- and sand-filled channels are too small.

The channel fills are generally found in topographic lows which flood before adjacent land. Flood waters will probably tend to drain slowly from these areas because of the low to moderate permeability and consequent poor internal drainage. Locally willows and other water-tolerant vegetation are present.

The low to moderate permeability and the rather poor internal drainage of the mud and sand would seemingly make this land resource suitable for disposal of wastes, brines, sludges, and other noxious fluids or for development of feed lots. Susceptibility to flooding and close proximity to permeable sands makes these uses generally inadvisable, however. Carefully designed landfills are acceptable, but only with proper modifications to insure impermeability of the surrounding host and to prevent ponding of water or erosion of cover material. Continuous monitoring of such sites is essential.

The low topographic setting and poor natural drainage of the land do make it an ideal place in which to hold surface runoff, provided a sufficiently large catchment basin exists to fill the tank. Adjacent areas may be too permeable to hold surface water long.

Engineering characteristics of the mud and sand are not severely limiting, but do present some problems for construction. Shrink-swell potential is moderate to high and foundation strength is only low to moderate. Plasticity and compressibility are high. Corrosion potential of the acidic, somewhat organic-rich mud and sand is very high. Excavation may be difficult, and fill material will probably require additional stabilization. Designs necessary to overcome these engineering problems tend to be expensive.

A10. Mud-filled channels, beach swales, and topographic lows

Several geologically different types of land--mud-filled abandoned scars, abandoned lake deposits, mud-filled tidal channels, and mud-filled beach swales--have been combined into this single resource unit because of their similar occurrence in topographic lows, predominance of more or less organic-rich mud, and small areal extent.

The mud-filled topographic lows cover approximately 70 square miles in the Corpus Christi area.

Mud-filled meander scars and lake deposits occur mostly in the sourthern part of the Corpus Christi area associated with thin belts of moderately permeable sand and silt (A-3) and widespread areas of low permeability mud (A-8) that were deposited by Pleistocene age rivers and deltas. Accumulation occurred in cut-off segments of channel bends and in lakes where suspended mud settled from ponded water. Principal land use is farming.

Mud-filled tidal channels occur mostly in the northern half of the area, associated with widespread moderately permeable sand and silt (A-3) and sand veneered sandy muds (A-6). Mud eroded from nearby areas apparently choked and filled the tidal channels. Moisture retention by soils developed on mud-filled tidal creeks is sufficient for farming, but the land area is generally too small to make farming worthwhile. Chief present-day land use is grazing.

Mud-filled beach swales are present in the northernmost portion of the Pleistocene age highly permeable sand (A-1) that accumulated parallel to the modern mainland coast and is now part of the Aransas National Wildlife Refuge (E-3). Mud eroded from nearby sediments and mud lens within the highly permeable sand was deposited by storm waters ponded in topographic lows.

Low permeability would seemingly make the muddy lands a good host for waste disposal, holding ponds, or feed lots. The occurrence of low permeability, poorly drained mud in topographic lows makes this land highly susceptible to early flooding and long-term ponding of water, however. Water held in the depressions might wash contaminants from such sites into adjacent permeable sand aquifers or water bodies. Septic tank systems also may fail to work properly for the same reasons: low permeability, commonly saturated conditions, and susceptibility to flooding.

Structures placed in the depressions may have to be elevated to avoid flood damage. In addition to potential flooding, construction should be designed in consideration of the high shrink-swell potential, low foundation strength, very high plasticity, very high compressibility, poor slope stability, and very high corrosion potential. Footings may have to withstand soaking by the very shallow ground water. During times of extreme wetness and extreme dryness, excavation will be difficult. Fill will probably require stabilization because of its poor engineering characteristics.

A11. Calichified sand

A small area (3.3 square miles) of sand cemented by caliche occurs in the western part of the area near Lake Corpus Christi. Topography is much more rugged here than in the rest of the Corpus Christi area, and low scarps are common. The presence of caliche reflects increasing dryness of the climate to the south and west of the Corpus Christi area. Dominant present-day land use is rangeland, in part because of lack of water and in part because of generally low moisture retention capacity of soils developed on the caliche-cemented sand. Locally level areas are farmed, and there are numerous caliche pits.

Moderate to low permeability of tightly cemented calichified sand (dry climate) make it generally suitable for disposal of solid and liquid wastes, brines, and sludges. Locally areas that are not tightly cemented might present some limitations to waste disposal, but these can be largely overcome at properly designed and modified sites. Septic tanks should also work satisfactorily although placement in heavily calichified areas may be difficult. Regular inspections with follow-up maintenance will insure that filtration fields continue to work properly.

Low shrink-swell potential, high foundation strength, low corrosion potential, low plasticity and compressibility, and moderately easy excavation present few problems to construction. Fill will naturally tend to stabilize because of its caliche content.

A12. Lakes, ponds, sloughs, and streams

Numerous brackish to saline and fresh-water bodies covering about 46 square miles are present in the Corpus Christi area. Inland water bodies are fresh and occur as ponds and sloughs in ancient and modern river bend cut-offs and abandoned channel courses, and in heart-shaped lakes that are possibly wind-modified remnants (Price, 1958) of Pleistocene estuaries or delta margin lows. Some water bodies, such as Lake Corpus Christi and soil conservation ponds, are man-made. Fresh water lakes, ponds, and sloughs are important for surface water supply, ground water recharge, soil conservation, recreation, and as fish and wildlife habitats.

Along the coastline countless fresh to saline water bodies also occur in small restricted areas of bays and estuaries, low-lying areas, and open areas in coastal marshes. These water bodies are probably remnants of once more extensive water bodies, and they are important chiefly as wildlife habitats, primarily of water-fowl.

Coursing across the Coastal Plain are several rivers--the Nueces, Aransas, and San Antonio Rivers--and numerous moderate sized to small streams. These streams are important as drains for rainwater run-off, limited surface water supply, ground water recharge, fish and wildlife habitats, and recreation. All the streams are fresh for most of their length; during dry periods when flow is sluggish, the streams that enter the bays and estuaries become brackish near their mouths. Commonly streams enter marshes, contributing sediment and nutrients to their maintenance. For further discussion of streams and their related sediments, refer to the section on active floodplains (B).

In addition to natural water bodies and man-made surface water storage areas, miscellaneous water units such as coastal canals and large holding ponds are included in this unit for cartographic simplicity. These should be readily recognizable because of their straight boundaries. They are important primarily for economic reasons, although coastal canals which deepen tidal inlets may increase water exchange between the open Gulf and the bays, tending to reduce the occurrence of extreme conditions in the bays.

Natural and man-made water bodies are fragile ecosystems that are extremely important to man and to wildlife in terms of water supply, food production, and recreation. Most of the water bodies are interconnected to the ground water system and to the bays, lagoons, and estuaries. All water bodies, except industrial waste holding and cooling ponds, support a variety of life and are important in natural food production. Many of the lakes, ponds, and sloughs are suitable for swimming, boating, fishing, and hunting. Draining and filling, polluting or contaminating with chemicals or wastes, using water from them excessively for irrigation or industry, and over-recreation, such as intensive hunting and fishing, will decrease or destroy their natural beauty and utility. Adverse conditions in the water bodies can affect adjacent areas, such as marshes, that are themselves important wildlife habitats and nursery grounds.

A13. Ephemeral lakes, ponds, and sloughs

Large depressed areas (up to 2 miles across, but covering only about 4 square miles) that are frequently or seasonally flooded are mapped as ephemeral lakes, ponds, or sloughs. Permeability and internal drainage are naturally low. Most of these areas were once permanent water bodies that have filled with mud and silt through natural processes and are now too shallow or too far above the water table to retain water through dry spells. Because the areas are either inundated or dry for fairly lengthy periods of time, they are commonly devoid of vegetation; water-tolerant plants are destroyed by subaerial exposure and water intolerant plants are drowned. The lack of vegetation and consequent exposure of bare soil for some period of time makes these areas susceptible to wind erosion.

The nature of these ephemeral water bodies is such that they have little natural capability for use. Water stored temporarily can be drawn upon for irrigation before permanent and man-made water storage areas and ground water sources are tapped, forestalling use of these other sources until more severe conditions occur. Draining and filling to develop some of the bottomland for agriculture also is possible, as is deepening to provide for permanent water storage.

Disposal of wastes, placement of brine or sludge holding ponds, and development of septic tank fields and feed lots in ephemeral water bodies present problems because of the susceptibility to flooding. Leachate, effluent, or other contaminants could easily mix with ponded waters and be transported to adjacent areas, polluting surface streams or percolating to the water table.

Long-term submersion and subsequent drying, and generally weak foundation conditions of the mud and silt bottoms of these areas also present problems for construction. Structures may have to be elevated to prevent flood damage and foundation footings will have to be designed to withstand long periods of soaking above and below ground. High shrink-swell potential, high compressibility and plasticity, low foundation strength and slope stability, and very high corrosion potential are other difficulties that probably require expensive solutions. Excavation of material from this unit may be difficult because of extremely dry or extremely saturated conditions, and fill will probably require stabilization if it must support heavy loads or be graded to steep slopes.

Active Floodplains (B)

Floodplains of the Nueces, Aransas, San Antonio and Guadalupe Rivers, and of the numerous creeks that cross the Coastal Plain in the Corpus Christi area define active, dynamic environments whose natural capability for use is determined by susceptibility to frequent flooding and erosion as well as by physical and biological characteristics of the environments. Floodplains along the major rivers have been built over the last 4,500 to 18,000 years in deep, scallop-shaped valleys incised into Coastal Plain sediments during the last glacial event when sea level was approximately 400 feet lower than it is today. These deep valleys have been partially filled. Along the Nueces River there is as much as 80 feet of relief between the Coastal Plain and the modern floodplain. The drowned lower portions of the ancient valleys are now parts of Nueces, Corpus Christi, Copano, Mission, and San Antonio Bays.

Normal stream processes that have built these floodplains are still occurring. Most of the time, very little sediment is carried or eroded by streams. During and after storms and in times of rising water, however, streams move considerable amounts of sediment that has been contributed by tributaries and eroded from channel banks. If channel bank erosion is severe, streams may migrate to a new position.

When runoff is very high, flood water can overtop stream banks. Water leaving the channel loses velocity quickly as it spreads over the broad area adjacent to the channel, depositing much of the sediment load that was carried by fast moving water confined in the channel.

Floodplain sediment is comprised of mud, silt, sand, and, locally, gravel. Several kinds of deposits record past flooding and channel migration: sandy point bar deposits commonly form the inside banks along stream bends; raised levees composed of sand, silt, and mud line stream margins, and muddy overbank and flood basin deposits lie in topographic lows and abandoned segments of the channel course between the levees and the valley walls. Each of these deposits is distinct and will be described in detail.

Smaller creeks are recent features that have cut into the Coastal Plain sediments and are actively extending their channels through headward erosion. Large volumes of eroded Coastal Plain sediment are moved along these creeks to rivers, bays, estuaries, and marshes during periods of excessive rainfall. These creeks are a significant source of sediment entering coastal waters each year.

Floodplain environments are generally more wooded than adjacent Coastal Plain environments and are the habitat for numerous species of animals and plants, many of which are not found elsewhere. Desirability of maintaining these wildlife habitats is an important aspect of the capability of the floodplains.

Four distinct capability units have been recognized in active floodplains.

B 1. Highly permeable sand and gravel

Along all major streams and many of the minor streams in the Corpus Christi area, highly permeable, loose sand and gravel accumulate as point bars on the inside banks of stream bends. During floods, streams commonly migrate, eroding older deposits on the outside banks of meander bends and transporting the sediment to new point bars downstream. The net effect of erosion, transportation, and redeposition in the dynamic floodplain environment is accumulation of a belt of highly permeable sand and gravel intermixed with adjacent flood basin muds, and slow and intermittent movement of this sediment to the sea. There are approximately 107 square miles of floodplain highly permeable sand and gravel in the Corpus Christi area.

Point bar sand and gravel is coarsest near the base, becoming finer upward and grading laterally into mud. Upper surfaces of active point bars slope toward the stream and commonly exhibit an accretionary ridge-and-swale topography. Generally, active point bars are barren or are sparsely vegetated. Older point bars are lens shaped and commonly support grasses, mesquites, and water-tolerant hardwoods such as willow or oak.

Flowing streams, particularly those which flow throughout much of the year, are intimately connected to the ground water system. Ground water movement is toward streams much of the time, and ground water discharge helps to maintain stream flow. Streams may also serve to recharge ground water during drought periods when the water table drops below stream level and during times of flooding when stream levels are very high. Thus, the loose, highly permeable sand and gravel can be a significant source of shallow ground water.

Because of high permeability of the sand and gravel and interconnection between the stream and ground water system, and because of susceptibility to flooding and erosion, contaminants placed in or on the loose sand and gravel may be picked up by the streams or may percolate to the water table. Ultimately these pollutants may be carried into bays and estuaries downstream.

Foundation characteristics of the loose sand and gravel are generally good. Corrosion potential of unprotected pipes and cables is very high. Shrink-swell potential is low, foundation strength is high (where the substrate will not be removed by erosion), and excavation is generally easy.

Despite the generally favorable engineering conditions, development of urban complexes and residential areas within the stream floodplain probably should be discouraged. These activities are not in themselves necessarily damaging to the environment, but attendant release of waste products may be, and man-made structures may interfere with flood water movement, perhaps raising or diverting flood water to where it otherwise would not have gone. Furthermore, damage to structures, by inundation or by undercutting foundations, placed in known floodplains is an unnecessary social expense.

The loose sand and gravel adjacent to modern streams is commonly considered a potential source of relatively cheap aggregate. Good aggregate material is in great demand but short supply in the rapidly developing Coastal Zone. Much sand and gravel probably can be removed from floodplains without undesirable side effects, but natural streams exist in a state of dynamic equilibrium, and poorly planned or excessive excavation of sand and gravel from floodplains may possibly induce accelerated erosion or deposition elsewhere along the stream course. Excavations with steep sides may also lead to slumping and additional erosion.

Natural river processes involved in eroding and depositing these coarse point bar sediments can be altered by man and commonly are. These modifications may have attendant side effects such as reduced aesthetic value and possibly lower stream and ground water levels. Natural vegetation and proximity to water enable the land to host a diverse fauna. Use of the land area for most purposes means that this habitat will be modified or destroyed. Devegetation will also accelerate erosion.

B2. Low to moderate permeability mud and silt

Low to moderate permeability mud and silt occur on floodplains laterally from point bar sand and gravel and occupy about 16 square miles in the Corpus Christi area. These fine sediments accumulate during flood stages when flood water overtops stream banks and spreads out over the low-lying floodplain; for this reason, the sediments are commonly called overbank or flood basin deposits. Fine detritus that is easily carried by rapidly moving water confined in stream channels is deposited as water loses velocity on the floodplain. Thickest accumulations occur where water flow is impeded and in local low areas where water ponds during the waning stages of floods. Vegetative cover includes mesquites, stands of water-tolerant hardwoods, and open grassy areas.

Flood waters that overtop natural channel banks are potentially damaging to structures and crops on the floodplain. The fine mud and silt can accumulate to significant thicknesses during floods, partly or completely burying most vegetation or buildings. Poorly placed structures may in turn induce erosion or higher flood levels by altering flood water flow, creating additional problems. Water ponded in flood basins may be slow in draining from these low lying areas. Of course, crops can be grown that resist destruction by floods and tolerate high soil moisture and short-term inundation, or that require short seasons, allowing their planting and harvesting between late winter or spring floods and before hurricane-produced floods. Animals grazing on the land can be easily moved to safety if sufficient warning of impending flooding is received.

Susceptibility to flooding also limits use of this land for solid or liquid waste disposal, brine or sludge holding ponds, or septic tank systems. Contaminants may be transported into natural water bodies. In the case of septic tanks, low permeability and poor drainage may inhibit the ability of a filtration field to function properly. During floods, household waste disposal systems will probably cease to function entirely. Low foundation strength, high shrink-swell potential, low slope stability, possible difficulty in excavating saturated or extremely dry material, and very high corrosion potential can produce construction problems on this land.

B3. Elevated natural levees

Natural elevated areas adjacent to stream courses are called levees. These levees consist of mixed sand, silt, and mud deposited by floods that overtop channel banks and spread out over the floodplain. Overbanking flood waters lose velocity quickly. The loss in velocity allows much of the sediment carried by fast moving flood water to accumulate in a wedge-shaped deposit sloping away from streams into flanking flood basins where the finest material settles out (B-2). With successive floods, additional accumulations are piled on previous ones, effectively deepening the stream channel, building channel banks above other parts of the floodplain, and increasing channel capacity before flooding. The highest levees are commonly on the outside banks of stream meanders and a little upstream from point bars. There are about 13 square miles of natural levees in the Corpus Christi area.

The importance of levees is to contain storm runoff within stream channels and to reduce the incidence of flooding. Critical to that role is vegetative cover. Levees are commonly grass covered or support growths of mesquites and water-tolerant hardwoods. The tenacious root network helps to prevent erosion and increases bank stability. This vegetation also serves as a wildlife habitat.

Natural levees are so close to surface streams (A-12) and ground water-charged point bars (B-1) that disposal of wastes, construction of holding ponds for brines, sludges, or heated fluids, and extensive use of septic tanks on levees will probably create pollution problems. Contaminants may percolate downward to ground water in underlying permeable sand and gravel or be picked up by flood waters overtopping the levees.

Engineering properties of levees are variable except for corrosion potential, which is high. Deep excavations, whether for construction or extraction of raw material, may weaken or destroy natural levees impairing their effectiveness in providing flood protection. Furthermore, residential and industrial developments on levees are likely to be damaged or destroyed by flooding or failure of the levee.

B4. Small active streams or stream alluvium

Numerous small streams covering about 42 square miles in the Corpus Christi area (natural streams only) have cut into older Coastal Plain sediments. Examples are Oso, Melon, Copano, Petronila, and Chiltipin Creeks. Most of the time these streams are dry or barely flowing. During and shortly after storms, however, the creeks can become bank-full torrents, particularly where they cut through low permeability mud (A-8) and where rainfall runoff is very high. While in flood, the streams remove material that has slumped off the soft steep banks or has been brought in by slopewash and the streams actively extend their courses in a headward direction. Alluvium in these streams is mixed mud, silt, and sand. Vegetative cover is mostly mesquites, hardwoods, and grasses.

Many small streams in Nueces, San Patricio, and parts of Refugio Counties have all or portions of their courses straightened or channelized. New channels have been dug to alleviate flooding of flat farmlands on low permeability mud (A-8), and these too commonly empty into the small creeks. The artificial drainage systems do reduce flooding, or at least more quickly drain valuable farmland, but at the cost of increasing peak discharge, increasing rates of erosion where channel banks are soft, unlined, or unvegetated, and may, in certain areas, lead to lowering of the water table by reducing time available for recharge. Erosion of channel walls is particularly a problem where ditches are dug across moderately permeable sand and silt (A-3) and where release of oil field brine has prevented vegetation from taking hold and stabilizing channel banks (McGowen and others, 1970).

These small streams are natural sites for construction of stock tanks, which in addition to providing drinking water will tend to reduce erosion. Use of such active streams or the alluvium for disposal of wastes and retention of brines, sludges, and heated fluids, however, will most likely lead to water pollution when flooding occurs when erosion exposes or releases contaminants. Placement of septic tank systems in alluvium may lead to the same problem. Trash dumped at stream heads in an effort to prevent erosion commonly is washed downstream. Structures placed on the alluvium or immediately adjacent to the streambanks may lose foundation support from bank undercutting and erosion. Filling the gullies to expand sites for development will only slow drainage and increase flooding of adjacent land.

Barrier Islands (C)

Barrier islands lie offshore and parallel to much of the Texas coast. Approximately 6 miles seaward of the mainland shore in the Corpus Christi area, there are three barrier islands--St. Joseph Island, Mustang Island, and northern Padre Island. St. Joseph Island is the northernmost island, lying between Cedar Bayou and Aransas Pass. The island is from 1 to 5 miles wide and is about 23 miles long. Mustang Island lies between Aransas Pass and Corpus Christi Pass (closed) to the south. This island is about 18 miles long and averages 2 miles in width. Padre Island is the longest and southernmost of the Texas barrier islands. Only the northern tip is included in the Corpus Christi area, where it is approximately 2 miles wide.

The barrier islands are Holocene and Modern in age and have been built largely by gulfward accretion since sea level reached its present position about 4,500 years before present (B.P.). Landward and seaward of the islands lie the numerous bays, estuaries, and lagoons, and the open Gulf of Mexico, respectively, that are discussed under a separate heading.

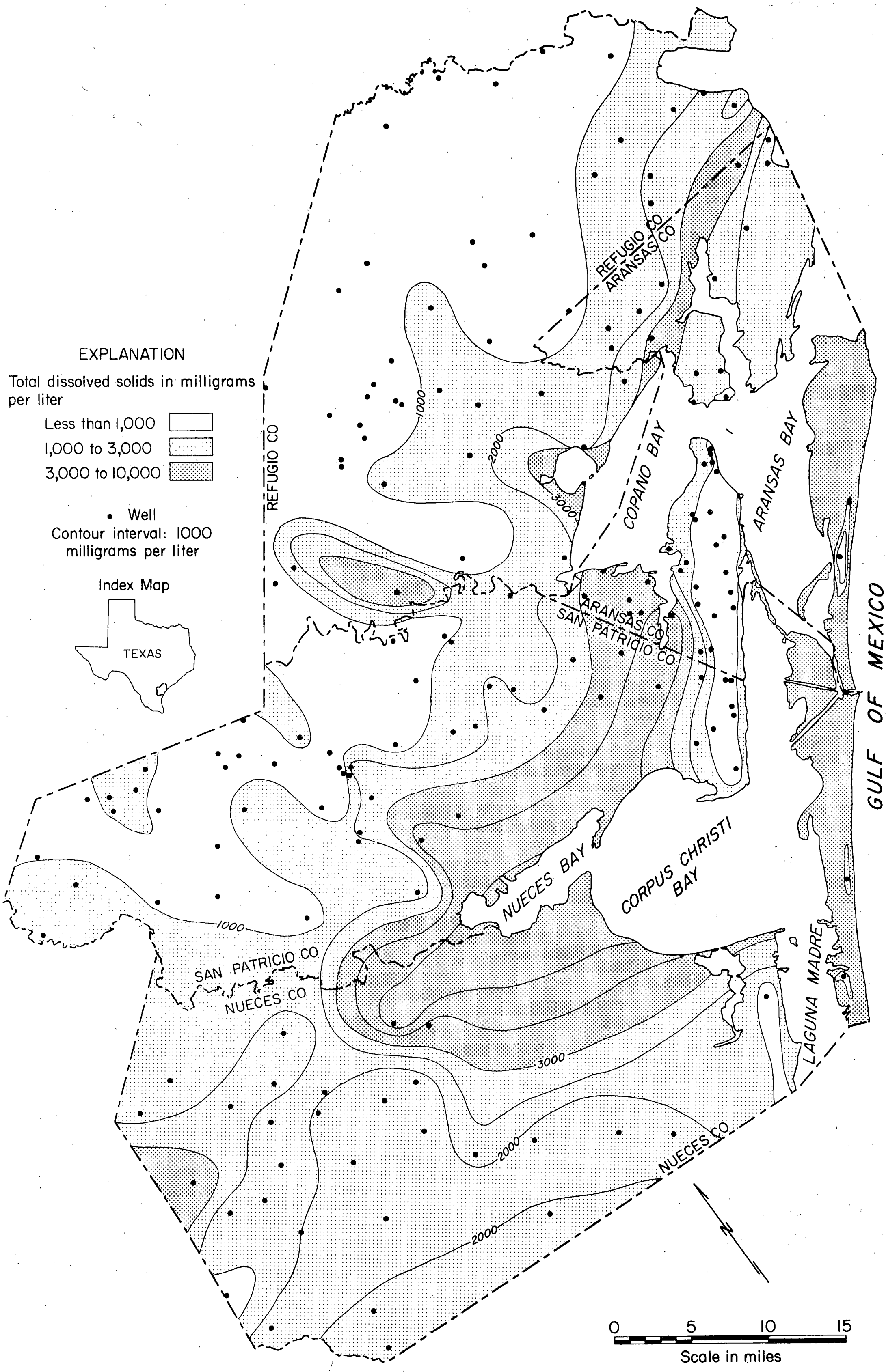
Sand and shell are the dominant constituents of the islands. Beaches, fore-island dunes, vegetated barrier flats, active dunes and sand blowouts, tidal flats, and hurricane surge channels are the capability components of the barrier island system. Salt- and fresh-water marshes also occur on barrier islands, but are discussed under Wetlands Units. All environments exist in a state of delicately balanced dynamic equilibrium. Alteration of one environment can strongly influence or lead to changes in another environment.

Barrier islands have three important functions: (1) as a first-line defense against the effects of storm-driven tides and hurricane surge, (2) as a source of fresh to moderately fresh ground water, and (3) as a site of extensive and varied recreation and second home development. Of these functions, protection of the more populous mainland coast from the full fury of hurricanes is by far the most important. Hurricanes strike the Texas coast on an average of once every 1.3 years (Hayes, 1967). Since 1900 at least four hurricanes, including Hurricane Carla in 1961 and Hurricane Celia in 1970, have passed through or near the Corpus Christi area. Barrier islands, beaches, and dunes absorb much of the terrific punishment from these severe storms, blocking high waves and slowing spillover into the bays and estuaries. This in turn tends to reduce flooding and damage on the mainland.

Vegetative cover on dunes and barrier flats is critical to this role. Without stabilization provided by vegetation, loose sand composing barrier islands would be washed into the bays, and the islands would be leveled. This vegetation is extremely delicate and once destroyed, particularly in the arid south Texas, has difficulty becoming reestablished.

Barrier islands are also local sources of fresh to brackish water. At least four wells are operating on Mustang and St. Joseph Islands producing water with less than 3000 mg/l total dissolved solids (TDS) (Figure 4). The density difference between seawater and fresh water and the pressure head maintained by precipitation falling on the islands confine fresh water to a lens beneath the barrier islands. Downward and outward movement of the fresh water prevents salt water intrusion. High permeability of barrier island sand assures that virtually all precipitated water, the only natural source of fresh water

Figure 4
General Ground Water Quality in the Corpus Christi Area
(After Fisher and Others, 1973b)



on barrier islands, is contributed to the ground water system.

Brackish water conditions on the barrier island aquifer develop where rainfall is insufficient to dilute or flush salts that accumulate from storm surge and the ever present salt spray and from gradual mixing along the fresh-salt-water interface. Ground water under the barrier islands in the Corpus Christi area contains up to 10,000 mg/l TDS (Figure 4), most of which is sodium chloride. Boundaries between TDS concentration levels shown in Figure 4 are highly subjective and can be, in any case, expected to vary considerably with climatic conditions.

A perched aquifer such as a barrier island aquifer can be easily polluted by contaminants from waste disposal sites, holding ponds, sludge pits, or septic tanks. Effluent or leachate would quickly percolate to the water table. Once polluted, rainfall is the only source of clean water available to flush the aquifer. Along the more arid south Texas Coast, rainfall may be inadequate to do the job.

In recent years, Mustang and northern Padre Islands have been receiving a large influx of vacationers and permanent residents. The Corpus Christi region is the closest seaside resort area to Austin, San Antonio, and much of South Texas. Large tracts of privately owned property are being subdivided and developed into first and second home recreational communities. Construction on state-owned spoil islands has increased and new motels, condominiums, and marinas are springing up near Port Aransas, along Corpus Christi and Packery Channels, and in the center of Mustang Island. Overall foundation strength of barrier island sand is relatively high, shrink-swell potential negligible, and excavation easy, thus presenting few problems for construction, although corrosion potential is very high and slope stability is low.

All of this development exacts a toll from natural barrier island environments. Barrier island environments are capable of supporting considerable activity if use is tempered with understanding of the natural system and natural carrying capacity. This understanding is critical because of the far-reaching consequences of misuse of the island resources.

At the same time, it must be understood that residential or commercial developments on barrier islands risk damage by flooding and by high winds. Should the dunes be breached, storm tides will inundate low-lying areas. Raised bay levels, from water pumped through tidal passes (F-5), across washover areas (C-4), and from high rainfall runoff from the mainland can add to flooding. Fast moving flood waters can quickly erode the loose sand removing foundation support. Only if foundation pilings are sunk deeply into the sand can damage from sand erosion be limited. Pilings also provide a more secure anchor to counter the forces of high winds and structures can be elevated above flood levels.

C 1. Beach

Fine-grained, highly permeable, loose sand and shell lying on the Gulf side of the barrier island between sea level at low tide and the dune vegetation line compose the barrier island beach. There are approximately 3 square miles of beach in the Corpus Christi area. Geologically, beaches consist of two parts: (1) a lower part or fore-beach that is subject to daily wave swash and tidal flooding, and (2) an upper part or backbeach that is inundated only by spring and severe storm-driven tides. A berm built by moderate storm waves usually separates the two components of the beach. Between inundations, the backbeach is affected by wind action; onshore breezes blow sand from the beach to the dunes behind.

Beaches are zones of high physical energy and dynamic equilibrium. Beach texture, constituent size, steepness, and whether a beach is eroding, stable, or accreting are functions of sediment supply and wave and current power. Natural variations in width and steepness and erosion versus accretion occur in response to seasonal or short-term weather-induced changes in wave and current energy. Storms are a major source of disequilibrium, altering the normal beach profile to an extent reflecting the severity of the storm. Very severe storms such as hurricanes completely regrade the beach to a broad low ramp covered with debris scoured from offshore. Hurricane Celia removed as much as 1.6 feet of sand from beaches in some areas along Mustang Island (McGowen and others, 1970). All or part of the fore-island dunes (C-2) may be eroded, considerably widening the beach (Hayes, 1967). Following storms, more normal conditions tend to restore the regular beach profile, usually in a matter of weeks on the Gulf side of the barrier (Hayes, 1967; McGowen and others, 1970).

Longer term changes reflect a balance between sediment supply and erosion. Longshore currents generated by waves striking the beach at an angle move considerable amounts of sand along beaches, particularly during storms. Sand moved down current has been eroded up current from island and mainland shores. Sand and shell eroded by longshore drift is naturally replaced only by sediment derived from offshore or brought from the interior by rivers. If sediment input is greater than erosion, beaches become accretionary. If sediment removal from beaches is greater, they are erosional. In between various degrees of stability exist.

The Coastal Bend is unique along the Texas Coast in that longshore drift convergence lies between central Padre Island and southern St. Joseph Island. Sand eroded from north and south is swept along the coast to the Corpus Christi area where the average angle of wave incidence is so low that little net sediment transport occurs. This continued influx of sand has countered the effects of erosion, and most of the beaches along northern Padre, Mustang, and southern St. Joseph Islands are stable or are eroding very slowly (McGowen, 1974; Morton, 1974, personal communications). Elsewhere along the Texas coast most beaches are eroding at various rates.

Man can effect changes in beaches by modifying the sediment budget or incoming wave and current energy. Man-made modifications such as jetties or seawalls can induce considerable accretion in one place and severe erosion in another by changing the pattern of longshore drift. Considerable amounts of sand have accumulated on both sides of the jetties at Aransas Pass. Since the jetties were first constructed in the late 1880's, approximately 8,280,000 cubic yards of sand has piled up to the north and the south of the pass (based on U.S. Army Coastal Research Center figure of 1 ft^2 change in beach surface area equals 1 yd^3 of beach material).

Modification of the beach can affect other environments on barrier islands as well, perhaps at places far distant from the original change. For example, loss of beach sand can lead to a decrease of sediment supply to fore-island dunes. Limiting sand supply to the dunes reduces their effectiveness in protecting against flooding by hurricane surge or storm tides. This in turn can lead to an increased incidence of storm washover and further erosion of the barrier islands.

Barrier island beaches are also intimately associated with the subaqueous upper shoreface sands (F9). The boundary between the two is arbitrary and in reality a zone of transition that can shift from time to time depending on conditions. Disturbance in the dynamic equilibrium of shoreface sands will directly affect beaches and vice versa. Thus, any modifications to the beach should be in consideration of the best possible assessment of long- and short-term effects of such changes and what maintenance is likely to be needed.

Beaches are primarily used for recreation: swimming, surfing, fishing, picnicking, and the like. The long-term aesthetic appeal and recreational value of beaches is dependent, however, on insuring that beaches remain clean, pollution free, and relatively free of vehicular traffic. Designated transportation corridors to and along beaches, suitable parking and sanitary facilities, and regular policing and removal of trash will help maintain quality beaches. Poorly planned construction can lead not only to shoreline retreat, but possibly elimination of recreation from the beach. Excavation of sand will affect the sediment budget and can lead to beach destruction and possibly storm washover. Construction of piers, groins, jetties, seawalls, or other structures on the beach without regard to natural beach characteristics can result in their failure, such as the loss of the original Mansfield jetties to the south of the Corpus Christi area, or other undesirable affects. Canals dug through beaches and spoil piled on beaches destroy their utility as recreational areas and alter their dynamic equilibrium.

In addition, because of longshore drift, beaches tend to reheal across channels, necessitating abandonment or expensive maintenance. Spoil is commonly reworked and deposited elsewhere. Structures placed on the beach will have to be strong enough to withstand heavy pounding by storm waves. Because of salt spray and constant inundation with salt water, corrosion potential is very high. Disposal of liquid and solid wastes on beaches presents an almost certitude of polluting proximate portions of the Gulf or ground water in the barrier. The loose permeable sand will not hold or retard movement of fluids.

C 2. Fore-island dunes and vegetation-stabilized barrier flats

A major portion of a barrier island consists of fore-island dunes and barrier flats (about 31 square miles). Fore-island dunes are 5 to 20 feet high and occupy a position immediately landward of the beach. Vegetation that is tolerant of salt spray serves to trap sand blown off the beach, building up the dunes and prevent their bayward migration. Behind the dunes is the barrier flat--a hummocky, ramplike accumulation of sand, 0 to 5 feet above mean sea level and sloping towards the lagoons. This sand represents upbuilding of tidal flats and marshes by sand blown from dunes and beaches or deposited by storm washovers and stabilized by vegetation. Periodically, portions of the fore-island dunes become devegetated and are driven bayward (C-3) by the predominant onshore wind until restabilized. Random occurrence of the restabilized dunes produces the hummocky surface.

Occasionally vegetation is also stripped from part of the barrier flat, dunes re-form, and again move toward the bays until they build into the bays or are revegetated.

Fore-island dunes are the highest part of the barrier islands. Their presence is the best protection against damaging storm surge. Without the vegetation cover, dunes are easily eroded by wind and water; the vegetative cover is this critical in maintenance of the dunes and prevention of storm surge washover. The delicate nature of vegetation on the dunes means that it is easily destroyed. Too many people will trample and kill dune vegetation as will vehicular traffic and camping. Vehicle access to the beach across the dunes at designated and carefully chosen routes that are not cut through the dunes but are built over them will help preserve the stabilized dunes. Although dunes are the most elevated building sites, construction on the dunes will most certainly lead to devegetation. They are too important in their natural state as a storm barrier to disturb. Once fore-island dunes become mobile, their movement is difficult to stop. Portions of the barrier flat become covered with actively moving dunes (C-3) leaving behind blowout depressions that are susceptible to early flooding and further erosion (see later). Barrier flats are more tolerant of construction activities than dunes, but certain types of construction projects such as excavation of sand or excessive roadways tend to destroy the vegetation and may lead to blowouts, storm washovers, or breaches in the barrier island.

C 3. Active dunes and sand blowouts

Sparsely to nonvegetated active dunes and sand blowouts covering about 4.5 square miles occur in several places along the barrier islands. Active dunes and blowouts originate where vegetation has been stripped from fore-island dunes and barrier flats. Drought and destruction during storms are some of the natural causes of devegetation; overgrazing, fires, trampling and excavating are some causes of devegetation related to human activity.

Active dune fields can be a few miles wide and many miles long. The largest dune fields in the Corpus Christi area are in the southern parts of St. Joseph and Mustang Islands. Dune sand migrates to the northwest, carried by the prevailing southeasterly winds; movement continues until the sand is transported across the barrier islands or until it is restabilized by vegetation, upbuilding the barrier flats. Sand blown across the barrier islands may cover valuable back-island wetlands. Natural revegetation of active dunes and blowouts is slow because of the generally dry climate in the Corpus Christi area. Reestablishment of dunes can be encouraged by placing snow fences or other barriers across the blown out area, perpendicular to the prevailing wind to catch and hold sand blown off the beach. Recently experiments in artificially revegetating dunes have been attempted on Padre Island with moderate success by Otteni and others (1972). Hopefully these experiments will prove more fruitful in the future and artificial revegetation can be accomplished at a reasonable cost.

Unvegetated dunes and blowouts are more susceptible to flooding and erosion by storm surge than adjacent vegetated dunes and barrier flats. Lowered or flattened portion of the fore-island dunes provides easy access for storm washover and may lead to breaching of the barrier during especially severe storms. Sand carried across the island by surge can be deposited in adjacent marshes and grassflats.

Active dunes are also exceedingly unstable areas for construction. Movement of sand may remove foundation support or bury structures. Construction activities may perpetuate or enlarge the area of moving sand by destroying incipient vegetation. Overuse as a recreational area, particularly by dune buggies and motorcycles, also can lead to enlargement of the unvegetated areas or to destruction of new vegetation that will stabilize the sand. Extensive vehicular traffic to these dunes might be harmful to adjacent areas. Of course, active dunes and sandy blowout areas are extremely permeable. Waste or other fluid contaminants placed or generated in these areas will quickly percolate downward to the perched ground water lens or flow into adjacent water bodies.

C 4. Storm washover areas

Segments of the barrier islands that are commonly breached or overridden by storm tides and surges are called storm washover areas. Some washovers occur at sites of abandoned tidal channels and are relatively narrow. Other washovers tend to be somewhat wider--up to 5 or 6 miles wide--and occur where fore-island dunes are absent, poorly developed, or were weakened by blowouts. Major washover areas occur at both ends of St. Joseph Island and near Packery Channel at the southern end of Mustang Island. Smaller areas occur in the middle parts of the islands. There are about 23 square miles of storm washover area on the barrier islands.

During storms, these washover areas are sites of intense erosion, transportation, and deposition of sand. Most sand movement is from the front side of the barrier toward the bays. Larger washovers can be easily recognized by their fanlike bayward bulge. During the latter stages of storms and after they have passed, water stacked up behind the barriers may return to the Gulf through the washovers, transporting some sand seaward.

Between major inundations, commencing immediately after a storm, sand carried by longshore drift begins to heal channels and straighten the shoreline. Sand spits can build across and close Gulfside channel openings in a matter of days or a few weeks (Hayes, 1967; McGowen and others, 1970). This new supply of sand may be transported into the bays during the next storm. Modification of channel mouths on the backsides of barrier islands is a longer term process.

Unvegetated washover areas are subject to extensive wind modification. Windblown sand tends to fill in channels, to be built into dunes, or to be deposited in parts of the lagoon behind the barriers. Vegetation can sometimes become established on the higher areas between washover channels, helping to stabilize the loose sand.

Washovers commonly function as ducts for storm tides and surge for many years. Eventually, the area is built up and restabilized by vegetation, or a new washover develops at a weaker site allowing the old washover to be incorporated into the barrier flat.

Washover areas are suitable for few human activities except short-term recreation. Washovers will be the first areas of the barrier islands to be flooded during major coastal storms and are the loci of high current velocities. Extensive erosion and deposition of sand can undermine or bury most structures placed on the sand. Construction of roads across washovers is not damaging to the environment, but the roads should be high enough and sufficiently well anchored to prevent their being buried or undermined. Roads may slow water movement during storms and actually help to heal washover areas. Excavation of sand from these areas will only tend to increase incidence of flooding and to further disrupt the sand budget.

Disposal of solid and untreated liquid wastes, storing of brines, sludges, or heated fluids, or use septic systems will be damaging to this and several adjacent environments. Effluents can easily percolate through the permeable sand to the aquifer below, or be transported along with solid material into adjacent bays and lagoons. Discussion of the sensitivities of these adjacent environments is presented in the following sections (D and F).

C5. Tidal flats

Sand and muddy sand flats that are subject to daily or occasional flooding by astronomical and wind-driven tides are present on the back sides of barrier islands. The flats slope gently bayward and are generally barren except for fiddler crabs, sparse blue-green algae, and scattered clumps of salt marsh grasses. On frequently flooded flats, the blue-green algae flourish shortly after inundation and thin evaporitic salt crusts and mud veneers may form. Locally, tidal flats with similar characteristics are also present along the mainland shore of bays, lagoons, and estuaries. Altogether, there are about 40 square miles of tidal flats in the Corpus Christi area. Tidal flats thus actually occur in several coastal systems, but because greatest development is on the bay side of barrier islands, they are described here.

Likelihood of inundation and generally saturated conditions render tidal flats unsuited for most human activities. Flooding is inevitable unless dikes are constructed to prevent it. If insufficient supply of sand is present, tidal flats may subside and be replaced by marshes. Alternatively, an abundant sand supply builds the sand flat high enough so that barrier flat vegetation can become established.

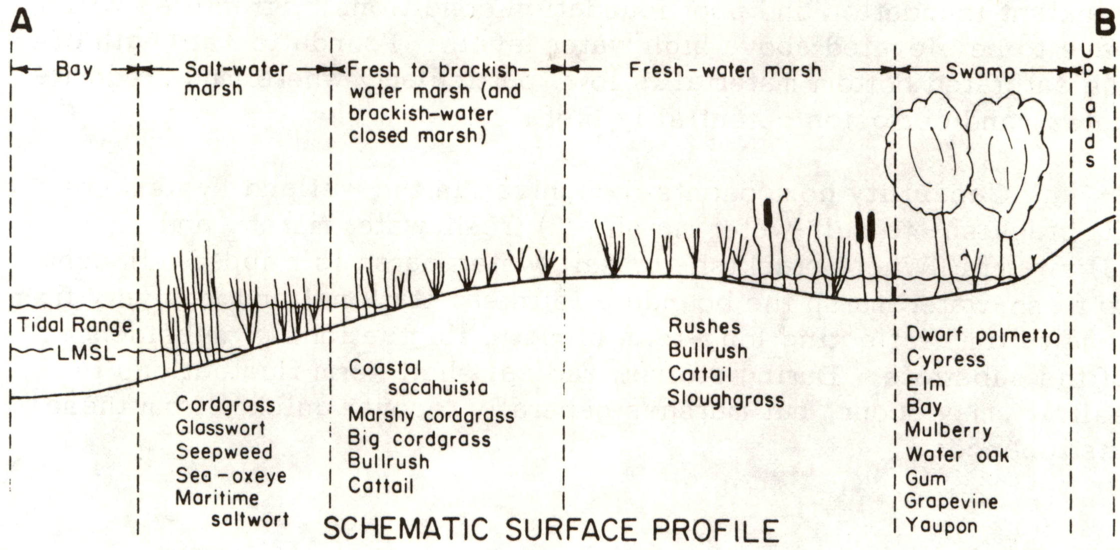
Construction on tidal flats presents problems. Foundation conditions are poor, corrosion potential is very high, and, of course, flooding is common. Spoil placed on tidal flats, bulkheaded to prevent reworking by waves and currents, can be used to make the area more suitable for construction without destroying a biologically productive area. It must be understood, however, that tidal flats are actually flood basins and waters prevented from inundating the sand flats must go somewhere else.

Disposal of other waste products on tidal flats will most certainly pollute contiguous marshes and lagoons. Excavation of material from tidal flats will unbalance the sand budget, perhaps leading to erosion of the vegetated barrier flat.

Wetlands (D)

Brackish- to salt-water marshes, fresh-water marshes, and swamps occupy low places in coastal areas and river valleys (Figure 5). Vegetation inhabiting these areas requires a substrate that is perenially

Figure 5
Schematic Profile of Modern Marsh-Swamp System
Occupies Areas Landward of the Gulf of Mexico Shoreline and Within the Lower Valleys of Major Rivers and Headward-Eroding Streams of the Corpus Christi Area
(Modified After Fisher and Others, 1973a)



wet and that has a permanently high water table or is nearly constantly submerged. Grasses are the dominant vegetation type in marshes; water-tolerant trees characterize swamps.

Fresh- and brackish- to salt-water marshes are extensively developed along the lower mainland coast and at the mouths of river valleys. Marshes also occur on the back sides of barrier islands (C), in abandoned tidal creeks (A-10), in abandoned stream meanders in modern stream valleys (B-2), and on the Pleistocene age barrier-shoreline deposits (A-1). Each of these occurrences is important as a valuable wildlife habitat.

Beyond the evident need to preserve marshes and swamps for biologic reasons, use of them is severely limited by frequent or even constant inundation and poor foundation conditions. Structures will have to be elevated above high water levels. Foundation strength of the saturated bottom material is low, particularly where mud predominates, and corrosion potential is high.

Capability components recognized in the wetland system are (1) brackish- to salt-water marsh, (2) fresh-water marsh, and (3) swamp. Where brackish- or salt-water marsh is mapped adjacent to fresh-water marsh the boundary is interpretational and may vary from time to time reflecting long-term climatic fluctuations or subsidence of the substrate. During storms, radical short-term fluctuations in salinity may occur, but marshes generally recover quickly from these distrubances.

D1. Brackish- to salt-water marsh

Brackish- to salt-water marshes are areas of intertidal grasses and succulents occurring on the back sides of barrier islands bayward of the tidal flats, along the mainland coast, in tidal creeks, and on the distal parts of estuarine deltas. Salinities range from approximately the same as normal sea water, or even somewhat hypersaline, to nearly zero during times of strong fresh-water influx. Daily temperatures vary up to 10°C (18°F). Bottom substrates are either sand or mud, but in general, topographically higher marshes have coarser bottoms than topographically lower marshes. Brackish- to salt-water marshes cover about 41 square miles in the Corpus Christi area.

Brackish- to salt-water marshes can be further zoned by frequency and intensity of exposure to water of varying salinity. Low salt-water marsh is characterized by stands of smooth cordgrass that grow in water a few inches deep at the margins of salt-water bodies (Figure 5). High salt-water marsh is inundated almost daily by astronomical tides and is characterized by stands of salt-tolerant succulents showing an orderly succession from the water margin toward higher and more saline substrates.

Brackish-water marsh is intermediate between salt-water and fresh-water marsh in terms of water and substrate salinities and vegetation types. During prolonged dry periods, salt-water marsh vegetation commonly dominates the floral assemblage; during wetter times, fresh-water marsh vegetation may predominate. Relatively dry conditions are normal for the Corpus Christi area and for this reason brackish-water marshes have been lumped with salt-water marshes.

Preservation of the salt marsh environment is critical to marine and estuarine ecology. Many game and commercially valuable fish and shrimp breed and nurture there. Activities such as (1) dredging, draining, and filling for development; (2) disposal of solid or untreated liquid wastes; (3) constriction of water circulation and wildlife access by blocking tidal channels or sectionizing contingent bays and estuaries; (4) construction of water-holding areas that permanently flood marshes; (5) excessive recreational use, particularly with air boats, marsh buggies, and other vehicles; and (6) indiscriminate use of biocides in and adjacent to the marshes could be extremely harmful. Activities such as grazing, mariculture, fishing, hunting, and nature study are more harmonious with the natural marsh environment.

Although it has not been established how much marsh is necessary to maintain fish and shrimp populations, nor which marshes are the most productive, the risk of depleting the numbers of these organisms is too great to allow significant damage to or destruction of their nurturing grounds. Only after careful study can it be ascertained how many, if any, marshes can be altered from their natural state. Too much destruction of the marshes will strike a telling blow to the fishing industry and to sport fishing.

D 2. Fresh-water marsh

Inland from coastal brackish- and salt-water marshes, permanent and ephemeral fresh-water marshes occur in topographic lows in which succulents, reed and cord grasses, cattails, and rushes are the dominant vegetation types (Figure 5). These marshes are found in areas where the water table is permanently high or is high for long periods following heavy rainfalls. Fresh-water marshes are common in such areas as (1) the lower portions of modern river valleys, particularly in abandoned stream courses and inland from salt marshes surrounding deltas, (2) inland from salt marshes along the bay margins, (3) the margins of coastal lakes or in other low places on the Coastal Plain, and (4) in swales on the interior portions of modern and ancient barrier-shoreline systems. Fresh-water marsh substrates are generally muddy. There are about 31 square miles of fresh-water marsh in the Corpus Christi area.

Fresh-water marshes provide breeding, nesting, and feeding grounds for numerous birds, reptiles, mammals, and crustaceans. Ducks, geese, trout, frogs, clams, and other animals make their homes in fresh-water marshes for all or part of the year. Many of the birds and animals are prized by sports fishermen and hunters. Vast amounts of edible plant material are produced by fresh-water marshes too. Some of this material is consumed in the marshes, but much is flushed from the marshes into the bays and estuaries providing nourishment for many marine animals. Bacterial action converts marsh plant cellulose into proteinaceous material that can be assimilated by higher animals. Fresh-water marshes are thus important in the life cycles and the feeding of much of the coastal wildlife. These attributes--a wildlife habitat and a producer of feed for animals in other environments--limit the kinds of activities that can take place in fresh-water marshes. Marsh water is intimately connected to surface- and ground-water systems too, making pollution of fresh water sources possible. For these reasons, activities such as (1) overgrazing, burning, or other excessive devegetation; (2) overuse of recreational vehicles; (3) indiscriminate use of biocides; (4) draining and filling; (5) damming to create permanent water storage areas; (6) construction, particularly of highways without bridges that block flow or sectionize the marsh; and (7) disposal of solid and untreated liquid wastes should be discouraged. Limited hunting, fishing, nature study, and grazing are uses more compatible with the natural character of fresh-water marshes. It must be further realized that activities which are harmful to fresh-water marshes affect other environments, and that similar activities in adjacent areas are deleterious to the marshes.

D3. Swamps

Swamps are areas characterized by a high water table and by frequent fresh water inundation in which water-tolerant hardwood trees are the dominant type of vegetation. Swamps occur in topographically low stream channel cut-offs in modern and ancient river valleys where the water table intersects or lies slightly above the ground surface. They are generally inland from marsh development. Biologic productivity is high; numerous animals make their homes in swamps and some of these animals are not found elsewhere. Swamp bottoms are generally muddy. As is true for marshes, activities harmful to swamps affect the ground water and adjacent water bodies; activities in adjacent areas can be damaging to swamps too.

Only a few small areas of swamp, amounting to 1.1 square miles along the Mission, Nueces, and Guadalupe Rivers occur in the Corpus Christi area.

Man-Made Features (E)

Over the past 100 years, man has made many alterations in coastal environments and has produced some new environments. The characteristics of these new environments are generally variable, but on the whole they are distinctive in that man-made and modified areas have their own special attributes and limitations. Capability units described here are: subaerial spoil and other made land, subaqueous spoil, and the Aransas National Wildlife Refuge. Man-made features such as canals and reservoirs were covered briefly in the description of small coastal lakes (A-12). Culturally defined entities, other than the preserve, are excluded, although generalized urban buildup areas and State parks are shown for reference on the map accompanying this report.

E1. Made land and spoil

At numerous places amounting to about 29 square miles along bay, estuary and lagoon margins and within the coastal water bodies, man has piled up sand, silt, mud, and shell removed from bay and estuary bottoms or excavated from land areas. This new land has been created to fill depressions, to make room for residential and industrial development, and to dispose of excess material dredged from navigation channels. The composition of this spoil and made land is variable, depending mostly on the composition of the material at the site of dredging or excavation and in what engineering modifications are made to the new land.

Made land and subaerial spoil can be used to provide much needed space for residential and industrial development in places where critical coastal environments are not present. All such new land is unconsolidated and is generally more permeable than the parent material. Other engineering characteristics are highly variable;

shrink-swell potential can be high, foundation strength and slope stability are generally low, and corrosion potential is high to very high. Substantial piers probably are necessary to support heavy structures and made land next to waterways will probably have to be bulkheaded to prevent slumping. Furthermore, most spoil or newly made land remains barren or becomes only lightly vegetated for considerable periods of time. The loose material is easily eroded by wind and water. Sheetwash and wind can carry sediment from the new land into adjacent water bodies where waves and currents redistribute it to other coastal environments. The area of land and bay bottom occupied by spoil and made land can be, therefore, markedly increased.

Subaerial portions of the new land can be planted to prevent the erosion. Spoil placed where it can be leached should be examined to insure it does not contain contaminants harmful to marine biota of to nearby aquifers.

Spoil dredged during construction and maintenance of coastal waterways can also be used to build up areas susceptible to flooding rather than using some other source of material. Excavation of sand from barrier islands to build up developing areas makes little sense when spoil is readily available. Existing areas of subaerial spoil can be developed for recreational parks or wildlife habitats.

High permeability and a high water table make the new land a poor place to dispose of solid or untreated liquid wastes, construct holding ponds, or use septic tanks extensively. Contaminants on the unit will soon appear in adjacent water bodies. All waste products generated on made land should be collected and treated to prevent pollution.

E2. Subaqueous spoil

Fringing areas of subaerial made land along and in coastal water bodies, and particularly parallel to navigation channels, spoil from dredging operations has been dumped, but not piled so high as to be above water level. Like subaerial spoil and made land (E-2), the composition of subaqueous spoil is highly variable, consisting of different portions of sand, silt, mud, and shell. In time, the upper surface becomes sorted by wave and current activity, producing a rather even texture and composition. Fine detritus removed during sorting is redistributed to other parts of the bays and estuaries, commonly enlarging the area of bay bottom covered by spoil material.

There are about 23 square miles of subaqueous spoil in the Corpus Christi area.

Disposal of spoil close to dredging operations is cheap, but can destroy critical, natural bay- and estuarine-bottom environments. Subaqueous spoil mounds tend to compartmentalize portions of the coastal water bodies. Compartmentalizing the water bodies can in turn lead to reduced water circulation, changes in salinity and temperature patterns, and lower biologic productivity in the enclosed parts.

During dumping of the spoil, water turbidity will be high, perhaps also harming bay-bottom environments. Ultimately, natural environments do tend to adjust to the presence of spoil, but dredging and dumping related to maintenance or enlargement of channels again causes high turbidity, and possibly reduced productivity of the bay waters. As much as possible, existing subaqueous spoil areas should be allowed to equilibrate with other coastal environments; new spoil can be piled on land areas that need upbuilding or where erosion can be controlled.

It is conceivable that subaqueous spoil, free of contaminants harmful to plant or animal life, can be piled in such a way that growth of marine or marsh grasses is encouraged. This practice may help to compensate for the loss of these environments elsewhere. In addition, siting of offshore platforms and bridge abutments on subaqueous spoil may be economically advantageous. Use of these shoal areas may reduce depths to which pilings must be sunk and also reduce disturbance of other natural environments.

E3. Aransas National Wildlife Refuge

This special resource capability unit is distinguished because its use is regulated by federal law. The preserve was obtained for a wildlife sanctuary and the land, amounting to about 98 square miles, can be used for no other purpose. This, in effect, delineates the capability of the land.

Several natural land and water capability units are present in the wildlife refuge, too. These include: (1) highly permeable recharge sand (A-1), the dominant unit; (2) moderately permeable sand and silt (A-3); (3) mud-veneered moderately permeable sand and silt (A-5); (4) low permeability mud (A-8); (5) local mud-filled tidal channels and beach swales (A-10); (6) lakes and ponds (A-12); (7) brackish- to salt-water marsh (D-1); (8) fresh-water marsh (D-2); and

(9) local beaches and storm berms (F-11). In addition to legal restrictions, management activities in the preserve should consider the attributes and limitations of the natural units.

Bays, Lagoons, Estuaries, and Open Gulf (F)

Bays, lagoons, and estuaries are shallow water masses occupying the drowned portions of ancient river valleys and elongate lows between the modern barrier islands and the mainland, a position that is physically, biologically, and chemically gradational between open marine environments in the Gulf of Mexico and fluvial environments. Seven subaqueous capability units were delineated in the bay, estuary, and lagoon environments: river influenced bay, enclosed and/or restricted bay, open bay, tidally influenced open bay, bay-margin sand and muddy sand, grassflats, and oyster reefs, adjacent reef flank and interreef areas; and one subaerial capability unit, local sand and shell beaches and berms. Two subaqueous capability units, the upper shoreface and the lower shoreface and open Gulf shelf were mapped in the Gulf environments. One capability unit, tidal inlets and tidal deltas, is transitional between the open Gulf and bay environments.

All of these environments are dynamic and their boundaries change slowly or quickly with changes in ambient conditions. Geologically, bays are evolving and transient, displaying slow but natural changes; biologically, these areas and the fringing marshes are highly productive, delicately balanced systems that are essential to the life cycles of many commercially valuable marine organisms; and chemically, the water masses are highly variable and susceptible to external influence of man's activities in the shallow waters and on nearby land. The bay, lagoon, and estuarine system is a complex of numerous interdependent, shifting, and subtle subsystems, all of which are sensitive to induced changes. This complexity is not always appreciated because the precise nature of the coastal water environment is poorly understood.

Despite the absence of comprehensive biologic, geologic, and chemical data, general relationships between certain human activities and observed natural environments are understood. It is known that bays, lagoons, and estuaries are inseparably part of an even larger complex coastal system encompassing bottom substrate, marginal sources of sediment and fresh water, subaqueous vegetation, benthonic (bottom dwelling), nektonic (swimming), and planktonic (floating) organisms, tide-, storm-, and wind-generated currents, dissolved salts, and suspended colloidal sedimentary particles.

It is known that the quality of the estuarine environment is dependent on inflow from rivers. Nutrients and debris from the rivers provide a large amount of food for organisms farther out in the bays, and some biota need fresh to brackish water conditions to survive. Flood waters from rivers help to periodically flush the bays and to prevent buildup of contaminants that sluggish tidal flow cannot remove. Therefore, upstream and seaward activities which alter water flow or sediment movement affect the estuaries. Significant reductions in fresh water influx by damming the rivers or by withdrawing large quantities of water could impair bay quality and biologic productivity. Permanent disequilibrium of the ecological balance between fresh water and nutrient supply and tidal or current activity may destroy the estuaries as nursery grounds. These possibilities must be balanced against potential flood control, water supply, and recreational value of artificial lakes, and the possibility of using reservoir water to maintain fresh water inflow to the bays during droughts when salinities, water temperatures, and pollutants can reach dangerous levels. It is known that coastal water bodies are intimately linked to the open Gulf, in part through tidal channels. Communication between the bays and Gulf waters is essential to maintain productive environments.

Thus, the total system naturally changes with time, but man can significantly alter the processes, resulting in economic, aesthetic, and cultural benefits and losses. Cause and effect relationships of the changes must be investigated and adequate steps taken to prevent permanent environmental damage. Yet the necessity of maximizing utility of these water bodies for coastal transportation, industrial and residential development, recreation and aesthetics, and as a source of food is patently obvious. Empirical, pragmatic caution is warranted during development to limit harm to the system.

Boundaries shown on the map (in pocket) are those interpreted in part from photomosaics, constructed from late 1950's photographs, with as much update as possible from more recent photographs and coastal charts, and in part from known circulation and salinity patterns in the bays and estuaries. Many boundaries, such as between the open bay and the tidally influenced open bay, are gradational and are subject to rapid and sudden shifts with short-term weather conditions. This should be borne in mind when considering the characteristics, limitations, and possible uses of the bay, estuarine, and lagoonal environments.

F 1. River-influenced bay

Water masses at the heads of bays and estuaries where rivers and major creeks discharge are generally less saline (less than 10 $^{o}/oo$) than other parts of the bays and estuaries. Following major storms, the water may be entirely fresh; during periods of exceptionally high tides and/or drought, salinity values may be almost those of normal sea water. There are approximately 21 square miles of river influenced bays in the Corpus Christi area.

In general, biologic species diversity is low in river-influenced bays. River water entering these upper bays and estuaries is commonly turbid, and light penetration and photosynthetic activity are correspondingly low. Fresh water is also usually high in humic acid. High turbidity, low salinity, and low pH from humic acid content preclude significant growth of most shellfish. Some types of clams are present, as are a few kinds of crustaceans and foraminifers. Ostracods are common, and brown and white shrimp reside in the associated marshes during their juvenile stages.

Bottom sediments in river-influenced bays are mostly laminated mud and sandy mud with some mottled mud in the seaward portions. The soft, water-saturated, muddy bottom hampers construction of even elevated structures. Long pilings must be driven into the bottom until they reach harder substrate below or until surface resistance (skin friction) will support the weight of the pilings and structure. Potential for corrosion of metal is, of course, very high. Dredging and disposing spoil from navigation channels or to fill in and seaward of the upper parts of bays can impair circulation; part of the food supply to many marine organisms in the rest of the bays would be cut off and flushing action would be limited. Construction activity in the estuaries should consider the need to maintain circulation and prevent needless increases in water turbidity or release of waste products. Disposal or release of solid or untreated liquid wastes, toxic chemicals, brines, sludges, or heated fluids will contaminate not only the river-influenced environment, but will be carried into other parts of the bays and to adjacent marshes (D-1, D-2).

F 2. Enclosed and/or restricted bay

Certain bays and portions of other bays are enclosed or segregated in such a way that they are influenced very little by normal tidal or riverine input. Enclosure and/or restriction of the bays may be for natural or man-made reasons. Small- to medium-sized bays, such as Port Bay, closely surrounded by land, far from tidal inlets and with few fresh-water streams discharging into them, are naturally enclosed and restricted. Large oyster reefs that grow to water level may restrict current movement, as they have in and at the entrance to Copano Bay and in the northern part of Aransas Bay. Man can contribute to restriction of bay current movement by indiscriminantly placing spoil that compartmentalizes parts of the bays. Circulation in portions of Corpus Christi Bay has been cut off in this way. Enclosed and restricted bays are generally less than 8 feet deep. There are at least 94.0 square miles of these bay areas in the Corpus Christi area.

Water exchange into and out of these bays is very limited. Bay water salinities are variable; high and low extremes are often reached. Near bayheads with minimal saline water influx, such as lower St. Charles Bay, water may remain brackish (less than $35^{o}/oo$) for considerable periods of time. In other bays or parts of bays such as Laguna Madre, high rates of evaporation combined with low rainfall produce hypersaline conditions much of the time.

Poor circulation in enclosed and restricted bays allows decline of the dissolved oxygen content of the bay waters. This decline induces reducing conditions at the sediment water interface, favoring accumulation of organic material on the bay bottoms and lower pH of bay waters.

Enclosed or restricted bays generally display an abundance of fine bottom sediment and low species diversity, but with large numbers of individuals. Absence of circulation reduces current activity, and organic-rich mottled mud accumulates. Extremes and variances of salinity limit the number of species to those sufficiently tolerant of the conditions. Benthonic organisms are dominantly infaunal deposit feeders, accounting for the mottled appearance of the bottom mud. Without competition, each species multiplies because there is plenty of organic material to eat, and large numbers of individuals are common except in hypersaline areas. Conditions in very saline waters are too severe for most biota. Very little bioturbation occurs in hypersaline bays, and thin (1 to 4 mm) laminae of mud remain undisturbed.

Placement of structures in or across this unit will be hampered by the thick water-saturated ooze that floors enclosed and restricted bays. Bearing strengths are so low that exceedingly long piles must be driven into the bottom until firmer substrate is reached or until skin friction will support the weight. Potential corrosion of metal is very high, and an aqueous environment always presents construction difficulties.

Reduction of the inflow from fresh-water streams by damming or diversion may induce or accentuate hypersaline conditions. Disposal of spoil or construction of jetties and storm barriers may further compartmentalize these parts of the bays, also changing salinity patterns. Changes in salinities may be deleterious to organisms in and adjacent to the area.

Poor circulation further limits use of these bays. Release or disposal of solid and untreated liquid waste products is a particular problem. Discharge of industrial wastes, particularly toxic or heavy metal-bearing chemicals and sludges, hot fluids, storm runoff, and seepage of septic tank effluent from residential developments marginal to the bays may render them unsuitable for fishing, oystering, or many other commercial and recreational activities. Even mildly deleterious products will accumulate through time in restricted bays, rather than be diluted by dispersion. Long after flushing or cessation of disposal, pollutants leached from the bay bottom sediments can contaminate the overlying water.

F 3. Open bay

The central portions of Corpus Christi and Aransas Bays (more than 157 square miles) are reasonably open, unrestricted water masses with moderate tidal and/or riverine influence. Water depths range from 6 to 13 feet and salinities are nearly normal. Circulation and exchange with other parts of the bays are moderate to good, salinity and turbidity fluctuations are generally moderate, and the dissolved oxygen content is moderate to high. These conditions are conducive to support of an abundant and varied biotic community, and species diversity is high.

Bay bottoms are mostly mottled mud with local concentrations of shell material. This generally thick water-saturated ooze has very low bearing strength. Structures placed on the muck must be constructed on long pilings sunk into the mud or perhaps placed on broad pads. Potential corrosion of metal is very high.

Disposal of solid and untreated liquid wastes, brines, sludges, toxic or heavy metal-bearing chemicals, and hot fluids in open bays can cause significant harm to the prolific biotic community. Seepage from poorly engineered septic tanks or holding ponds adjacent to the open bays can contribute to their pollution. The generally good circulation and exchange with other parts of the bays mean that waste products or other contaminants will probably be diluted, but will also be transported rather readily to adjacent environments, such as fringing marshes. Spoil from dredging operations connected with water transportation should be disposed of on land. New spoil mounds may tend to compartmentalize the bays, reducing circulation and exchange.

F4. Tidally influenced open bay

Water masses whose characteristics are similar to open bays (F-3), but with relatively strong tidal influence have been mapped separately near tidal and navigation channel openings at the lower or seaward ends of Corpus Christi and Aransas Bays. Water depths in these parts of the bays range from 6 to 13 feet; there are approximately 25 square miles of tidally influenced open bay in the Corpus Christi area.

Bottom sediment in tidally influenced open bays is mostly water saturated mottled mud. Structures need to be placed on long pilings driven into the bottom or on large, thick pads to be properly supported. During storms, wave and current energy which also should be considered in any construction plans will be particularly great in these parts of the bays.

Circulation and water exchange with the Gulf and other parts of the bays are very good. Salinity variations are low to moderate, and salinity values are generally from $20^{o}/oo$ to $35^{o}/oo$. These conditions are favorable to bay biota, and species diversity is high. The number of species increases, and the number of individuals of each species decreases as salinity values become more like normal sea water ($35^{o}/oo$). Benthonic filter and deposit feeders are among the most common types of organisms present. Benthonic foraminifers and various kinds of phytoplankton and zooplankton are also abundant. Of course, numerous nektonic animals occur, too.

In the dynamic tidally influenced open bay, spills of petroleum or toxic chemicals will quickly spread to other parts of the bays, perhaps causing long-term environmental damage. Similarly, these conditions render the lower bays unsuitable for disposal of solid or untreated liquid wastes, brines, sludges, or hot fluids. Storm runoff and seepage from septic tanks in residential development adjacent to the bay can also pose problems.

Proliferation of structures, construction of long jetties and hurricane barriers, and disposal of spoil will tend to restrict circulation and exchange in these parts of the bays. If environmental quality and numerous biotic niches present in the lower bays are to be maintained, it is essential to permit normal sea water to flow into other portions of the bays and fresher water to flow out of the bays.

F.5 Tidal inlets and subaqueous tidal deltas

Tidal inlets or passes are areas of rapid sediment transport and relatively intense current energy in restricted openings between barrier islands and within the bays. Tidal inlets between barrier islands are the only natural linkage between the Gulf and the bays for exchange of water and for fish migration. Tidal channels within the coastal water bodies link different parts of the bays.

Associated with most major inlets (Aransas Pass only in the Corpus Christi area) where they open out into the Gulf and bays are depositional areas called ebb and flood tidal deltas, respectively. In general, the flood delta is the larger of the two, partly because flow into the bay is greater than outflow and partly because longshore drift modifies the ebb delta and disperses much of its sediment down the coast. The ebb tidal delta is generally entirely subaqueous; portions of some flood deltas are subaerial and are covered by salt marsh (D-1) which has been mapped separately. The main inlet channels and tidal channels on the flood tidal delta are areas of shifting localized sedimentation and erosion. Sediment in the channels is mostly sand and shell. There are approximately 11 square miles of tidal inlets and subaqueous tidal deltas in the Corpus Christi area.

There are no longer any continuously open natural tidal passes between the Gulf and bays in the Corpus Christi area. Lydia Ann Channel was the natural pass between St. Joseph Island and Mustang Island leading to Aransas Bay, but its opening to the Gulf has been modified by the enlargement and stabilization of Aransas Pass. Cedar Bayou, the pass between St. Joseph and Matagorda Islands leading to Mesquite Bay, is extremely shallow or closed much of the time between storms. Normal water movement into and out of this restricted bay is to the northeast and southwest. At the southern end of Mustang Island and the northern end of Padre Island, three passes--Corpus Christi Pass, Newport Pass, Packery Channel--were natural openings from Corpus Christi Bay to the Gulf at different times in the past. They are now closed except during major storms. Increased flow through the Corpus Christi Ship Channel, a completely artificial channel, and the relatively deep and wide Aransas Pass has seemingly rendered these natural openings to Corpus Christi Bay unnecessary. Less than a mile north of Corpus Christi Pass, however, a new pass was dredged in 1972 to allow fish migration. This pass has been filling rapidly and will require continuous maintenance to keep it open. Low tidal exchange between the bays and the Gulf can apparently maintain only one pass per bay.

Natural water depths of passes in the Corpus Christi area are generally less than 13 feet. Aransas Pass has been dredged to 42 feet. During tropical storms and hurricanes, as well as during mainland floods, large amounts of marine and fresh water, respectively, flow through the passes. Under normal tidal conditions, tidal exchange is minimal; during the summer, evaporation along the southern part of the Texas coast is so great that there is a net inward flow of water through the passes. Salinities range from $10^{o}/oo$ to $40^{o}/oo$, depending on flow conditions. Normal salinities are from $30^{o}/oo$ to $35^{o}/oo$.

A diverse faunal assemblage is present in the inlet environment. Molluscs and echinoderms dominate the benthonic community. Small encrusting epifauna such as corals live attached to the molluscs, and clams and snails are often attacked by the boring clinoid sponges. Large schools of mullet, shrimp, and other commercially valuable marine organisms pass through the inlets.

Species diversity decreases on the shoal water tidal deltas. Infaunal species and echinoderms dominate the faunal assemblage; abundant southern flounder also live and feed there. Portions of the flood tidal deltas are alternately subaqueous and emergent, and in these areas, marsh vegetation (D-1) has proliferated. These salt-water marshes are among the most biologically productive areas in the bays.

Open, unobstructed tidal channels are essential to bay and estuarine quality. Blocking the inlets inhibits fish and shrimp migration, alters circulation patterns, prevents beneficial periodic flushing of pollutants from the bays, and in all likelihood increases chances of the barriers being breached in new, perhaps less desirable places by storm surge waters.

Furthermore, modification of the shape and orientation of the passes influences flushing and circulation. Natural passes through the barriers trend approximately north-south or northwest-southeast and tend to be on the southern side of the bays. They are no larger than necessary to handle normal tidal flow. Dredging and placement of jetties altering this configuration mean that natural processes will no longer be efficient and continued maintenance will be required.

Solid and untreated liquid wastes, brines, sludges, toxic chemicals, hot fluids, and other undesirable products placed in tidal inlets or on tidal deltas will be quickly dispersed down drift along the coast and throughout the bays and lagoons. The contaminants are potentially damaging to the ecological framework of the area and to marine animals that use the pass during migration.

F 6. Bay-margin sand and muddy sand

Shallow water deposits (less than 6 feet deep) of sand and muddy sand occur along the mainland margins of most bays, and along spits and barrier island shorelines in the Corpus Christi area. Much of the sand in these deposits is derived from erosion of tidal deltas, washover fans, and ancient sandy substrates exposed along bay margins. Relatively high wave and current activity along the bay margins, particularly during storms has led to considerable erosion, transportation and redeposition of the sand. In this respect, the marginal sands are similar to shoreface sand (F-9 and F-10) along the Gulf side of the barriers. Landward these deposits grade into tidal flats (C-5) and thin narrow beaches that are commonly too small to show on the map. Seaward, the sand content decreases and the deposits grade into normal muddy bay-bottom sediments. There are about 29 square miles of the marginal sand and muddy sand in the Corpus Christi area.

These shallow sandy areas commonly support a sparse growth of marine grass and a relatively diverse faunal community including motile pelecypods, carnivorous snails, crustaceans such as ostracods, isopods, mud shrimp, and crabs, and numerous kinds of fish. Species diversity increases toward the tidal inlets (F-5) where there is greater circulation and mixing between Gulf and bay waters. Away from the inlets, salinities and temperatures are more variable, and there are seasonal changes in the faunal assemblage. Mobile invertebrates migrate to deeper water during periods of extreme high and low temperatures and/or salinities.

The mobile bay margin sand and muddy sand exist in a state of dynamic equilibrium between erosion, and deposition. If this equilibrium is allowed to operate naturally, presence of the marginal sand reduces undercutting and erosion of the shoreline by dissipating wave and current energy along its bayward sloping surface. Disturbance of the dynamic equilibrium can lead to undesirable shoreline changes and sedimentation in bordering grassflats (F-8), oyster reefs (F-7), and salt marshes (D-1), perhaps even distant from the source. For example, construction of jetties, groins, piers, platforms, or other structures that block water movement and sand transfer may induce rapid sedimentation in one place and considerable erosion in another. Deposition of sand around the structures can render them ineffective or necessitate frequent and expensive dredging. Dredging channels through the sand can also block sediment movement, leading to deposition in the channel and to starvation of areas down drift. A sand bypass system may be desirable to aid in keeping channels open and to prevent erosion along the coastline.

Excavation of sand for concrete of fill will similarly affect the sand budget. The excavated hole will tend to trap sediment carried along bay margins, perhaps inducing sediment starvation in a down current direction. Spoil placed on the mobile sand belt may be easily eroded, leading to rapid shoreline accretion and probably increasing dredging costs in nearby channels.

Finally, leaching or chemical alteration of the solid waste and release of untreated liquid wastes, brines, sludges, petroleum spills, toxic or heavy metal-bearing chemicals, and hot fluids can have a deleterious affect on biota inhabiting the marginal sands. Also, these substances will be quickly carried to other environments, too.

F 7. Oyster reef, adjacent reef flank, and interreef areas

Colonial, elongate growths of oysters (*Crassostrea virginica*) are, or were, present in most of the bays in the Corpus Christi area, including Nueces Bay, Corpus Christi Bay, Copano Bay, and Aransas Bay. Oyster reefs become established where one or more juvenile oysters attach themselves to the bay bottom. If the place is favorable for growth of oysters, new oysters attach to those already there, gradually increasing the length, width, and height of the oyster mass until it has become a distinct mound or shoal. The reef mass is then predominantly dead oysters with a fringe of living oysters.

Salinity values where oysters grow are between $10^{o}/oo$ and $30^{o}/oo$. Reefs tend to be oriented perpendicular to prevailing currents and can be several miles long, significantly baffling and locally blocking bay circulation including hurricane surge. Extensive occurrence of oyster reefs in Aransas and Copano Bays is one reason these bays are classed as enclosed and/or restricted bays (F-2). Vertical growth of the reefs is limited by sea level and the ability of the bottom substrate to support the reef mass. Lateral growth is limited by circulation patterns and food supply; some reefs are exposed at low water and are a hazard to navigation.

Reef flanks are composed of shell debris dislodged from the reef during storms, mud and sand carried in by strong storm currents, and lesser numbers of living and dead oysters. These areas slope steeply away from the reefs and enlarge in size with increased growth of the reef. Interreef areas are the relatively flat bay bottoms up to 12 feet deep consisting of mud, sand, broken shell, and a few isolated clumps of oysters. Activities in and around the reef flanks and interreef areas will definitely affect the living oyster reefs. There are about 17 square miles of oyster reefs, reef flank, and interreef areas in the Corpus Christi area.

Oyster reefs and related areas serve as feeding grounds for many varieties of commercial and game fish and crabs. Other reef-associated animals include brittle stars, chitons, barnacles, corals, bryozoans, and worms. Where reefs occur in normal sea water ($30^{o}/oo$ to $35^{o}/oo$), oyster predators, such as oyster drills (snails) and starfish, are abundant. Periodic flushing with fresh water helps to control these predators and other parasites such as the horny sponge and certain fungi. Too much fresh water over a long period of time can be harmful to living oysters, however. Green algae may also grow on the oyster shells.

Many of the reefs in the Corpus Christi area are now dead and covered by a layer of sand and mud, or have been dredged to the extent that only remnants of the reefs remain. In 1971, 30,000 pounds of oyster meat were taken from Aransas Bay by commercial operators (Oppenheimer and Isensee, 1973). Shell dredged from oyster reefs has been used extensively on the Texas Coastal Plain (Kern, 1968) in the manufacturing of cement, as a source of high grade lime and caustic soda used in the production of aluminum and magnesium, in cattle and poultry feed, and as a substitute for gravel in construction of road surfaces and road beds, graded parking lots, driveways, and foundation material, particularly on soft mud substrates (capability units A-4, A-5, A-6, A-7, A-8, A-9, B-2, D-1, D-2, D-3, and E-1). Dredging for oyster shell destroys dead reefs and may increase turbidity, causing siltation that partly or completely buries adjacent live reefs. Destruction of oyster reefs alters bay circulation and eliminates an important feeding ground for marine organisms. Economically feasible substitutes exist for some uses of oyster shell, and additional substitutes will have to be found for many other uses as the supply of this slowly renewing resource is diminished. Dredging operations are now regulated, and limited to dead reefs more than 300 feet from a living reef (Vernon's Annotated Texas Statutes, Arts. 40-51 and 40-52), but the rate of extraction of shell is probably greater than replenishment.

Dredging of navigation channels through or near reefs and disposal of spoil are similarly harmful to living oyster reefs. Bottom sediment stirred up during dredging and sediment eroded from nearby spoil banks can quickly cover reefs. Large spoil mounds may alter bay hydraulics; adult oysters are immobile and depend on natural currents to bring them food. Placement of pipelines, platforms, or other structures on reefs may disrupt reef ecology, effectively limiting growth or destroying part of the reef.

Disposal of solid and liquid wastes, brines, sludges, or other unnatural fluids in the bays can also seriously affect oyster reefs. Oysters are filter feeders and often retain and concentrate contaminants that enter their digestive systems. Some contaminants may sicken, weaken, or kill oysters immediately. Others such as heavy metals, biocides, bacteria, and viruses are not particularly harmful to live oysters, but are hazardous to man and to marine animals that feed on oyster reefs.

F 8. Grassflats

Grassflats are shallow (less than 6 feet deep) sand and muddy sand areas with moderate to dense growths of marine grasses including Diplanthera, Thalassia, and Ruppia. Some of the most extensive developments of grassflats, along the entire Texas coast, amounting to about 50 square miles, are in the Corpus Christi area, principally in the lagoons along the back sides of the barrier islands and stretching to the mainland landward of Harbor Island and in northern Laguna Madre.

Grassflats are low energy environments, in part protected from strong currents and wave activity by spits and storm berms. The rooted vegetation baffles residual currents, further slowing water movement and stabilizing the sandy bottom. Water temperatures in these shallow areas vary considerably, but dense growths of grass aid in maintaining satisfactory ranges for many organisms. Salinities generally range from 20°/oo to 35°/oo. Spotty concentrations of shell debris are produced by bottom-feeding, shell-cracking fish.

Next to marshes, grassflats produce more in terms of species diversity and standing crop than any other environment in the estuaries. Green, red, and brown algae are common in grassflats; sea urchins, starfish, brittle stars, sea cucumbers, various types of clams and snails, innumerable kinds of commercial and game fish, and crustaceans are abundant. Although relatively few of these organisms are permanent residents of grassflats, grassflats do play an important role in the organisms' life cycles by providing shelter and organic debris for food.

Grassflats are sensitive environments that are easily harmed by some of man's activities in the Coastal Zone. Channelizing, maintenance dredging, and spoil disposal in or near grassflats directly destroys grassflats or increases water turbidity that may sicken the inhabitants and reduce photosynthetic activity. Sediment eroded from spoil mounds located elsewhere can also damage or destroy grassflats by inundation. Construction on grassflats may permanently disturb the natural ecology of the area. Traversing the shallow-water flats in vehicles during construction or for recreational purposes leaves tracks through the grass that do not heal quickly. Excessive navigation can stir up the bottom sediment, cut swaths through the grass, or otherwise disturb the area. Disposal of solid and untreated liquid wastes, brines, sludges, toxic chemicals, or heated fluids can pollute the grassflats.

Grassflats must be protected and managed wisely. Their major role is biologic productivity, making them one of the critical environments in the Coastal Zone.

F 9. Upper shoreface

Sand and shell deposits extending gulfward from the barrier islands at a gradient of approximately 30 feet per mile to approximately 8 feet of water depth comprise the upper shoreface. The lower shoreface lies between 8 and about 30 feet of water depth and is included with the open Gulf, continental shelf unit (F-10) to be described next. Landward of the upper shoreface is the barrier beach (C-1); locally, the upper shoreface is breached by tidal inlets and is partly covered by tidal deltas (F-5). There are about 8 square miles of upper shoreface in the Corpus Christi area.

The upper shoreface is an area of high wave and current energy and includes the surf zone. Normal wind-driven waves 2 to 4 feet high begin to feel bottom where water depth is 10 to 20 feet, and break on the upper shoreface. Considerable movement of sand occurs because of this wave action, both back and forth and with longshore drift. Where there is sufficient sand, several offshore bars 2 to 4 feet high, called breaker bars, are constructed. These are temporary and shift about with changing wave and tidal conditions. The bars are destroyed during major storms, in which considerable erosion, transportation, and deposition of shoreface sediment take place. The upper shoreface is thus a dynamic environment in which energy conditions and sediment supply, movement, and deposition are balanced. It is closely connected to other coastal environments, particularly the beach (C-1) to which the shoreface supplies sand. Disturbances in the upper shoreface can seriously affect adjacent environments.

Because of the high energy conditions, marine organisms in, on, or above the upper shoreface are highly mobile. These organisms are generally unbothered by shifting sand, and are able to quickly dig through considerable thicknesses of sediment. Salinities are normal (35^{o}/oo) except perhaps briefly during severe rainfalls.

Construction of large structures on the upper shoreface, such as piers, jetties, groins, seawalls, breakwaters, or revetments will impede sediment movement or otherwise alter the dynamic equilibrium of the shoreface and associated areas. Disturbance of the equilibrium will be translated into accelerated erosion and/or deposition elsewhere along the coast. Possible consequences are (1) rapid deposition rendering the structure useless, (2) considerable erosion that undermines the structure, also rendering it useless, and (3) reduction in available sand down the coast leading to beach erosion and possible hurricane washover. Excavation of sand will most certainly disturb the equilibrium and possibly lead to beach erosion because sand carried by longshore drift is diverted to fill the hole. Channels or passes dug through the shoreface will tend to heal as do other excavations. Continuous, expensive dredging or a bypass system may be required. Placement of spoil in the upper shoreface will result in rapid erosion of the spoil and deposition or accretion down the coast.

Of course, disposal or release of solid or untreated liquid wastes, brines, sludges, toxic chemicals, and heated fluids is detrimental to marine organisms and beach recreation far down drift from the source. Pollutants entering the upper shoreface area will be quickly distributed downcurrent and along the beach, and perhaps carried through tidal inlets into the delicate bays and estuarine environments. These pollutants may even form a barrier to migrating organisms seeking to enter the bays through tidal inlets.

F 10. Lower shoreface and open Gulf shelf

Seaward from the upper shoreface, muddy fine sand and mud of the lower shoreface and continental shelf occur. The lower shoreface ranges from 8 to approximately 30 feet of water depth and has a gradient of about 20 feet per mile; the open shelf ranges from approximately 30 feet of water to the edge of the continental shelf, about 600 feet below sea level, at a gradient of 10 feet per mile or less.

Energy conditions on the lower shoreface and open shelf are considerably lower than on the upper shoreface. Only during major storms do waves begin to feel bottom out on the shelf and break on the lower shoreface. Partly as a consequence of this lesser activity, sand content decreases and mud content increases with increasing water depth and distance from land. The absence of breaking waves, the slow rate of sedimentation, and normal salinities lead to a predominance of biological activity. Species diversity is great--including benthonic, planktonic, and nektonic organisms--and most of the sediment, at least on the lower shoreface, is extensively burrowed.

Principal factors affecting use of the lower shoreface and open Gulf shelf are great water depth and susceptibility to high wind, wave, and current activity. Structures must be placed on long pilings or piers and be built strong and high enough to be able to withstand hurricane force winds and escape waves several tens of feet high. Construction of platforms for production of hydrocarbons probably causes no significant long-term deleterious effects if the structures are built with consideration of the elements and all feasible technological innovations are used to guard against discharge of wastes or accidental spills. If the platforms are close to shore, however, they can be a visual blight. These problems are well known to those who construct platforms in the Gulf of Mexico, and although most have been solved, occasionally accidents will happen.

One of the most unfortunate uses of the lower shoreface and open Gulf areas is as an out-of-sight, out-of-mind infinitely large waste disposal sink. Although the Gulf is large, it can be contaminated, and normal circulation patterns will distribute pollutants widely along the coastline. Its maintenance in a pollution-free condition is essential for continued biological productivity and commercial and sport fishing.

F 11. Local sand and shell beaches and berms

Thin local deposits of sand and shell along the mainland coast, on spits, on subaerial portion of tidal deltas and along the southern margins of heart-shaped lakes (A-12, A-13) high on the coastal plain are found throughout the Corpus Christi area. The beaches are similar to barrier island beaches, but are thinner, lower energy features, and generally contain more shell debris than barrier island beaches. Most of the beaches were constructed where minor erosion has left a sand lag or where spits are built above sea level. Berms are storm deposits where high waves have tossed coarser material above normal water level.

There are about 8.5 square miles of beaches and berms in the Corpus Christi area. These beaches and storm berms are commonly found adjacent to marshes or inland water bodies. Many are now abandoned where modern river mouths and marshes have built seaward, bypassing the local deposits. A few others have been abandoned because of beach accretion or because the size of a coastal lake has shrunk. Abandoned and active features have been lumped for cartographic simplicity, largely because the beaches and berms are relatively minor features.

Active beaches and berms are highly susceptible to erosion, modification, and flooding during storms. Tidal fluctuations are small in the Texas Gulf coastal bays, but the deposits are also so small that a significant portion of them will be flooded during even the daily tidal cycle.

Proximity to marshes means that pollutants placed on the beaches and berms will be quickly carried into the wetlands and their important biotic communities. These beaches and berms can be used for recreation, such as fishing and swimming, that do not significantly affect sediment movement or impinge on the marsh environments.

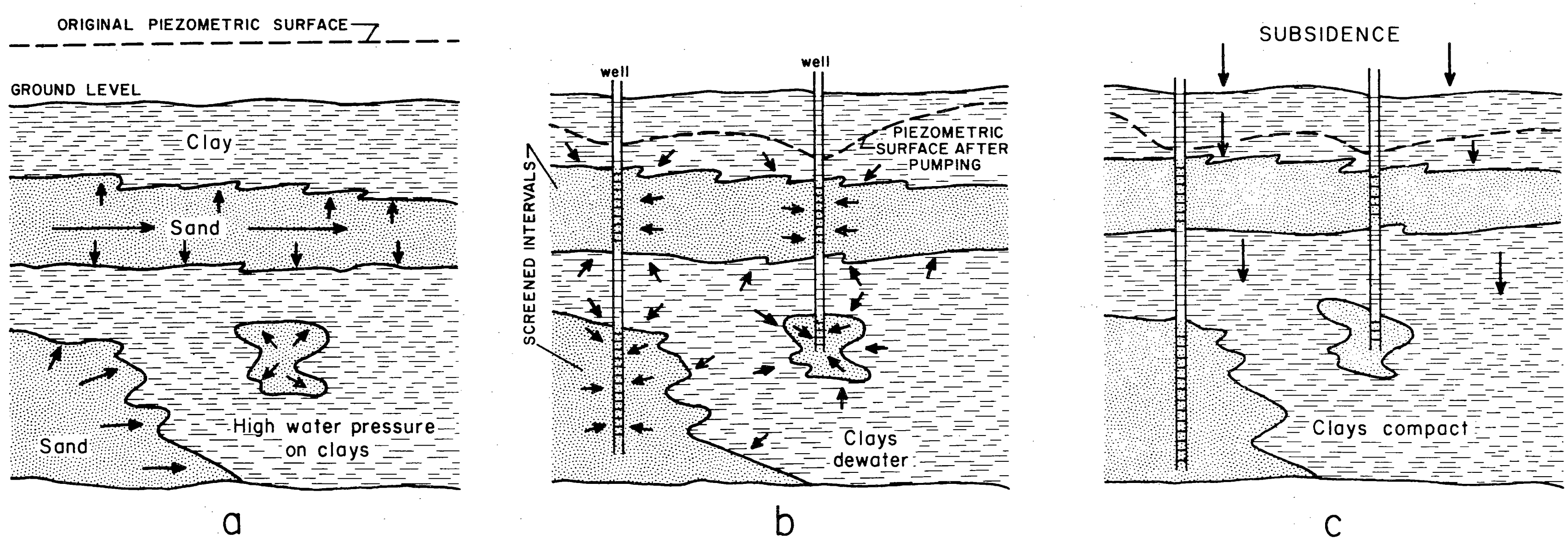
Aerial Photo Lineations (G)

Lineaments or grain displayed on aerial photomosaics apparently represent surface traces of fracture zones, potential faults, and possibly active faults cutting Coastal Plain sediments (Fisher and others, 1972, 1973; Kreitler, 1974, personal communication). These lineations were mapped on photomosaics of the Texas Coastal Zone (approximately 400 miles along the coastline and 100 miles inland) by marking alignments of streams or other natural features and photo anomalies crossing two or more mosaics. The photomosaics are at a scale of 1:24,000 and each covers the same area of a USGS 7-1/2 minute topographic map.

Although no definite interpretation of the significance of the photo lineations is possible at this time, they are most likely related to some sort of crustal movement. In the Houston area to the northeast, where similar kinds of sediments occur at the surface, some photo lineations correspond to known faults along which there has been recent movement (Turner and others, 1966; Reid, 1973; Van Siclen, 1967; Sheets, 1971; Fisher and others, 1972; Kreitler, 1974, personal communication). Active faulting in the Houston area appears to be related to differential ground subsidence that has been linked directly to withdrawal of subsurface fluids or alternatively, may be caused by some other mechanism related to subsurface fluid withdrawal (Winslow and Wood, 1959; Turner and others, 1960; Gabrysch, 1969; Reid, 1973; Kreitler, 1974, personal communication). These fluids, primarily ground water, but including oil and gas, are largely contained in sand layers bounded by clay horizons under considerably hydrostatic pressure. Extraction of subsurface fluids reduces pore pressure, and thus buoyancy, in the sands and bounding clay layers. Loss of buoyancy increases the effective weight of the overburden and drives out some of the fluids held by the clays. Loss of fluids from the clays allows consolidation and concomitant subsidence of the ground surface (Figure 6).

To this date, no lineation mapped in the Corpus Christi area shows evidence of active movement, such as matching reoccurring breaks in pavement. The only known active fault in the Corpus area, located near Clarkwood just west of the City of Corpus Christi, does not correspond to any mapped lineations; the fault trace, although visible in aerial photomosaics, is too short to have been mapped as a lineation. Small areas of significant declines in ground water artesian pressure, as much as 200 feet near Bishop, have been delineated in the Corpus Christi area (see later), but these declines are still far less than in the Houston area where water levels have dropped approximately 400 feet. Subsidence of up to 1 foot centered about Clarkwood is evident from available leveling data (Kreitler, 1974, personal communication), but this subsidence and the faulting mentioned earlier has most likely been induced by removal of oil and perhaps associated brines, not ground water used for municipal, industrial, or agricultural purposes.

Nevertheless, analogy with the Houston area suggests that the photo lineations in the Corpus Christi area are at least potentially active faults or fault zones. Movement along faults does not appear to be a significant hazard to man and his structures at this time, but would be if extensive subsidence occurred. It is certainly prudent to identify the existence of lineations or faults near new construction and to possibly design foundations to withstand some differential displacement.



System in balance before pumping.

System out of balance because of decline of artesian pressure. Removal of fluid pressure increases effective pressure of overburden. Water moves from clays to sands.

Movement of water out of the clays allows them to compact. Compaction of clays lowers the ground surface.

Figure 6
Schematic Illustration of Gulf Coast Subsidence Due to Withdrawal of Artesian Ground Water

ADDITIONAL ASPECTS OF LAND AND WATER CAPABILITY

Mapping of natural capability units is a necessary first step in considering capability, but basic data needed for defining capability for land- and water-use management include more than qualitative mapping of surface and near surface environments. Among the additional data needed are: (1) delineation of subsurface extent and relationships among the different capability units; (2) quantification of physical and hydrologic parameters of the units, particularly those related to construction, waste disposal, and use of ground water; (3) documentation of the kinds, rates, and causes of change in the dynamic units along the coastline; and (4) inventorying of the economically valuable mineral and fossil-fuel resources of the area.

Each of these tasks was addressed during the two years of study, and the results are contained in the companion report on Land Resources of the Coastal Bend region. Summaries of the investigations are contained in the following sections on: historical monitoring, quantitative characterization, hydrogeology, mineral resources, and subsurface geology.

Historical Monitoring

Several resource capability units, particularly those along the coastline, are dynamic because they are biologically and physically active and subject to changes measured over a period of a few years. These units require special consideration in assessing resource capability, for it is along the coastal zone that population and industrial pressures are among the greatest and where many legal boundaries are defined to correspond to natural boundaries. Documentation of the kinds, rates, and causes of changes along the coastline is necessary.

Mapping on sequential controlled aerial photo mosaics constructed from photographs taken in the 1930's, 1950's, 1960's, and early 1970's, USGS topographic maps dated from 1925 to 1971, and coastal charts published from 1887 to 1971 provided a means for monitoring these changes. Coastline alterations noted were classified as (1) natural changes, those that result from wave and current activity; (2) man-induced changes, resulting from the direct actions of man; and (3) natural changes related to man's activities.

During the last century, portions of the coastline appear to have been in a state of equilibrium. Although natural changes occurred, they were slow and at rates of change seldom exceeding 10 feet per year (Figure 7). Man has become a significant geologic agent in the Coastal Zone, and many changes in size and position of coastline environments, particularly during the last 30 years, have been influenced by human activity.

Quantitative Characterization

Land resource units that are physically defined were characterized quantitatively, using engineering test data available from public agencies and private firms. These data provided a means of determining physical parameters that are important in predicting ability to support construction of highways, canals, and buildings, and probable costs. Types of data collected are listed in Table 3. Over 17,500 engineering tests were recorded from more than 7,500 core samples taken from nearly all the major, physically defined resource capability units that occur in developed areas along the coastline. Means and standard deviations of each engineering test were determined as functions of depth in the capability units to 50 feet below the ground surface. Assignment of test data to individual capability units was based on core locality in relation to resource capability units, driller's log description, and prediction of substrate type at depth through analysis of depositional systems in which the sediments originally accumulated.

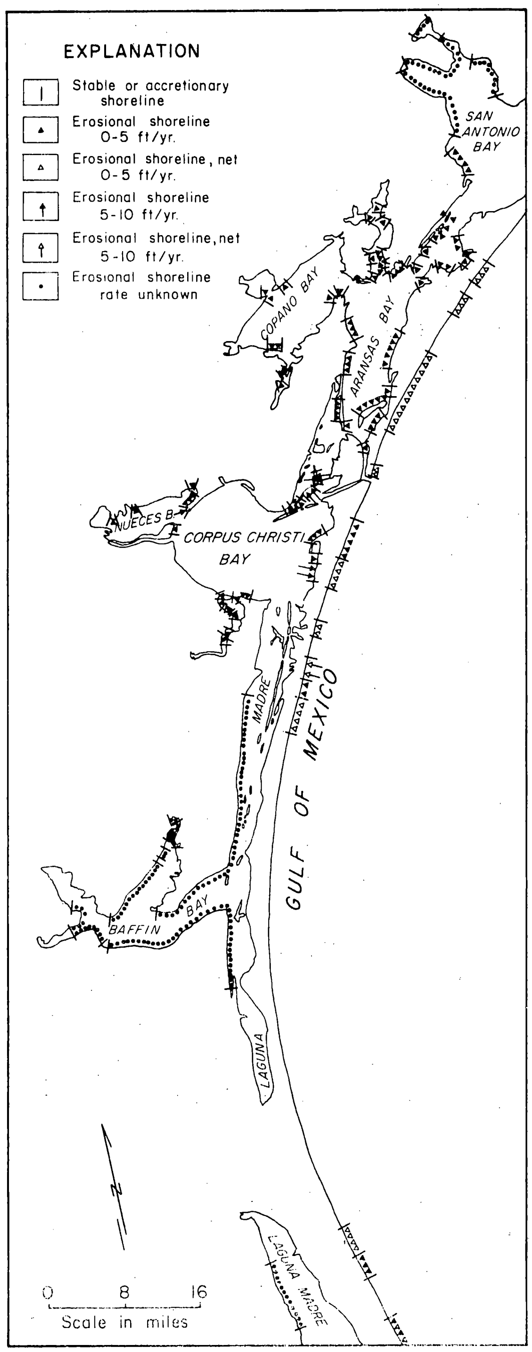
In general, mean values of the various engineering parameters correlate well with expected characteristics of the capability units. Units that are dominantly mud have low unit dry weights, high natural moisture contents, low foundation strengths, and high shrink-swell potentials. Units that are dominantly sand have higher unit dry weights, lower natural moisture contents, higher foundation strengths, and lower shrink-swell potentials. In addition, units that are variable tend to have more variable means and larger standard deviations.

Although means and standard deviations of engineering parameters may not represent actual values at any given locality, they should aid planners in predicting substrate characteristics, and perhaps will reduce or eliminate the cost of extensive investigations to locate sites that are probably suitable for particular uses.

Hydrogeology

Hydrogeologic characterization is an important part of resource

Figure 7
Location and Rate of Shoreline Erosion in the Coastal Bend Region



Data derived from R. A. Morton, personal communication, 1974, and the Environmental Geologic Atlas of the Texas Coastal Zone--Port Lavaca, Corpus Christi, and Kingsville areas.

Table 3
Physical Test Data

1. Unit dry weight (lbs/ft^3)

2. Natural moisture (% dry weight)

3. Foundation strength
    a. in-place vane shear
    b. standard penetrometer
    c. Texas Highway Department cone penetrometer
    d. unconfined compression
    e. triaxial shear
    f. hand penetrometer

4. Shrink-swell
    a. Absorption swell (% volume)
    b. Absorption pressure (lbs/ft^2)
    c. Linear drying shrinkage (% distance)

5. Atterberg limits
    a. Liquid limit (% dry weight)
    b. Plastic limit (% dry weight)
    c. Plasticity index (% dry weight)

6. Grain size distribution
    a. Gravel (% sample)
    b. Sand (% sample)
    c. Silt (% sample)
    d. Clay (% sample)
    e. Passing 200 mesh

7. Permeability

8. Void ratio

capability. Ground-water levels including fluctuations, drawdown, and water quality bear directly on such aspects of capability as public and private water supply, waste disposal, and construction. Ground-water level and water-quality data provided by the Texas Water Development Board for wells in the Coastal Bend region and from published reports by the U.S. Geological Survey acting in cooperation with the Texas Water Development Board were used to compile information on (1) extent and location of fresh to slightly saline ground water, (2) direction and rate of ground water flow, (3) water quality, (4) locations favorable for future development of ground water supplies, and (5) problems that might limit available ground water.

Based partly on response of water levels to climatic fluctuations and on well depth, unconfined or water table aquifers were distinguished from confined or artesian aquifers. Withdrawal of ground water from these two kinds of aquifers can increase more than 100 percent before water will be removed from storage. Areas favorable for future development of ground water are not evenly distributed throughout the Coastal Bend region, however. The extent of permeable surface material and the general climatic regime determine the amount of recharge to aquifers; depositional environments in which sediments originally accumulated determine the spatial distribution, thickness, and permeability of water-bearing sand, and, thus, the amount and quality of ground water available. Areas most favorable for development of water table aquifers are in the east-central and northeastern parts of the Coastal Bend region. Areas most favorable for development of artesian aquifers are in the north-central, central, and south-central parts of the region.

Mineral Resources

Mineral-resource data for the Coastal Bend region is scarce, and unfortunately much of what is available is proprietary information. A figure and table included in the companion report on Land Resources of the Coastal Bend region show the dollar value of mineral commodities produced over a 12-year period and types and quantities of fossil fuels produced.

Subsurface Geology

As a complement to quantification of the physical and hydrogeologic characteristics of the resource capability units, knowledge of the three-dimensional configuration of these units is desirable. For instance, an understanding of whether an aquifer is perched, isolated, or likely to be intimately connected with other aquifers is needed to properly evaluate its capability. Available subsurface work indicates that ancient sediments in the Coastal Bend region were deposited in a complex assemblage of fluvial (river)-deltaic, barrier-strandplain (shorelines), and bay-estuary-lagoon systems producing a variety of sedimentary types and relationships toward the coast, the effects of rapidly fluctuating sea level were superimposed.

Delineation of subsurface environments allowed prediction of the occurrence of certain resource capability units at depth and provided general understanding of the relationship between the hydrogeology and the subsurface extent of permeable substrates. Most of the subsurface data are contained in capability unit descriptions and the section on hydrogeology in the companion report on Land Resources of the Coastal Bend region.

Our knowledge of the subsurface needs to be refined considerably by detailed analysis of well and core logs. Assignment of resource capability units below the ground surface can then be corroborated and ground water movements and quality variances can better be understood.

CURRENT LAND USE

Basic to the task of ascertaining the environmental affects of demographic expansion in the Corpus Christi area is determining changes in land use patterns, principally the amount and kind of agricultural land taken out of production. Current land use in Nueces, San Patricio, Aransas, and Refugio Counties was mapped primarily on aerial photomosaics (constructed by Edgar Tobin Aerial Surveys) at a scale of 1:48,000 from air photos taken in the fall of 1971. Where the 1971 mosaics did not provide coverage, late 1950's aerial photomosaics at a scale of 1:24,000, also from Edgar Tobin Aerial Surveys, were used. Additional information was obtained for the latest U. S. Geological Survey 7-1/2 minute topographic maps and from Texas Highway Department County Highway maps. The General Land Office of Texas and the Texas Water Development Board supplied maps showing the distribution of state-owned lands and irrigated land, respectively. Central Power and Light Company of Corpus Christi compiled information on locations of new and expanded industry in the Corpus Christi area.

Eight kinds of land use were recognized in the Corpus Christi area: rangeland, cropland, land irrigated by surface water, land irrigated by ground water, urban and industrial land, new and expanded industrial sites, state parks, and national parks and wildlife refuges. Land that had been entirely cleared and replanted in grasses for intensive grazing was placed with cropland, reflecting its true potential. Land being held in abeyance of unannounced development was assigned to its original use category; even though it is not being used for that purpose, it still could be. Land areas already purchased for announced industrial expansion or relocation were mapped separately. Cooling ponds were considered to be urban and industrial land even though they were coded as fresh water (A-12) in the classification of land and water resources. Areas and land uses not matching any of these categories, including most of the barrier islands, and bays and estuaries, were lumped into a single unallocated category. The primary purpose of mapping land use area was not to delineate all land uses in the Corpus Christi area, but to allow determination of agricultural land irrevocably taken out of production.

The kinds and amounts of land use in each county of the Corpus Christi area are contained in Table 4; the map itself has not been reproduced. San Patricio and Nueces Counties contain the prime croplands. Most of the irrigated land is in northwestern San Patricio County where ground water quality and quantity are adequate for irrigation purposes. Refugio and Aransas Counties are primarily

Table 4
Approximate Amounts of Various Kinds of Land Use
in the Corpus Christi Area

	Counties			
	Nueces	San Patricio	Refugio	Aransas
	(in square miles)			
Rangeland	121.0	201.3	625.1	153.2
Cropland	612.2	414.3	138.3	12.4
Irrigated land (surface water)	8.0	0.7	0	0
Irrigated land (ground water)	0.7	28.4	0	0
Urban-industrial land	81.8	23.7	6.8	12.8
New and expanded industrial sites	7.1	10.5	0	0
State parks	7.2	1.1	0	0.5
National parks and wildlife refuges	0	0	0.8	97.1
Unallocated	300.0	46.1	73.4	362.9

rangeland. Locally the land has been cleared and is cropped or has been planted for intensive grazing. These different kinds of land use correspond strongly to the natural capability of resource units mapped in the Corpus Christi area. The relationship between use and capability has been discussed with descriptions of the resource units.

DEVELOPMENT OF A DATA MANAGEMENT SYSTEM

Purpose

Specific goals of the interdisciplinary team include developing a systematic approach to evaluate economic and environmental consequences of implementing various land management policy decisions in the Texas Coastal Zone, and testing the proposed methodology by applying it to differing hypothetical policies. Three policies were selected for consideration: (1) no change from 1970 public policy, (2) no development within 1,500 feet of the waterline after 1980, and (3) improved waste water treatment. Spatial allocations for the years 1980 and 1990 of new single and multifamily residential and commercial developments, and of recreational community and industrial expansion in the Corpus Christi area were generated by the Economics and Land Use task force and the project coordinator, respectively, based on projections of economic growth in the Coastal Bend region. The no-change policy imposed no environmental constraints on developments. The 1,500 foot policy modified economic and demographic projections by excluding all new development within 1,500 feet of the shoreline after 1980. It was assumed at the outset that economic changes, coupled with improved waste water treatment requirements, would not result in spatial distribution of new development different from the no-change policy. Estimation in quantitative terms of the locational environmental effects of development and concomittant loss of productive agricultural land comprised a major effort of this task force.

Projected allocations within the Corpus Christi area of residential and commercial expansion are by census tract in Nueces County and part of San Patricio County, and by whole county areas in Refugio and Aransas Counties. Industrial growth and certain recreational community developments on Mustang and northern Padre Islands and near Rockport are allocated to particular sites.

There are 59 census tracts in the Corpus Christi SMSA (Nueces and San Patricio Counties). Along with the two whole-county areas (industrial expansion and the recreational communities were considered entirely separately), there are up to 61 areas for which quantitative environmental and land-use changes must be specified for two future dates, 1980 and 1990. Within these areas, 39 land and water resource units and nine kinds of land use were mapped (including unallocated land use). Although some census tracts were filled as of 1970 and not subject to future environmental and land-use changes, and few census tracts have all the different kinds of land and water resource units, there are still far too many changes to be quantitatively determined using manual processes.

For this reason, an automated data management system was developed, permitting storage and retrieval of vast amounts of data and rapid determination of the amounts of land and water resources and land-use areas affected by projected growth in the Corpus Christi area. Computerizing land and water resource and land-use information is advantageous in that quantitative results are repeatable, update and modification procedures are relatively simple, and the data are permanently stored for future use. Furthermore, the systematic approach that must be designed into an automated data management system facilitates direct quantitative comparison of the environmental effects of several policies, even beyond the implications demonstrated for the two policies tested as part of this project.

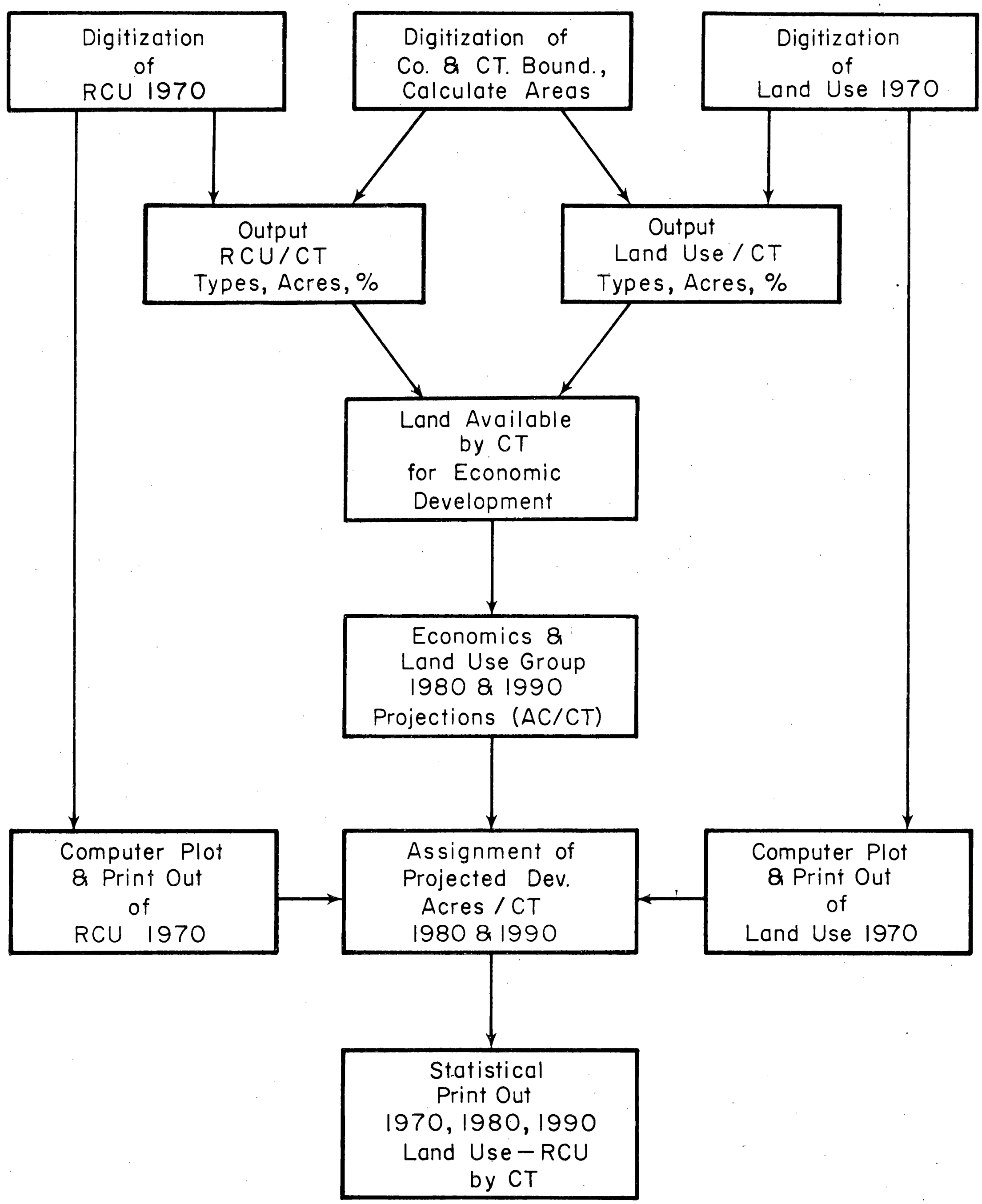
Basic Format of the System

The data management system is designed to translate maps of land and water resources and current (1970) land use in the Corpus Christi area into a computer compatible format allowing retrieval of relevant map data for any designated area within Nueces, San Patricio, Aransas, and Refugio Counties. All programs used in the system are contained in the Appendix. Statistical output from this system is in terms of acreages and percentages of capability units and land use units within the area searched. A simplified flow diagram illustrating the data management system is presented in Figure 8; a more detailed flow diagram containing all programs used is presented in Figure 13 (Appendix); a listing of all programs with flow charts is in the Appendix. Although all map data can be and frequently was plotted using symbols, this is not the primary function of the data management system.

To facilitate interfacing with other data management systems in the future, all map information was located by Universal Transverse Mercator (UTM) coordinates.

Map and county boundaries were digitized from U.S. Geological Survey 7-1/2 minute topographic maps (in a few areas where 7-1/2 minute coverage was not available, 15 minute topographic maps were used). Census tract boundaries (1970) in Nueces and San Patricio Counties were supplied by the Economic and Land Use task force. These boundaries were located on 1971 aerial photomosaics and then

Figure 8
Simplified Flow Diagram Illustrating the Data Management System



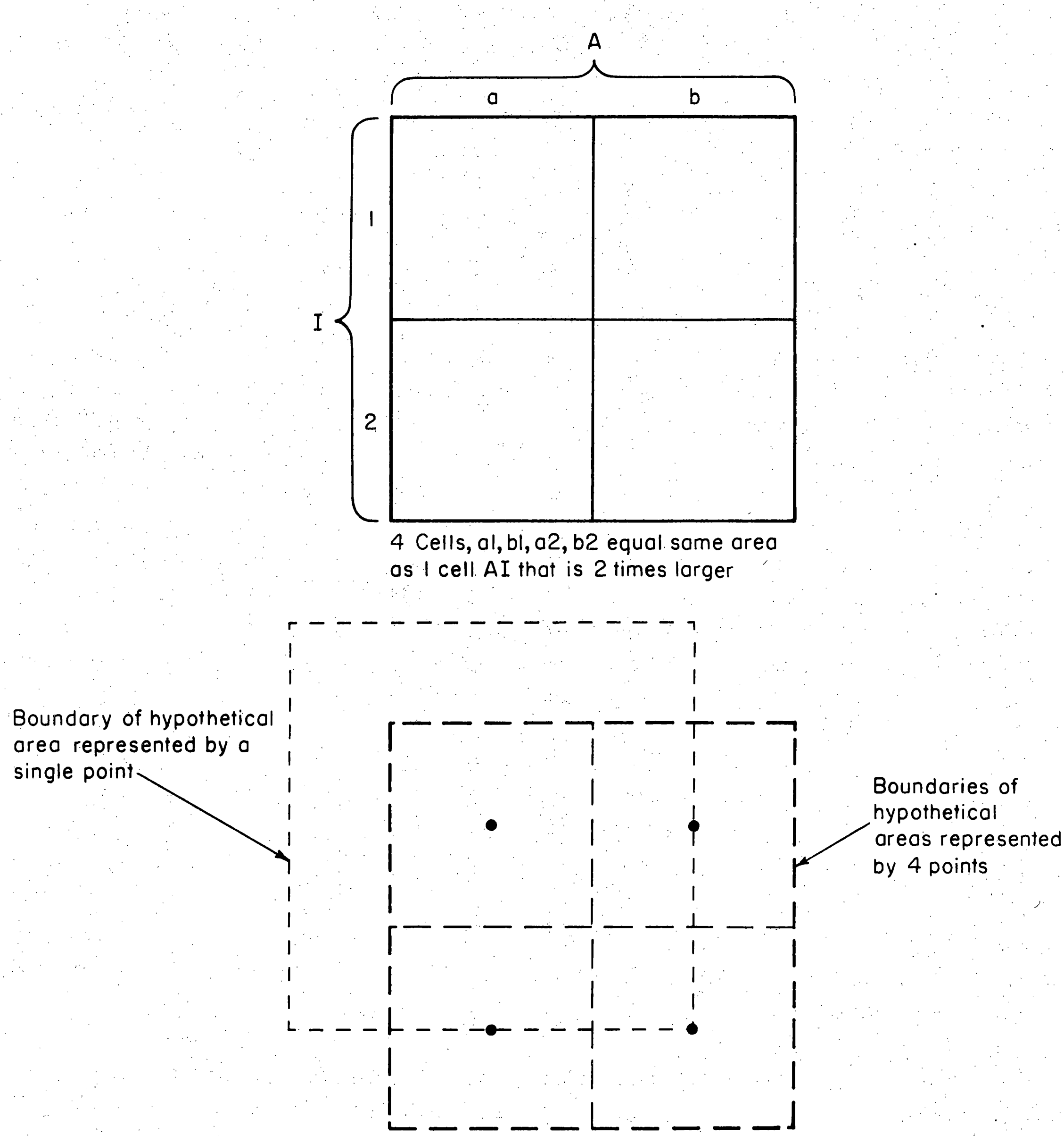
transferred to the U.S. Geologic Survey topographic maps for digitization. Short, straight-line segments were selected to approximate boundary curves. Although this method induces an error in areal calculations, the error is not thought to be significant in that the 7-1/2 minute topographic maps are at a scale (1:24,000), 5 times larger than the scale (1:125,000) of Land and Water Resources and the Current Land Use Maps. Computer plots of county and census tract boundaries at 1:125,000 compared favorably with boundaries plotted cartographically and manually, respectively, on the current land use maps. In addition, computed areas of the four counties were adjusted to correspond to areal measurements in the Texas Almanac (The Dallas Morning News, 1966). Census tract areas were determined geometrically by dividing the tracts into triangles and solving for the area of each triangle.

Land and Water Resource units and Land Use units were digitized on a point basis. The process is identical to point counting thin sections. Map units directly beneath each point are counted and recorded, and specific procedures are adopted to handle situations where grid points fall on boundaries. The technique is relatively simple and can be mastered quickly by personnel with little or no computer or map reading experience. Digitization can be done manually or with an automatic digiter. Statistically, a true representation of the map is stored.

This method of digitization was chosen even though most other automated management systems for map data use a cellular basis for storing information (Mathis and others, 1972). Digitization using cells, however, requires interpretation of which of two or more map units is dominant, or determination of the relative percentage of each map unit occurring in the cell. While this is not difficult, it does require a more highly skilled encoder, and it is more time consuming.

Chief advantages of using cells to store map information are that all map units are encoded exactly where they occur (although they cannot be located within the cell) and it is easier to change the scale or cell size at which data are stored or retrieved, or to combine data storage systems with different cell sizes. For example, four cells of a given size can be made to represent a single cell whose dimensions are 2x's larger (Figure 9). However, four points on a grid of a given spacing do not represent the same area as a single point on a grid in which the point spacing is 2x's larger. The total area represented is the same, but it is not exactly the same area on the map unless the grid origins are shifted. Of course the accuracy of map data stored and plotted using either method of entry is a function of cell size or

Figure 9
Comparison Between Areal Representations of Cell-Based Grids and Point-Based Grids



Area represented by 4 points is the same total area as is represented by a single point on a grid 2 times larger, but it is not the same representative area point spacing with respect to the size of area being searched.

Experiments with different sized grids revealed that vertical and horizontal spacing between points of 500 meters (approximately .3 mile; each point represents about 62 acres) was the best compromise between statistical accuracy of the output and cost of storing and retrieving data. Storage space and retrieval time change approximately geometrically with changes in point spacing. The land use map and the western part of the land and water resources map (both at scales of 1:125,000) were digitized at the 500 meter spacing.

Despite the general adequacy of the 500 meter point spacing, because the multidisciplinary group chose to consider no development within 1500 feet (about 457 meters) policy, digitization of land and water resources along the shorelines at closer spacing was obviously desirable. A grid with points spaced at 250 meter intervals (approximately .15 mile: each point represents about 15.5 acres) was selected. Because there are four times as many points in a 250 meter grid as are on a 500 meter grid, considerably better resolution is obtained. Better resolution along the coast is advantageous, because there are so many critical environments, but it is achieved at increased cost of time, storage space, and money. Furthermore, digitizing part of the land and water resources map at a 500 meter point spacing and part at a 250 meter spacing was a constant source of error and trouble, as is described later.

The 500 meter and 250 meter coding grids were arbitrarily located by major 10,000 meter grid lines that completely bounded the Corpus Christi area. Coordinants of the 10,000 meter grid intersections permitted identification of all points in the area. Each county was encoded separately. The westward limit of digitizing the Land and Water Resources Map at 250 meter spacing was at the first 10,000 meter multiple inland of the desired coverage.

Map units beneath grid points were encoded using map symbols (e.g. A-8, B-4; Table 2) in a systematic manner. Where a map unit boundary occurred beneath a point, the dominant unit within the surrounding point bounded square was recorded; if the units occupied approximately equal portions of the square, the unit to the north of an east-west boundary or to the east of a north-south boundary was recorded.

Each line was recorded from west to east, beginning at the northernmost point in each county. Only points falling within or on county boundaries were encoded. (This induced a minor source of error; only points within the boundaries should have been encoded.) Blanks in each recording line indicated locations outside of the county boundary. All coding was done manually because a suitable automated digitizer was not available.

UTM coordinates of each encoded piece of map information were automatically assigned, based on the western and northwestern coordinates of each county and the systematic recording procedure. Each county area was then plotted at the same scale as the original map (1:125,000) and encoding mistakes corrected.

To combine land and water resource data encoded at the two different spacings, all the data encoded at the 500 meter spacing was translated to a 250 meter spacing. Translation was accomplished as follows: (1) the area within each census tract was searched at the 500 meter spacing; this converted the basic area of storage from the county to the census tract; (2) a new array of data points was created at a 250 meter spacing; (3) each resource unit code from the 500 meter spacing was assigned to the newly created point 250 meters to the east; (4) the new line of data, now at a 250 meter spacing, was repeated 250 meters to the south (Figure 10).

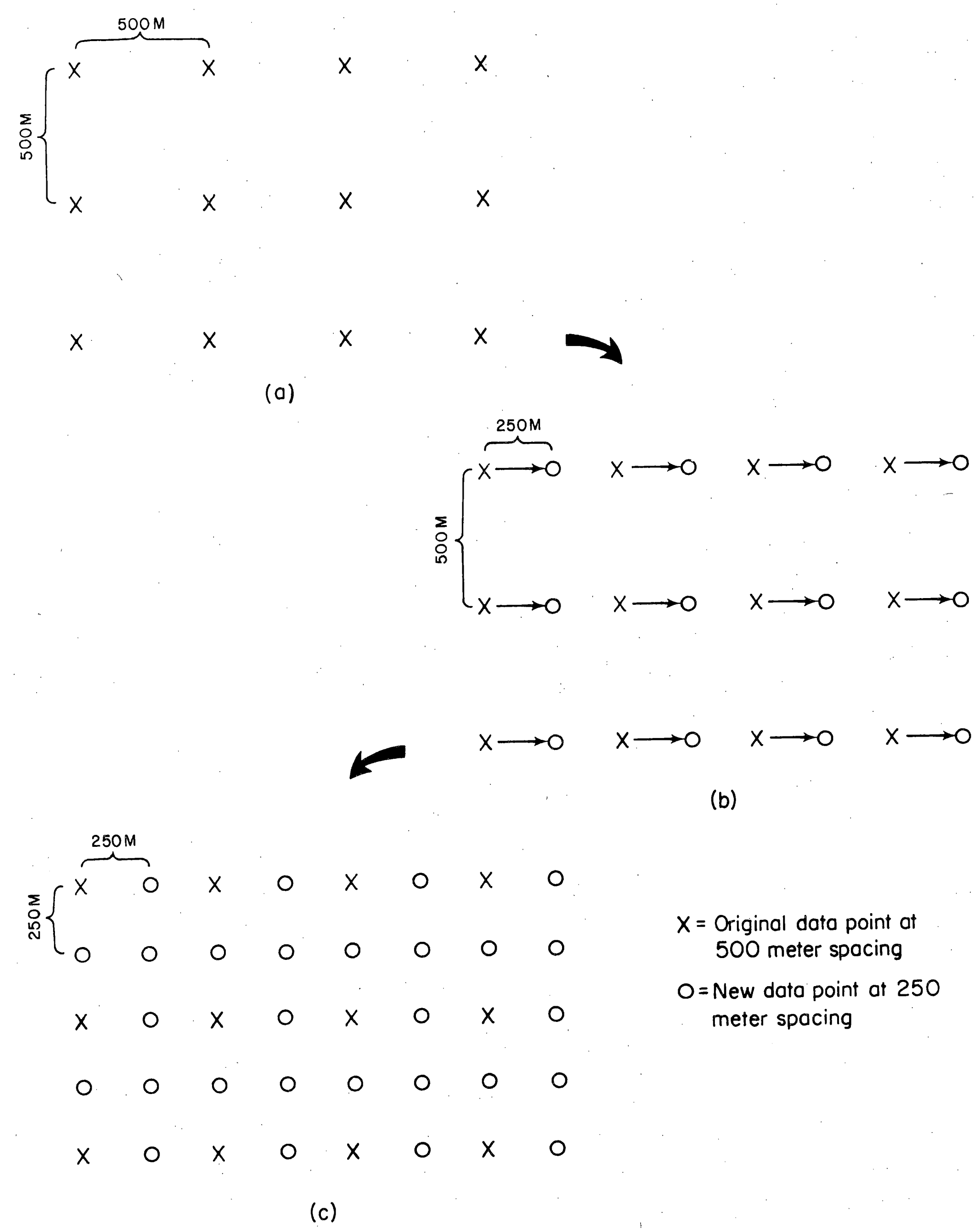
This procedure introduced two sources of error: (1) A resource unit may be assigned to a point where the unit does not actually occur; if the entire map had been recorded at a 250 meter point spacing, a different capability unit would have been encoded at that point. This error should not significantly alter the statistical validity of map data stored in the system, however. Map units encoded at the 500 meter spacing are generally large with respect to the point spacing. (2) Because the translation program shifts data at the 500 meter spacing to new sites to the east and south, data are acquired outside of boundaries of the census tract. These extraneous data points were eliminated by researching each census tract.

The new data set was combined with the data originally encoded at 250 meter spacing; the entire land and water resources map was then stored at a data spacing of 250 meters.

Land use data was similarly translated from 500 meter spacing to 250 meter spacing by: (1) searching each census tract at the 500 meter spacing to establish the census tract or the basic storage area; (2) translating the 500 meter spacing to 250 meter spacing; and, (3) reapplying the search program to eliminate extraneous points. Points lacking a land use code on the borders of the census tract were manually corrected later.

To relate land and water resources and land use changes to

Figure 10
Graphic Display of Method Used to Translate Map Data Encoded at 500 Meter Spacing to 250 Meter Spacing
(a) Search Area at 500 Meter Spacing
(b) Assign New Points 250 Meters East of Original Point
(c) Create New Line of Data 250 Meters to South



expansion in the Corpus Christi area, the land and water resources data set was combined with the land use data set. Data points lacking resources land use information along the boundaries of census tracts were then corrected by placing computer plotted overlays of land and water resources and land use on the respective maps and manually adding the additional codes needed. Each encoding point within the four county area was then characterized by the UTM coordinates, a land use code, and a land and water resources code.

Output

There are many possible ways to display the output from the combined data base. For the purposes of this project, land and water resource areas were related to land use to determine the capability units affected by each kind of land use (Table 5). The basic unit of output is the census tract. For each census tract, the kinds of land use, their acreage, and the percent that each land use occupies of the census tract, the county, the SMSA, and the four-county area are listed. For each different kind of land use, resource units affected by that land use, their acreages and percentages of the particular land use area that each resource unit occupies in the census tract are listed, along with the percentage of the total amount of that resource unit in the census tract affected by the particular land use.

In addition it is desirable to show the relationship between the land use and resource types in a particular census tract and the amounts of these units occurring in the region. No land use or resource unit is evenly distributed throughout the entire four-county area, and it is important to know how much of a given land use or land and water resource present in the region is being affected by local development. Therefore, the percentage of the total amount of each land use and each resource unit occurring in the county, the SMSA, and the whole Corpus Christi area that is being affected by expansion in a census tract was computed.

Acreages of land use and land or water resources were determined from counting the number of points encoded in each kind of unit. At 250 meter points spacing, each point represents exactly 15.44375 acres (the area of a square 250 meters on a side; last figure rounded). However, to normalize the areas determined by point counts to the calculated areas for each census tract, a small correction factor may be needed. For example, in census tract 16, there are 48 points equivalent to 741 acres. The calculated area of census tract 16 is 759 acres. Therefore, a correction factor of 1.02 was applied to adjust the areal

CENSUS TRACT NO. 19

1970

LAND USE: URBAN

LU ACREAGE	PERCENT OF CT AREA	PERCENT OF CO. AREA	PERCENT OF SMSA	PERCENT OF 4 COUNTY AREA	PERCENT OF TOTAL LAND USE IN CO.	PERCENT OF TOTAL LAND USE IN SMSA	PERCENT OF TOTAL LAND USE IN 4 CO.
1336	71.0	.2	.1	.1	2.6	2.0	1.7

RCU AFFECTED BY LAND USE	RCU ACREAGE AFFECTED	PERCENT OF LU AREA	PERCENT OF TOTAL RCU AREA IN CT	PERCENT OF TOTAL RCU AREA IN CO.	PERCENT OF TOTAL RCU AREA IN SMSA	PERCENT OF TOTAL RCU AREA IN 4 CO.
A3	577	43.2	100.0	.4	.2	.1
A8	759	56.8	58.1	.3	.2	.1

A CORRECTION FACTOR OF .98 HAS BEEN APPLIED TO ALL POINT COUNT CALCULATIONS TO ACHIEVE THE CENSUS TRACT ACREAGE OF 1882.
.0 PERCENT INDICATES THAT ACREAGE INVOLVED IS <.05 PERCENT

Table 5
Example of Output Display

measurements of land use and land and water resources determined from point counts to the true area of census tract 16. Obviously different sized census tracts containing differing number of points will require somewhat different correction factors. Correction factors used are listed with the statistical output (Table 5).

Spatial Allocation of Expansion, 1980 and 1990

Assessment of the environmental consequences of expansion in terms of the kinds and amounts of land and water resources affected and changes in land use by 1980 and 1990 in the Corpus Christi area necessitated that the development be allocated to specific, if hypothetical sites. Among the information needed by the Economics and Land Use group to assign single and multifamily residences and commercial establishments to proper places in the Corpus Christi area, was a determination of the amount and location of land available for expansion. This was done as follows: (1) total land area in each census tract was calculated by subtracting the acreage of subaqueous resource units from the total area in each census tract; (2) area already occupied in each census tract in 1970 was found by adding the acreages consumed by (a) existing urban and industrial development, (b) announced new and expanding industrial sites, (c) state parks, and (d) national parks and wildlife refuges; and (3) area occupied in 1970 was then subtracted from the total land area in each census tract. The remainder is the area available for expansion (Table 6). The area of subaqueous units in the census tract was determined from resource data stored at the 250 meter spacing. (Because the land use data were needed before they were translated to 250 meter spacing, the acreage of occupied land was calculated from data originally encoded at a 500 meter spacing.)

These determinations of the amount and location of land suitable for expansion were based on the best available data at the time the calculations were made. Census tracts which are already filled (no land available) may actually have some unused land. These areas are very small, however, and either could not be distinguished on the aerial photomosaics used to map land use or did not fall beneath any of the digitization grid intersections. Where more land appears to be available for expansion than actually exists in the census tracts (1, 2 and 29) there are errors in the data encoded from the land and water resources and the land use map (Tables 6, 7). These errors arose because major UTM grid intersections used to locate the digitization grids were manually plotted on the two maps. Cartographically determined intersections were not available until after digitization was complete. Slight differences in placement of the grid intersections led to minor misalignments of the

Table 6
Land Available for Use 1980, 1990
in Nueces and San Patricio Counties, Texas

CT	Total acreage	Land area acreage	Land area in use, 1970	Land area available for use
001	360	327	360	0
002	866	561	619	0
003	447	262	262	0
004	366	366	366	0
005	283	283	283	0
006	1007	1007	1007	0
007	1256	1256	793	463
008	9965	9965	3838	6137
009	407	407	407	0
010	349	349	349	0
011	508	508	508	0
012	529	498	498	0
013	393	393	393	0
014	623	623	623	0
015	421	421	421	0
016	759	759	759	0
017	3008	3008	815	2205
018*	1918	1918	928	990
019*	1882	1882	1335	547
020	749	749	749	0
021	992	992	992	0
022	592	592	592	0
023	1588	1588	978	610

Table 6 (continued)

CT	Total acreage	Land area acreage	Land area in use, 1970	Land area available for use
024	1003	1003	1003	0
025	633	633	633	0
026	948	948	948	0
027	5078	2931	2264	667
028	88084	2005	0	0
029	2603	2494	2543	0
030	3114	3052	1183	1869
031	4936	4584	1937	2647
032	3961	3119	557	2562
033	2131	2131	968	1163
034	1100	1100	984	116
035	6270	6270	905	5365
036	6466	6466	2095	4371
037	2022	2022	632	1390
050A	10322	8649	4574	4075
050B	4005	1573	0	1573
050C	1074	1074	0	1074
051A	109074	36653	6007	30646
054	113169	110349	5628	104721
056	2522	2522	1513	1009
057	380	380	317	63
058	109572	109313	1510	107803
059	111190	110753	991	109762
060	99473	99411	1298	98113
061	1558	1558	779	779

Table 6 (continued)

CT	Total acreage	Land area acreage	Land area in use, 1970	Land area available for use
101	23281	21592	3932	17660
102	3166	3018	1393	1625
103	4502	4502	1965	2537
104	45705	44541	6258	38283
105	738	716	492	224
106	2563	2147	1247	900
107	111972	111115	1195	109920
108	1105	1105	967	138
109	151204	150163	1849	148314
110	917	917	860	57
111	453	453	453	0
112	103020	101140	1076	100064
113	1400	1400	852	548

Table 7
Projected Residential and Commercial Development of 1980 and 1990, Policy I
(In Acres)

Census* Tract		Vacant 1970	1980 Projections: Multi-Family	1980 Projections: Single Family	1980 Projections: Commercial	1980 Projections: Vacant	1990 Projections: Multi-Family	1990 Projections: Single Family	1990 Projections: Commercial	1990 Projections: Vacant
7		463	305	158	0	0	0	0	0	0
8		6,137	219	2,599	0	3,309	3,319	0	10	0
17		2,205	285	1,745	0	163	175	0	12	0
18		990	376	600	14	0	0	0	0	0
19		547	130	417	0	0	0	0	0	0
23		610	583	12	15	0	0	0	0	0
	24	0								
24	33	1,163	227	1,042	10	0	0	0	0	0
	34	116								
27		667	334	333	0	0	0	0	0	0
	35	5,365								
	36	4,371								
50	37	1,390	81	1,964	0	15,803	2,648	7,803	0	5,352
	50a	4,075								
	50b	1,573								
	50c	1,074								
51a		30,646	14	245	0	30,387	0	0	0	0
	30	1,869								
53	31	2,647	147	5,164	0	1,767	0	0	0	0
	32	2,562								
54		104,721	13	37,484	0	67,224	5,312	21,500	10	40,402
56		1,009	92	917	0	0	0	0	0	0
57		63	4	59	0	0	0	0	0	0
58		107,803	7	956	0	106,840	2,352	8,849	5	95,634
59		109,762	5	304	0	109,453	0	0	0	0
60		98,113	10	14,652	0	83,451	0	0	0	0
61		779	255	524	0	0	0	0	0	0

* Includes only census tracts in Nueces County which are projected to be developed further by 1980 and 1990 under Policy I.

Data source of 1980 and 1990 projections: Economics and Land Use task force.

digitizing grids on the Land and Water Resources and Land Use Maps. The misalignments caused a few points (three) on or near the boundaries between land and water areas to be assigned to a water area when the resources map was digitized and range-pasture, farm, or undeveloped land when the land use map was digitized; in no instance is more than one point per census tract involved. Combining areal measurements determined from points spaced at 500 meters and at 250 meters undoubtedly produced some additional but indeterminant errors. All errors are less than 62 acres, however, which is the area represented by a single point at the 500 meter spacing.

Based on the amount and location of land available and the combined output of several economic, population, and transportation models, the Economics and Land Use task force projected acreages that will be occupied in 1980 and 1990 for each census tract (1-61) in Nueces County in terms of six kinds of single family residences, six kinds of multifamily residences, and commercial establishments. Residential and expansion outside of Nueces County was projected solely in terms of population increases; increases were projected only for the Gregory-Portland area.

Assignment of the location (hypothetical) of future development within census tracts in Nueces County was made by this task force using the following procedure: (1) Plots of land and water resources and current land use (1970) were generated at the 250 meter spacing. (2) The number of points equal to the acreage of expansion by 1980 and 1990 was determined for each census tract. For example, in census tract 7, the Economics and Land Use task force projected 463 acres of expansion by 1980. Four hundred sixty-three acres is equivalent to 30.1 points. (3) An equal number of points, rounded to the nearest whole integer, encoded as cropland, range-pasture land, irrigated land (surface and ground water), or unassigned land were recoded as urban-industrial. In census tract 7, 30 points were recoded. This procedure assumes no "leap-frogging" of development, and is predicted on convenience of recoding--blocks of points adjacent to existing urban-industrial land, parks, water, or announced sites of future industrial development were selected rather than nonadjacent points. The urban-industrial category was used although the expansion is residential or commercial only; industrial expansion was treated separately (see later). Only total acreages were used; no distinction was made between the locational effects of the 12 kinds of dwelling units.

Expansions projected for 1980 and 1990 were entered separately; 1990 development was located adjacent to 1980 development. Generally, it was not necessary to plot 1980 land use before assigning 1990 development to specific locations.

Expansion in the Gregory-Portland area was located using assumptions made by the Water Needs and Residuals Management task force to predict outfall of urban run-off. These assumptions are: (1) Gregory would undergo little change in size and may actually lose population. (2) Portland, census tract 106 and the surrounding census tract 104, would absorb all expansion in the area. (3) The population density (people per acre) in Portland is and will be the same as the population density in Robstown; this permitted translation of population projections to acreages of expansion. (4) Census tract 106 (900 acres) would fill before any development would occur in census tract 104. By this method, expansion in the Portland area is 7,353 acres by 1980 and 9,309 additional acres by 1990.

LOCATIONAL EFFECTS OF RESIDENTIAL AND COMMERCIAL EXPANSION

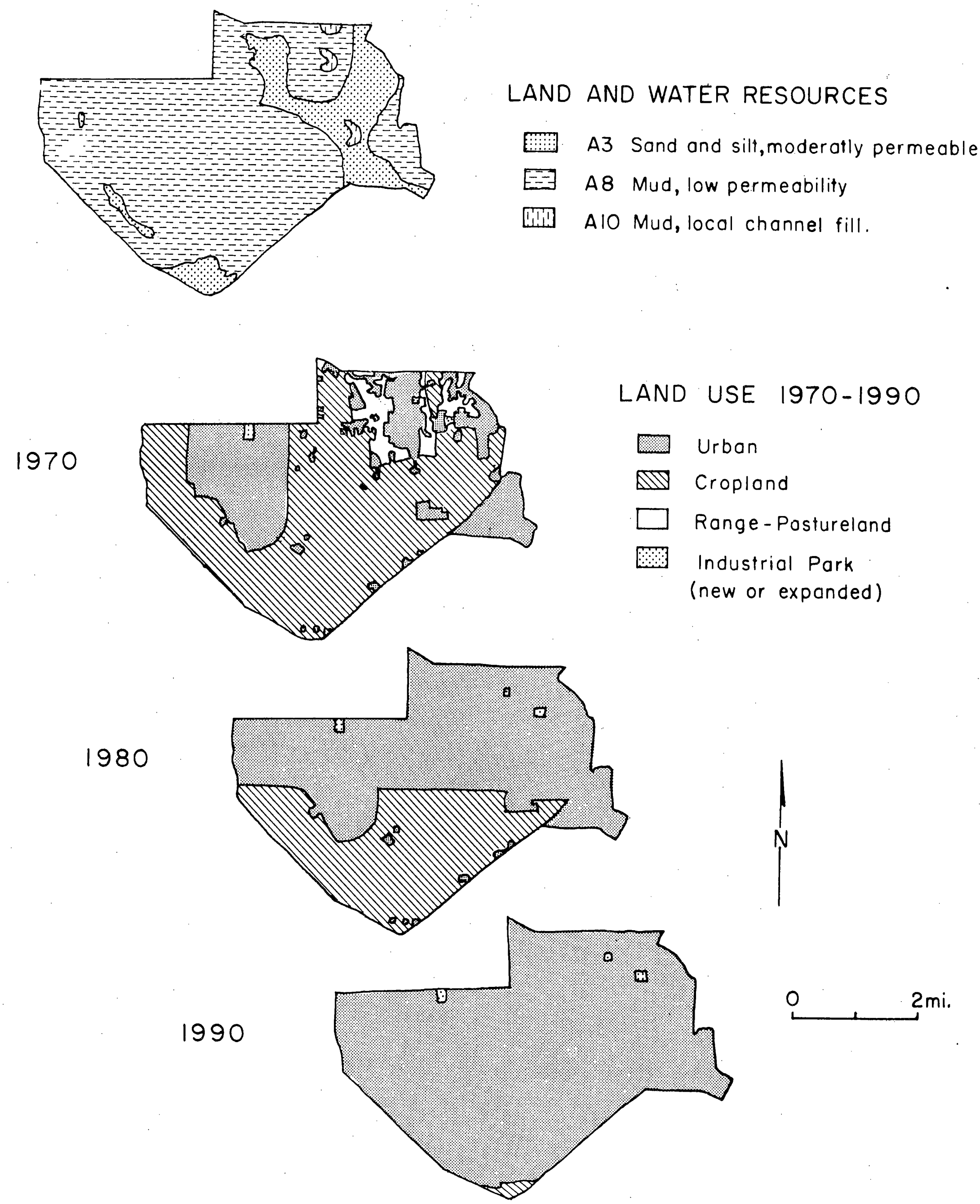
Using the procedures and the data management system outlined in the previous section, quantitative areal effects of residential and commercial expansion were computed for 20 census tracts in the Corpus Christi area (18 in Nueces County and 2 in San Patricio County) in which population and commercial growth are projected to occur by the years 1980 and 1990. Tabulated results and comments on the environmental effects are contained in a companion report entitled "Example Application II. Evaluation of Hypothetical Management Policies for the Coastal Bend Region", and are not duplicated here. Developmental changes and their environmental impact on land resource in census tract 8, along the southwest margin of the city of Corpus Christi, will serve as an example.

Census tract 8 encompasses 9,956 acres of land and includes Corpus Christi International Airport. Three kinds of land resources--moderately permeable sand and silt (A-3), low permeability mud (A-8), and local mud-filled channels (A-10) comprise 19.9%, 79.2%, and 0.9% of the census tract area, respectively. In 1970, the census tract consisted of 3,613 acres (36.3%) of urban land, 124 acres (1.2%) of industrial parkland, 5,986 acres (60.1%) of cropland, and 233 acres (2.3%) of range (pasture) land (Figure 11; Tables 8-17).

The Economics and Land Use task force projected (table 7) that by 1980 urbanized area in census tract 8 will expand by 2,818 acres (single family and multifamily) and that by 1990 an additional 3,319 acres will be developed (multifamily and commercial). Thus, between 1970 and 1990, 6,137 more acres will be "urbanized", and according to original census tract calculations of the area, there will be no more raw land in the census tract. Figure 11 shows the presumed pattern of growth.

Expansion acreages projected by the Economics and Land Use task force were followed as closely as possible in determining environmental impact. Minor discrepancies arise for two reasons: (1) refinements in determining the land area available for development since these data were given to the Economics and Land Use task force, and (2) limitations of the figures that can be accepted by the automated data management system.

Figure 11
Census Tract 8--Land and Water Resources and Land Use



CENSUS TRACT NO. 8

1970

LAND USE: URBAN

LU ACREAGE	PERCENT OF CT AREA	PERCENT OF CO. AREA	PERCENT OF SMSA	PERCENT OF 4 COUNTY AREA	PERCENT OF TOTAL LAND USE IN CO.	PERCENT OF TOTAL LAND USE IN SMSA	PERCENT OF TOTAL LAND USE IN 4 CO.
3613	36.3	.5	.3	.2	6.9	5.4	4.5

RCU AFFECTED BY LAND USE	RCU ACREAGE AFFECTED	PERCENT OF LU AREA	PERCENT OF TOTAL RCU AREA IN CT	PERCENT OF TOTAL RCU AREA IN CO.	PERCENT OF TOTAL RCU AREA IN SMSA	PERCENT OF TOTAL RCU AREA IN 4 CO.
A3	915	25.3	46.8	.7	.4	.2
A8	2698	74.7	34.1	.9	.6	.5

A CORRECTION FACTOR OF 1.00 HAS BEEN APPLIED TO ALL POINT COUNT CALCULATIONS TO ACHIEVE THE CENSUS TRACT ACREAGE OF 9956.
.0 PERCENT INDICATES THAT ACREAGE INVOLVED IS <.05 PERCENT

Table 8
Census Tract 8, 1970, Urban Land Use and Affected Resource Capability Units

CENSUS TRACT NO. 8

1970

LAND USE: CROPLAND

LU ACREAGE	PERCENT OF CT AREA	PERCENT OF CO. AREA	PERCENT OF SMSA	PERCENT OF 4 COUNTY AREA	PERCENT OF TOTAL LAND USE IN CO.	PERCENT OF TOTAL LAND USE IN SMSA	PERCENT OF TOTAL LAND USE IN 4 CO.
5986	60.1	.8	.5	.3	1.5	.9	.8

RCU AFFECTED BY LAND USE	RCU ACREAGE AFFECTED	PERCENT OF LU AREA	PERCENT OF TOTAL RCU AREA IN CT	PERCENT OF TOTAL RCU AREA IN CO.	PERCENT OF TOTAL RCU AREA IN SMSA	PERCENT OF TOTAL RCU AREA IN 4 CO.
A3	853	14.2	43.7	.7	.3	.2
A8	5040	84.2	63.7	1.7	1.1	1.0
A10	93	1.6	100.0	.8	.4	.2

A CORRECTION FACTOR OF 1.00 HAS BEEN APPLIED TO ALL POINT COUNT CALCULATIONS TO ACHIEVE THE CENSUS TRACT ACREAGE OF 9956.
.0 PERCENT INDICATES THAT ACREAGE INVOLVED IS <.05 PERCENT

Table 9
Census Tract 8, 1970, Cropland Land Use and Affected Resource Capability Units

CENSUS TRACT NO. 8

1970

LAND USE: RANGELAND

LU ACREAGE	PERCENT OF CT AREA	PERCENT OF CO. AREA	PERCENT OF SMSA	PERCENT OF 4 COUNTY AREA	PERCENT OF TOTAL LAND USE IN CO.	PERCENT OF TOTAL LAND USE IN SMSA	PERCENT OF TOTAL LAND USE IN 4 CO.
233	2.3	.0	.0	.0	.3	.1	.0

RCU AFFECTED BY LAND USE	RCU ACREAGE AFFECTED	PERCENT OF LU AREA	PERCENT OF TOTAL RCU AREA IN CT	PERCENT OF TOTAL RCU AREA IN CO.	PERCENT OF TOTAL RCU AREA IN SMSA	PERCENT OF TOTAL RCU AREA IN 4 CO.
A3	140	60.0	7.1	.1	.1	.0
A8	93	40.0	1.2	.0	.0	.0

A CORRECTION FACTOR OF 1.00 HAS BEEN APPLIED TO ALL POINT COUNT CALCULATIONS TO ACHIEVE THE CENSUS TRACT ACREAGE OF 9956.
.0 PERCENT INDICATES THAT ACREAGE INVOLVED IS <.05 PERCENT

Table 10
Census Tract 8, 1970, Range-Pastureland Land Use and Affected Resource Capability Units

CENSUS TRACT NO. 8

1970

LAND USE: INDUS.PARK

LU ACREAGE	PERCENT OF CT AREA	PERCENT OF CO. AREA	PERCENT OF SMSA	PERCENT OF 4 COUNTY AREA	PERCENT OF TOTAL LAND USE IN CO.	PERCENT OF TOTAL LAND USE IN SMSA	PERCENT OF TOTAL LAND USE IN 4 CO.
124	1.2	.0	.0	.0	2.7	1.1	1.1

RCU AFFECTED BY LAND USE	RCU ACREAGE AFFECTED	PERCENT OF LU AREA	PERCENT OF TOTAL RCU AREA IN CT	PERCENT OF TOTAL RCU AREA IN CO.	PERCENT OF TOTAL RCU AREA IN SMSA	PERCENT OF TOTAL RCU AREA IN 4 CO.
A3	47	37.5	2.4	.0	.0	.0
A8	78	62.5	1.0	.0	.0	.0

A CORRECTION FACTOR OF 1.00 HAS BEEN APPLIED TO ALL POINT COUNT CALCULATIONS TO ACHIEVE THE CENSUS TRACT ACREAGE OF 9956.
.0 PERCENT INDICATES THAT ACREAGE INVOLVED IS <.05 PERCENT

Table 11
Census Tract 8, 1970, Industrial Park Land Use and Affected Resource Capability Units

CENSUS TRACT NO. 8

1980

LAND USE: URBAN

LU ACREAGE	PERCENT OF CT AREA	PERCENT OF CO. AREA	PERCENT OF SMSA	PERCENT OF 4 COUNTY AREA	PERCENT OF TOTAL LAND USE IN CO.	PERCENT OF TOTAL LAND USE IN SMSA	PERCENT OF TOTAL LAND USE IN 4 CO.
6436	64.6	.9	.6	.3	12.3	9.6	8.1

RCU AFFECTED BY LAND USE	RCU ACREAGE AFFECTED	PERCENT OF LU AREA	PERCENT OF TOTAL RCU AREA IN CT	PERCENT OF TOTAL RCU AREA IN CO.	PERCENT OF TOTAL RCU AREA IN SMSA	PERCENT OF TOTAL RCU AREA IN 4 CO.
A3	1535	23.9	78.6	1.2	.6	.4
A8	4807	74.7	60.8	1.6	1.0	.9
A10	93	1.4	100.0	.8	.4	.2

A CORRECTION FACTOR OF 1.00 HAS BEEN APPLIED TO ALL POINT COUNT CALCULATIONS TO ACHIEVE THE CENSUS TRACT ACREAGE OF 9956.
.0 PERCENT INDICATES THAT ACREAGE INVOLVED IS <.05 PERCENT

Table 12
Census Tract 8, 1980, Urban Land Use and Affected Resource Capability Units

CENSUS TRACT NO. 8

1980

LAND USE: CROPLAND

LU ACREAGE	PERCENT OF CT AREA	PERCENT OF CO. AREA	PERCENT OF SMSA	PERCENT OF 4 COUNTY AREA	PERCENT OF TOTAL LAND USE IN CO.	PERCENT OF TOTAL LAND USE IN SMSA	PERCENT OF TOTAL LAND USE IN 4 CO.
3396	34.1	.5	.3	.2	.9	.5	.4

RCU AFFECTED BY LAND USE	RCU ACREAGE AFFECTED	PERCENT OF LU AREA	PERCENT OF TOTAL RCU AREA IN CT	PERCENT OF TOTAL RCU AREA IN CO.	PERCENT OF TOTAL RCU AREA IN SMSA	PERCENT OF TOTAL RCU AREA IN 4 CO.
A3	372	11.0	19.0	.3	.2	.1
A8	3024	89.0	38.2	1.0	.7	.6

A CORRECTION FACTOR OF 1.00 HAS BEEN APPLIED TO ALL POINT COUNT CALCULATIONS TO ACHIEVE THE CENSUS TRACT ACREAGE OF 9956.
.0 PERCENT INDICATES THAT ACREAGE INVOLVED IS <.05 PERCENT

Table 13
Census Tract 8, 1980, Cropland Land Use and Affected Resource Capability Units

CENSUS TRACT NO. 8

1980

LAND USE: INDUS.PARK

LU ACREAGE	PERCENT OF CT AREA	PERCENT OF CO. AREA	PERCENT OF SMSA	PERCENT OF 4 COUNTY AREA	PERCENT OF TOTAL LAND USE IN CO.	PERCENT OF TOTAL LAND USE IN SMSA	PERCENT OF TOTAL LAND USE IN 4 CO.
124	1.2	.0	.0	.0	2.7	1.1	1.1

RCU AFFECTED BY LAND USE	RCU ACREAGE AFFECTED	PERCENT OF LU AREA	PERCENT OF TOTAL RCU AREA IN CT	PERCENT OF TOTAL RCU AREA IN CO.	PERCENT OF TOTAL RCU AREA IN SMSA	PERCENT OF TOTAL RCU AREA IN 4 CO.
A3	47	37.5	2.4	.0	.0	.0
A8	78	62.5	1.0	.0	.0	.0

A CORRECTION FACTOR OF 1.00 HAS BEEN APPLIED TO ALL POINT COUNT CALCULATIONS TO ACHIEVE THE CENSUS TRACT ACREAGE OF 9956.
.0 PERCENT INDICATES THAT ACREAGE INVOLVED IS <.05 PERCENT

Table 14
Census Tract 8, 1980, Industrial Park Land Use and Affected Resource Capability Units

CENSUS TRACT NO. 8

1990

LAND USE: URBAN

LU ACREAGE	PERCENT OF CT AREA	PERCENT OF CO. AREA	PERCENT OF SMSA	PERCENT OF 4 COUNTY AREA	PERCENT OF TOTAL LAND USE IN CO.	PERCENT OF TOTAL LAND USE IN SMSA	PERCENT OF TOTAL LAND USE IN 4 CO.
9754	98.0	1.4	.8	.5	18.6	14.6	12.3

RCU AFFECTED BY LAND USE	RCU ACREAGE AFFECTED	PERCENT OF LU AREA	PERCENT OF TOTAL RCU AREA IN CT	PERCENT OF TOTAL RCU AREA IN CO.	PERCENT OF TOTAL RCU AREA IN SMSA	PERCENT OF TOTAL RCU AREA IN 4 CO.
A3	1892	19.4	96.8	1.4	.8	.5
A8	7769	79.7	98.2	2.6	1.7	1.5
A10	93	1.0	100.0	.8	.4	.2

A CORRECTION FACTOR OF 1.00 HAS BEEN APPLIED TO ALL POINT COUNT CALCULATIONS TO ACHIEVE THE CENSUS TRACT ACREAGE OF 9956.
.0 PERCENT INDICATES THAT ACREAGE INVOLVED IS <.05 PERCENT

Table 15
Census Tract 8, 1990, Urban Land Use and Affected Resource Capability Units

CENSUS TRACT NO. 8

1990

LAND USE: CROPLAND

LU ACREAGE	PERCENT OF CT AREA	PERCENT OF CO. AREA	PERCENT OF SMSA	PERCENT OF 4 COUNTY AREA	PERCENT OF TOTAL LAND USE IN CO.	PERCENT OF TOTAL LAND USE IN SMSA	PERCENT OF TOTAL LAND USE IN 4 CO.
78	.8	.0	.0	.0	.0	.0	.0

RCU AFFECTED BY LAND USE	RCU ACREAGE AFFECTED	PERCENT OF LU AREA	PERCENT OF TOTAL RCU AREA IN CT	PERCENT OF TOTAL RCU AREA IN CO.	PERCENT OF TOTAL RCU AREA IN SMSA	PERCENT OF TOTAL RCU AREA IN 4 CO.
A3	16	20.0	.8	.0	.0	.0
A8	62	80.0	.8	.0	.0	.0

A CORRECTION FACTOR OF 1.00 HAS BEEN APPLIED TO ALL POINT COUNT CALCULATIONS TO ACHIEVE THE CENSUS TRACT ACREAGE OF 9956.
.0 PERCENT INDICATES THAT ACREAGE INVOLVED IS <.05 PERCENT

Table 16
Census Tract 8, 1990, Cropland Land Use and Affected Resource Capability Units

CENSUS TRACT NO. 8

1990

LAND USE: INDUS.PARK

LU ACREAGE	PERCENT OF CT AREA	PERCENT OF CO. AREA	PERCENT OF SMSA	PERCENT OF 4 COUNTY AREA	PERCENT OF TOTAL LAND USE IN CO.	PERCENT OF TOTAL LAND USE IN SMSA	PERCENT OF TOTAL LAND USE IN 4 CO.
124	1.2	.0	.0	.0	2.7	1.1	1.1

RCU AFFECTED BY LAND USE	RCU ACREAGE AFFECTED	PERCENT OF LU AREA	PERCENT OF TOTAL RCU AREA IN CT	PERCENT OF TOTAL RCU AREA IN CO.	PERCENT OF TOTAL RCU AREA IN SMSA	PERCENT OF TOTAL RCU AREA IN 4 CO.
A3	47	37.5	2.4	.0	.0	.0
A8	78	62.5	1.0	.0	.0	.0

A CORRECTION FACTOR OF 1.00 HAS BEEN APPLIED TO ALL POINT COUNT CALCULATIONS TO ACHIEVE THE CENSUS TRACT ACREAGE OF 9956.
.0 PERCENT INDICATES THAT ACREAGE INVOLVED IS <.05 PERCENT

Table 17
Census Tract 8, 1990, Industrial Park Land Use and Affected Resource Capability Units

Translation of the land use data base from 500 meter spacing to 250 meter spacing allowed more accurate determination of acreages occupied by each kind of land use and better determination of areas available for additional expansion. Using the revised figures, there are 6,219 acres available for expansion after 1970 (range-pasture land plus cropland), or 82 acres more than the 6,137 acres figure used by the Economics and Land Use task force. The 82 acres are presumed to remain as cropland after 1990, despite assumptions that census tract 8 would be filled by 1990.

The method selected to consider expansion, i.e., creating new land use data bases for 1980 and 1990, is limited in that all input must be in terms of whole numbers of points. Each point is approximately 15.4 acres--the exact area represented by each point varies somewhat between census tracts--and acreages of land use changes must be in multiples of the acreage of each point (see earlier discussion under Spatial Allocation of Expansion, 1980 and 1990). For this reason areal increases in urbanized land contained in the output tables (e.g., Tables 12 and 15) are not exactly the same as increases projected by the Economics and Land Use task force (Table 7). In census tract 8, urbanized land will increase by 2,823 acres by 1980 and by 3,318 acres by 1990 (Tables 8, 12, and 15), increases that are 5 acres more and 1 acre less, respectively, than the increases projected by the Economics and Land Use task force. The assignment of 4 acres in addition to the total acreage of development projected by the Economics and Land Use Task Force reduces to 78 acres (Table 16) the amount of land in census tract 8 presumed to remain as cropland after 1990 (the previous presumption was 82 acres). Table 18 summarizes the revised land use figures for census tract 8. In all census tracts but census tract 56, areal differences between the figures projected by the Economics and Land Use task force and those presented in the output tables are no more than 10 acres--less than the area represented by a single digitization point. In census tract 56, there are 97 acres less land available for development than was originally calculated.

Environmental impact of urban growth in census tract 8 is minimal and is primarily in terms of loss of productive cropland. Secondary impacts involve the effects that physical characteristics of some of the land resource units may have on the proposed development.

Cropland in 1970, almost all of which will be consumed by 1990 residential and commercial expansion (in census tract 8), amounts to 0.8% of the total land area in Nueces County, 0.5% of the land area in the SMSA, and 0.3% of the land area in the four-county Corpus Christi area (Table 9). Loss of cropland production by 1990

Table 18
Land Use in Census Tract 8

Land use CT 8	1970 acres	1980 acres	1990 acres
Urban	3,613	6,436	9,736
Cropland	5,986	3,396	93
Range-pasture land	233	0	0
Industrial park (new or expanded)	124	124	124

will be about 1.5% of all the cropland in Nueces County, 0.9% of the cropland in the SMSA, and 0.8% of the cropland in the Corpus Christi area. Loss of rangeland is extremely small compared to the amount in the entire Corpus Christi area.

Land resource units associated with this cropland are A-8 (5,040 acres), A-3 (853 acres), and A-10 (93 acres) (Table 9). Resource unit A-3 is moderately permeable, but ground water quality contained in the sand and silt is poor and unlikely to suffer further deterioration from urban growth. It is presumed that sanitary sewers rather than individual septic tanks will be the chief method of liquid waste disposal. High shrink-swell potential, low bearing strength, and slow drainage from resource units A-8 and A-10 may present construction and maintenance problems for owners and renters, however.

LOCATIONAL EFFECTS OF WATERFRONT RESIDENTIAL/RECREATIONAL DEVELOPMENTS

In recent years, large tracts of privately owned property on the barrier islands and along mainland bay shores have been subdivided and developed into first and second home recreational communities. To evaluate the impact of such developments on land and water resources, hypothetical residential recreational communities were postulated in waterfront areas and on the barrier islands based on projected permanent and transitory (second-home) residential populations. Assumptions and methods used to establish the design, number, size, and location of projected developments in 1980 and 1990 are discussed in Chapter II of the Policy Evaluation Report. Hypothetical developments were planned for Rockport, Mustang Island, and Padre Island. To determine amounts of land and water resources affected by the hypothetical communities, a square count method where each square is equal to 6.4 acres was used.* The Mustang Island development, including kinds and coverages of land and water resources affected in 1980 and 1990, is shown in Figure 12 as an example. Major environmental impact is loss of fore-island dunes. The dunes are topographically the highest part of the barrier islands, and destruction of the dunes increases susceptibility of structures on the barrier islands to damage from hurricane washover. Construction of a seawall probably cannot entirely balance loss of the dunes although flooding of proposed development on the 73 acres of existing hurricane washover area probably will be limited.

Loss of other natural environments (tidal flats, active dunes and sand blowouts, and fresh-water marsh) are less consequential. Presumably devegetated active dunes ultimately will be stabilized although the areal extent of blowing sand may increase during construction. The fresh-water marshes are closed and ephemeral, providing only temporary, local biologic productivity.

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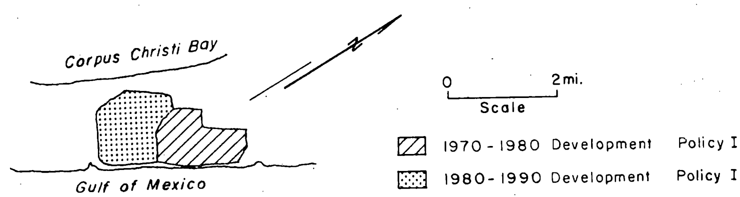
*Because the hypothetical developments were not drawn to scale originally, a correction factor was applied to each square where necessary, to achieve the total site acreage as defined in the report "Example Application II. Evaluation of Hypothetical Management Policies for the Coastal Bend Region."

Figure 12
Locational Effects of a Hypothetical Residential/Recreational
Community on Mustang Island
(For Specific Information on the Development,
See the Discussion of Hypothetical Policy 1 in the Policy Evaluation Report)



Affected Land and Water Resources (acres)

Resource	1970-1980	1980-1990
Fore Island Dunes & Vegetated Barrier Flats (C2)	633	751
Fresh Marsh (D2)	38	88
Active Dunes & Blowouts (C3)	29	0
Tidal Flats (C5)	28	0
Storm Washover (C4)	16	57

Imposition of a no development policy within 1,500 feet of the waterline after 1980 will reduce the extent of the Mustang Island development on the Gulf side of the island. One hundred and fifteen fewer acres of fore-island dunes and vegetation stabilized barrier flats (most dunes) and 12.8 fewer acres of storm washover area will be developed. This should result in improved protection from storms, although Gulfward extensions of storm washover channels will have to be blocked in any case to prevent storm surges from flooding back-island portions of the development.

LOCATIONAL EFFECTS OF INDUSTRIAL EXPANSION

Environmental impact of industrial expansion in the Corpus Christi area by 1980 and 1990 was evaluated for specific firms at specific sites. Although most industrial sectors in the Corpus Christi SMSA are projected to grow during the next 20 years, major industries within sectors 25--chemicals, drugs and related products, 26--petroleum refining and products, and 29--primary metals, foundaries and forgings, as well as announced expansion in other sectors were selected for evaluation. Information regarding selection procedure, the specific industries, and the methods used to determine acreage of expansion at each industrial site are discussed at length in the report, "Example Application II. Evaluation of Hypothetical Management Policies for the Coastal Bend Region."

Industries were located using a Port of Corpus Christi industrial district map (Nueces County Navigation District Number One, 1972) and other maps furnished by the Central Power and Light Company. Vacant areas within the industrial complexes were identified by using the port map and 7-1/2 minute topographic maps. Projected development acreage for 1980 and 1990 was assigned to these vacant areas. Locations for three firms were not available, and they are not included in the environmental impact assessment.)

It was assumed that all plant sites intended for future industrialization had been purchased by 1970; therefore, no agricultural land will be taken out of production by industrial development during the 20-year span. Evaluation of environmental impact of new and expanding industries in the Corpus Christi area is only in terms of the kinds and amounts of land and water resources affected.

Projections of industrial expansion included six different kinds of land use--production facilities, storage tanks, water disposal facilities, parking and streets, railroads, and unused areas. Only the total acreage of areas to be used was considered in the environmental affects of industrial development, however. Specific locations of the various uses within each industrial complex was not known, and allocation of the uses to particular sites would have been entirely arbitrary.

The acreage of each land or water resource affected by industrial development was determined manually using a square count method applied to the maps of Land and Water Resources of the Corpus Christi area (in pocket). Each square of the grid used equals 6.4 acres.

Acreages to be developed within industrial sites containing only one type of resource unit were assigned on a more or less random base. Generally, where several resource units are within the industrial expansion site, impact was assigned on a proportional basis. For example, if 70 percent of the undeveloped area is composed of land resource A-3, 20 percent of A-8, and 10 percent of E-1, then 70 percent of the projected acreage affected A-3, 20 percent A-8, and 10 percent E-1. Table 19 shows the kinds and amounts of each resource unit affected by projected industrial expansion for 1980 and 1990 in the Corpus Christi area. Development of floodplains (B-1, B-2, and B-4) and loss of grassflats (F-8) are the major environmental impacts.

Docking facilities necessary to meet the needs of projected industrial expansion were estimated from information provided by the Nueces County Navigation District. Impact on land resources as a result of dock construction along the inner harbor of the Port of Corpus Christi will be minimal because the primary land resources in this area are made land and subaerial spoil (E-1) and subaqueous spoil (E-2). Placing spoil on top of spoil should present few direct environmental problems.

Docks constructed outside the inner harbor along the north shore of Corpus Christi Bay will affect land resources other than made land and subaerial spoil. The general locations where docks will be constructed were identified by considering the particular shoreline site of the respective industries. It was assumed that the docks would be located immediately bayward of the plant. The exact position of dredging and installation could not be definitely established, however. Likely sites were selected with reference to the location of industrial property lines, the position of La Quinta Channel, and the location of existing docks. The type and quantity of the land and water resources affected by four industries (El Paso Natural Gas Co., Dupont, Reynolds, and Natural Gas Pipeline) located along the north shore of Corpus Christi Bay are shown in Table 20. Major impact is in terms of destruction of grassflats and disturbing mobile bay margin sand and muddy sand.

Table 19
Industrial Expansion

Affected Land Resources	Acres 1970-1980	Acres 1980-1990	Total Acres 1990 Policy I	Total Acres 1990 Policy II	Acreage difference between Policy I and II
A1	186	123	309	187	122
A3	791	497	1288	795	493
A7	309	191	500	309	191
A8	702	629	1332	949	383
A10	38	40	78	38	40
B1	13	6	19	13	6
B2	78	36	114	78	36
B4	50	46	96	50	46
E1	208	43	251	209	41
F8	10	7	17	10	7

Table 20
Locational Effects of New Industrial Docking Facilities
on the North Shore of Corpus Christi Bay

	Land and Water Resources	1980 (acres)	1990 (acres)
F3	Open bays	30.8	15.4
F6	Bay-margin sand and muddy sand	28.8	19.0
F8	Grassflat	8.7	3.7

SUMMARY

A multidisciplinary team consisting of specialists in economics, geography, engineering, biology, environmental health engineering, and geology has been functioning at The University of Texas at Austin since 1971. The purpose of this group has been to develop, apply, and evaluate a methodology for considering environmental and economic effects of alternative Coastal Zone management policies.

The 13 county region encompassed by the Coastal Bend Council of Governments has been the test site for this project; special emphasis has been on more populous, rapidly developing area around Corpus Christi Bay--Nueces, San Patricio, Refugio, and Aransas Counties.

Specific goals of the multidisciplinary team are: (1) to establish operating criteria specific to the Texas Coastal Zone by which to assess the economic and environmental impact of implementing various policies, (2) to develop a systematic approach for this evaluation that allows comparison between impacts of various policies projected to 1980 and 1990, and (3) to integrate and test the methodology by applying it to differing, but hypothetical policies (a) no change from 1970 public policy, (b) no development within 1,500 feet of the waterline after 1980, and (c) improved waste water treatment.

The principal purpose of the Bureau of Economic Geology task force of the multidisciplinary team was to provide an environmental base line against which to measure the consequences of man's activities and future economic development in the Coastal Zone and the effects of potential management policies. This report contains the data base, description of the systematic approach, and examples of the environmental effects of the hypothetical policies. A companion report, Land Resources of the Coastal Bend Region, contains broader descriptions of resource capability in the entire 13 county area.

Land and water areas of Nueces, San Patricio, Aransas, and Refugio Counties have been analyzed in terms of their natural carrying capacity considering (1) geology, soils, and substrate, (2) biology, (3) hydrology, (4) physical properties, (5) chemistry, and (6) natural processes. Forty distinct land and water environments, each with similar carrying capacity or ability to sustain man's use, were delineated.

These units are classified according to their association

together in natural systems, including: (a) coastal plain, (b) active flood plains, (c) barrier islands, (d) wetlands, (e) man-made features, (f) bays, lagoons, estuaries, and open Gulf, and (g) active and potentially active faults. A full-color map of the four-county area including culture, topography, and bathymetry at a scale of 1:125,000 has been prepared and is in the pocket at the back of this report.

Additional analysis of land and water capability in the Corpus Christi area has been in terms of the (1) kinds, rates, and impetus of changes in the dynamic coastal environments, (2) quantitative engineering properties of the major physically defined capability units, and (3) ground water hydrology and its relation to capability and the future development of usable ground water in the area.

An automated data management system was designed to permit storage and retrieval of resource capability and land-use data for the four-county area, and to allow rapid determination of the kinds and amounts of land and water resources and land-use types affected by projected growth in the Corpus Christi area. The automated data management system provided a systematic approach that facilitated direct quantitative comparison between the locational environmental effects of two alternative management policies.

Map data was digitized using grids of points spaced at 250 meters and 500 meters. Output is in terms of the kinds, acreages, and relative percentages of land-use types in each census tract as of 1970 and in each census tract for which changes are projected for 1980 and 1990 under policies 1 and 2; the kinds, acreages, and relative percentages of resource capability units affected by each type of land use are also given. All output is contained in the group policy report. An example, census tract 8, is presented in this report.

Locational environmental impact of industrial expansion and development of special recreational communities on the barrier islands and along the mainland shore between Aransas Pass and Rockport are also considered.

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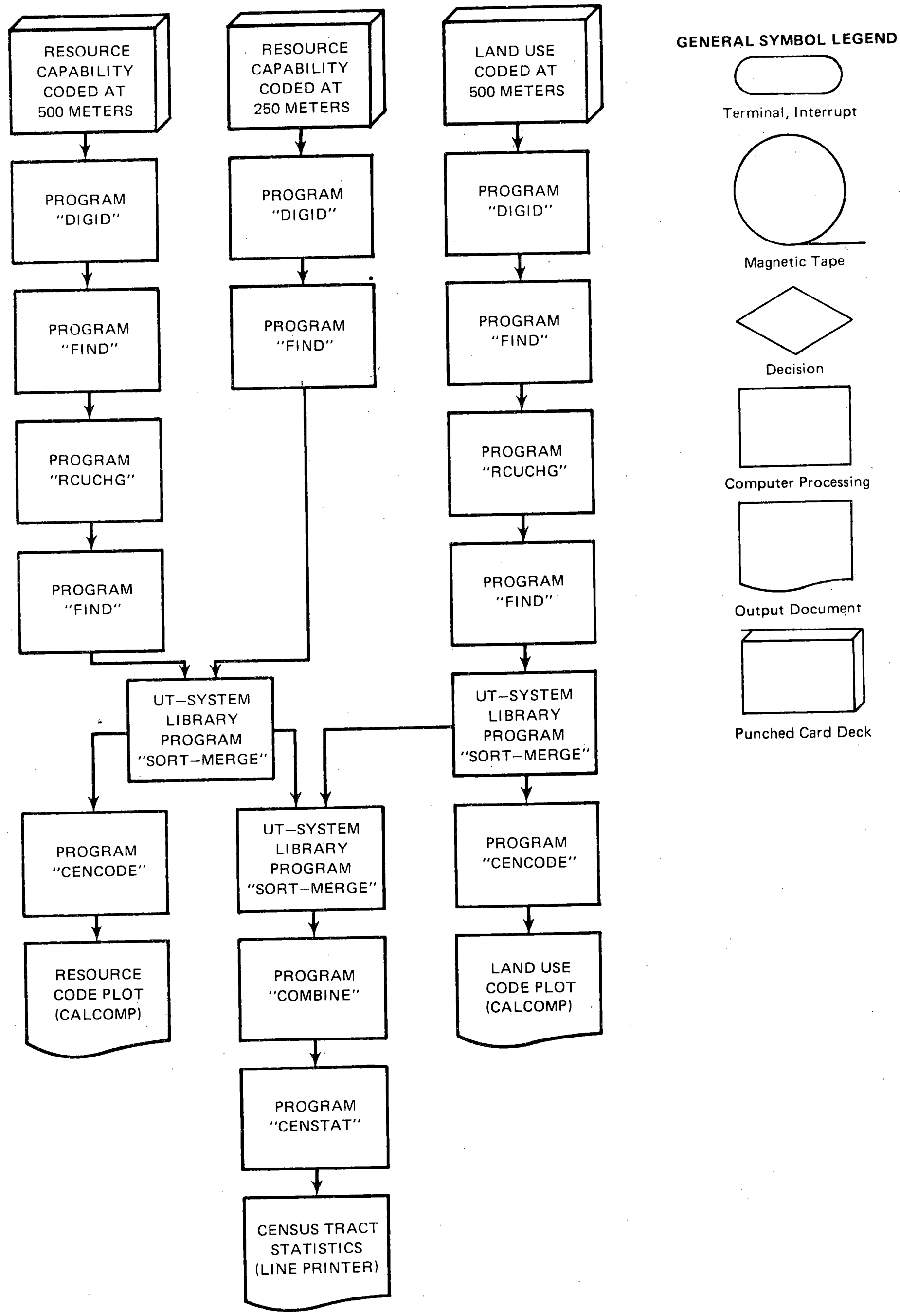
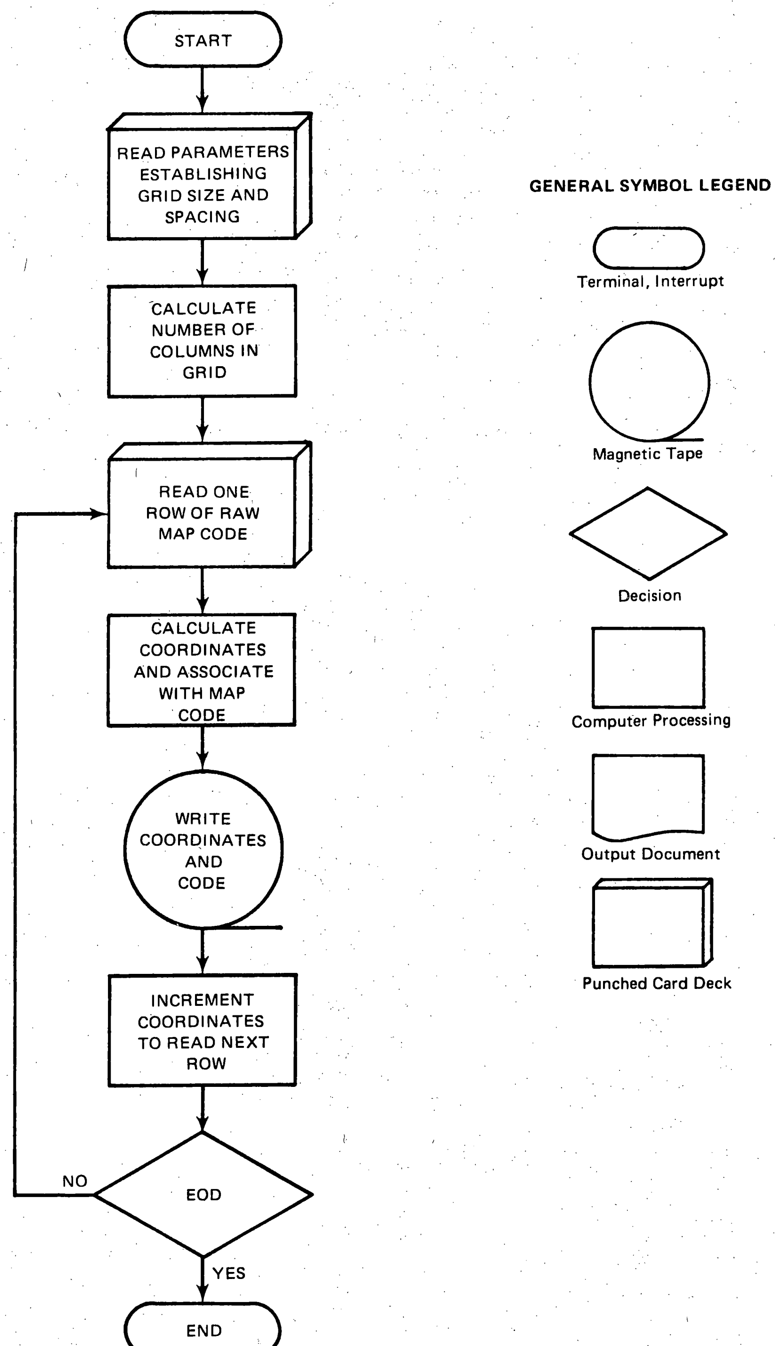
APPENDIX

Figure 13
Data Management System--Computer Programs



Note: Refer to program listings for program functions.

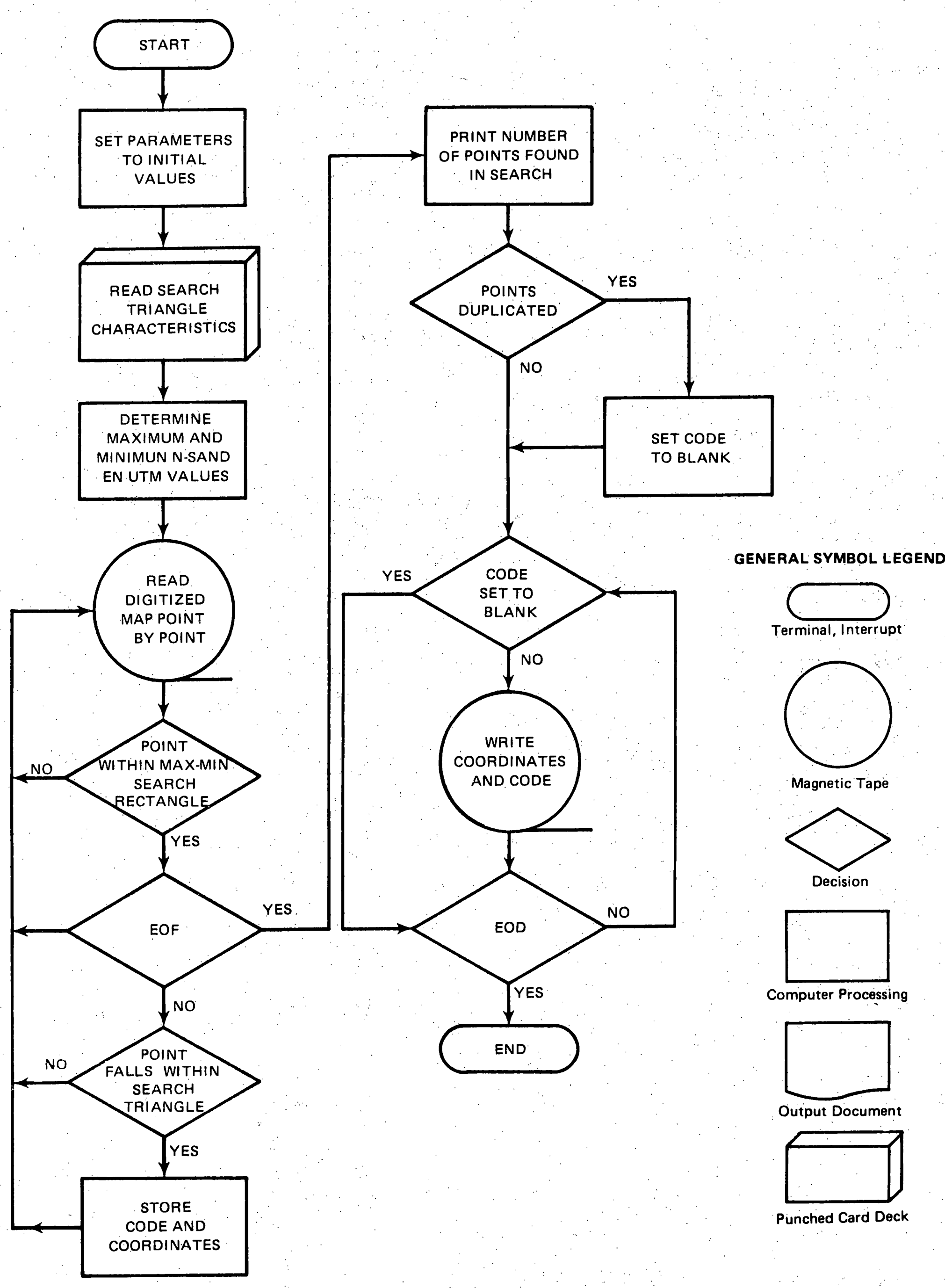
Figure 14
Generalized Flow Chart for Program DIGID



```
         C      ------------------------------------------------------------
                PROGRAM DIGID(INPUT,OUTPUT,TAPE16=OUTPUT)
         C
         C      ------------------------------------------------------------
         C
         C         THIS PROGRAM CONVERTS RAW DIGITIZED MAP CODE INTO DISCREET
         C         IDENTIFIABLE POINTS WHICH MAKE UP THE DIGITIZED MAP DATA BASE.
         C         THIS IS ACCOMPLISHED BY ASSIGNING A N-S AND E-W UTM COORDINATE
         C         TO EACH MAP CODE ON THE INPUT GRID ARRAY.
         C
         C         THIS PROGRAM IS DESIGNED TO BE COMPILED BY CDC FORTRAN RUN
         C         60.2 COMPILER AND TO RUN ON THE UNIVERSITY OF TEXAS AT AUSTIN
         C         CDC 6400/6600 COMPUTER OPERATING UNDER THE UT-2D SYSTEM.
         C         SOME CODE MAY BE UNIQUE TO THE SYSTEM.
         C
         C         TEXAS BUREAU OF ECONOMIC GEOLOGY--DLB--5/31/74.
         C
         C      ------------------------------------------------------------
         C
000002          INTEGER X,Y,UNIT(300),D(3)
000002          INTEGER LOX,LOY,UPX,UPY,COLUMNS,SIZE
         C
         C      SET LIST = 1 FOR A LISTING
         C
000002          LIST=0
         C
         C         READ MAX AND MIN N-S AND E-W UTM COORDINATE
         C
000003          READ 140, LOX,LOY,UPX,UPY
         C
         C         READ GRID SPACING
         C
000017          READ 150, SIZE
000025          COLUMNS=((UPX-LOX)/SIZE)+1
000032          Y=UPY
000034    110   CONTINUE
         C
         C         READ CODE BY ROWS.  ASSIGN COORDINATES TO EACH CODE IN ROW
         C         SKIPPING BLANKS
         C
000034          READ 160, (UNIT(I),I=1,COLUMNS)
000043          X=LOX
000045          DO 130 I=1,COLUMNS
000046             IF (UNIT(I).EQ.3H   ) GO TO 120
000050          D(1)=X
000051          D(2)=Y
000053          D(3)=UNIT(I)
         C
         C         WRITE N-S AND E-W UTM AND POINT CODE
         C
000055          CALL IOP (2HWB,16,D,3)
000060             IF (LIST.EQ.1) PRINT 170, (D(J),J=1,3)
000070    120   CONTINUE
000070          X=X+SIZE
000072    130   CONTINUE
000074          Y=Y-SIZE
000076             IF (Y.GE.LOY) GO TO 110
000100          CALL IOP (2HWF,16)
```

```
            C
000102       140  FORMAT  (2(I5,I6))
000102       150  FORMAT  (I2)
000102       160  FORMAT  (2X,26A3)
000102       170  FORMAT  (1X,I5,1X,I6,1X,A3)
000102            END

PROGRAM LENGTH INCLUDING I/O BUFFERS
004714

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS
110      -  000035   120      -  000071   140      -  000130   150      -  000133
160      -  000135   170      -  000140

BLOCK NAMES AND LENGTHS

VARIABLE ASSIGNMENTS
COLUMNS-    000643   D        -  000634   I        -  000646   J        -  000647
LIST     -  000645   LOX      -  000637   LOY      -  000640   SIZE     -  000644
UNIT     -  000160   UPX      -  000641   UPY      -  000642   X        -  000156
Y        -  000157

START OF CONSTANTS
000105

START OF TEMPORARIES
000144

START OF INDIRECTS
000152

UNUSED COMPILER SPACE
007400
```

Figure 15
Generalized Flow Chart for Program FIND



```
        C      -------------------------------------------------------------
               PROGRAM FIND(INPUT,OUTPUT,TAPE16,TAPE20,TAPE12=INPUT)
        C
        C      -------------------------------------------------------------
        C         THIS PROGRAM SEARCHES A DIGITIZED MAP TO OBTAIN POINTS THAT
        C         ARE LOCATED WITHIN A SPECIFIC SEARCH AREA.  THE SEARCH AREA
        C         IS DESIGNATED BY CREATING NUMEROUS TRIANGLES WHICH APPROXIMATE
        C         THE SEARCH AREA.  INPUT PARAMETERS FOR THE SEARCH AREA ARE
        C         THE COORDINATES OF VERTICES OF THE TRIANGLES AND CODES
        C         DESCRIBING THE SIDES OF THE TRIANGLES BETWEEN THE VERTICES.
        C         OUTPUT IS ALL POINTS OF THE DIGITIZED MAP THAT ARE LOCATED
        C         WITHIN THE ENTIRE SEARCH AREA.
        C
        C         THIS PROGRAM IS DESIGNED TO BE COMPILED BY CDC FORTRAN RUN
        C         60.2 COMPILER AND TO RUN ON THE UNIVERSITY OF TEXAS AT AUSTIN
        C         CDC 6400/6600 COMPUTER OPERATING UNDER THE UT-2D SYSTEM.
        C         SOME CODE MAY BE UNIQUE TO THE SYSTEM.
        C
        C         TEXAS BUREAU OF ECONOMIC GEOLOGY--DLB--5/31/74.
        C
        C      -------------------------------------------------------------
        C
000002         REAL X(11000),Y(11000)
000002         REAL X1(175),X2(175),X3(175),Y1(175),Y2(175),Y3(175)
000002         REAL E1(175),E2(175),E3(175)
000002         INTEGER D(3)
000002         INTEGER UNIT(11000)
000002         INTEGER BLANK
000002         DATA BLANK/3H   /
000002         REAL G,L
000002         DATA G,L/1HG,1HL/
        C
        C         INITIALIZE PARAMETERS
        C
000002         I=0
000003         I1=0
000003         XDMIN=1000000.
000005         XDMAX=0.
000005         YDMIN=1000000.
000006         YDMAX=0.
000007         M=1
        C
000011  110    CONTINUE
        C
        C         READ IN ONE TRIANGLE AT A TIME
        C
000011         READ (12,300) NAME1,NAME2,X1(M),Y1(M),E1(M),X2(M),Y2(M),E2(M),
             1      X3(M),Y3(M),E3(M)
        C
        C         CHECK FOR ZERO DATA INDICATING EOF
        C
000043            IF (X1(M).EQ.0..AND.Y1(M).EQ.0.) GO TO 120
        C
        C         DETERMINE MAX AND MIN X AND Y COORDINATES
        C
000052         XMIN=AMIN1(X1(M),X2(M),X3(M),XDMIN)
000061         XDMIN=XMIN
000061         XMAX=AMAX1(X1(M),X2(M),X3(M),XDMAX)
```

```
000072          XDMAX=XMAX
000072          YMIN=AMIN1(Y1(M),Y2(M),Y3(M),YDMIN)
000103          YDMIN=YMIN
000103          YMAX=AMAX1(Y1(M),Y2(M),Y3(M),YDMAX)
000114          YDMAX=YMAX
000114          M=M+1
          C
          C        CHECK FOR VARIABLE OVERSTORE
          C
000116             IF (M.LE.175) GO TO 110
          C
000120          STOP 5
000122     120  CONTINUE
          C
000122          M=M-1
000124          XMAX=XMAX+10.
000126          XMIN=XMIN-10.
000127          YMIN=YMIN-10.
000130          YMAX=YMAX+10.
          C
000132     130  CONTINUE
          C
          C        READ DIGITIZED MAP-- ONE POINT AT A TIME
          C
000132             IF (IOP(2HRB,16,D,3).NE.0) GO TO 250
          C
          C        CHECK TO SEE IF POINT IS WITHIN AREA DETERMINED BY MAX AND MIN
          C        N-S,E-W COORDINATES--IF WITHIN AREA, BEGIN SEARCHING TRIANGLES;
          C        IF NOT READ ANOTHER POINT
          C
000136          IF
               1       (D(1).LE.XMAX.AND.D(1).GE.XMIN.AND.D(2).LE.YMAX.AND.D(2)
               2       .GE.YMIN) GO TO 140
          C
000162             GO TO 130
          C
000162     140  CONTINUE
          C
          C        TRIANGLE SEARCH-- ONE TRIANGLE AT A TIME;  COMPUTER TIME CAN
          C        BE SAVED HERE IF THE TRIANGLES WITH THE MOST AREA ARE READ
          C        IN FIRST.
          C
000162          DO 240 MM=1,M
000164          IF (X2(MM)-X1(MM).EQ.0.) A=X1(MM)-D(1)
000171          IF (X3(MM)-X2(MM).EQ.0.) B=X2(MM)-D(1)
000176          IF (X1(MM)-X3(MM).EQ.0.) C=X3(MM)-D(1)
000203          IF (X2(MM)-X1(MM).NE.0.) A=(((Y2(MM)-Y1(MM))/(X2(MM)-X1(MM)))*
               1       (D(1)-X1(MM)))+Y1(MM)-D(2)
000217          IF (X3(MM)-X2(MM).NE.0.) B=(((Y3(MM)-Y2(MM))/(X3(MM)-X2(MM)))*
               1       (D(1)-X2(MM)))+Y2(MM)-D(2)
000233          IF (X1(MM)-X3(MM).NE.0.) C=(((Y1(MM)-Y3(MM))/(X1(MM)-X3(MM)))*
               1       (D(1)-X3(MM)))+Y3(MM)-D(2)
000247             IF (E1(MM).EQ.G.AND.E2(MM).EQ.G.AND.E3(MM).EQ.G) GO TO 150
000261             IF (E1(MM).EQ.L.AND.E2(MM).EQ.G.AND.E3(MM).EQ.G) GO TO 160
000274             IF (E1(MM).EQ.G.AND.E2(MM).EQ.L.AND.E3(MM).EQ.G) GO TO 170
000307             IF (E1(MM).EQ.G.AND.E2(MM).EQ.L.AND.E3(MM).EQ.L) GO TO 180
000322             IF (E1(MM).EQ.G.AND.E2(MM).EQ.G.AND.E3(MM).EQ.L) GO TO 190
000336             IF (E1(MM).EQ.L.AND.E2(MM).EQ.L.AND.E3(MM).EQ.L) GO TO 200
```

```
000350              IF (E1(MM).EQ.L.AND.E2(MM).EQ.L.AND.E3(MM).EQ.G) GO TO 210
000364              IF (E1(MM).EQ.L.AND.E2(MM).EQ.G.AND.E3(MM).EQ.L) GO TO 220
          C
000377          STOP 2
          C
000401     150  CONTINUE
000401              IF (A.GE.0..AND.B.GE.0..AND.C.GE.0.) GO TO 230
000414              GO TO 240
000414     160  CONTINUE
000414              IF (A.LE.0..AND.B.GE.0..AND.C.GE.0.) GO TO 230
000427              GO TO 240
000427     170  CONTINUE
000427              IF (A.GE.0..AND.B.LE.0..AND.C.GE.0.) GO TO 230
000442              GO TO 240
000442     180  CONTINUE
000442              IF (A.GE.0..AND.B.LE.0..AND.C.LE.0.) GO TO 230
000455              GO TO 240
000455     190  CONTINUE
000455              IF (A.GE.0..AND.B.GE.0..AND.C.LE.0.) GO TO 230
000470              GO TO 240
000470     200  CONTINUE
000470              IF (A.LE.0..AND.B.LE.0..AND.C.LE.0.) GO TO 230
000503              GO TO 240
000503     210  CONTINUE
000503              IF (A.LE.0..AND.B.LE.0..AND.C.GE.0.) GO TO 230
000516              GO TO 240
000516     220  CONTINUE
000516              IF (A.LE.0..AND.B.GE.0..AND.C.LE.0.) GO TO 230
000531              GO TO 240
          C
          C         POINT WITHIN TRIANGLE FOUND-- STORE DATA
          C
000531     230  CONTINUE
000531          I=I+1
000533          UNIT(I)=D(3)
000535          X(I)=D(1)
000537          Y(I)=D(2)
          C
000541              IF (I.LE.11000) GO TO 130
          C
000542          STOP 3
          C
000544     240  CONTINUE
          C
000547              GO TO 130
          C
000547     250  CONTINUE
          C
          C         CHECK FOR ANOTHER RECORD OF DATA
          C
000547              IF (IOP(2HRR,16).EQ.0) GO TO 130
          C
          C         PRINT NUMBER OF POINTS FOUND IN SEARCH AREA
000552          PRINT 310, NAME1,NAME2
000562          PRINT 320, I
          C
          C         CHECK FOR POINTS SOLVING MORE THAN ONE TRIANGLE
          C
```

```
000570          DO 270 I2=1,I
000572          DO 270 I3=1,I
000573             IF (I3.LF.I2) GO TO 270
000575          IF (X(I2).EQ.X(I3).AND.Y(I2).FQ.Y(I3).AND.UNIT(I2).EQ.UNIT(I3))
               1      GO TO 260
000610             GO TO 270
000610     260  CONTINUE
000610          UNIT(I2)=BLANK
000612          I1=I1+1
000614     270  CONTINUE
000621          I4=I-I1
000622          PRINT 330, I4
          C
          C        WRITE TAPE OF THE COORDINATES AND CODE OF THE POINTS SELECTED
          C
000630          DO 290 N=1,I4
000632             IF (UNIT(I4).EQ.BLANK) GO TO 280
000635          MX=INT(X(N))
000636          MY=INT(Y(N))
000640          CALL IOP (2HWB,20,MX,1)
000643          CALL IOP (2HWB,20,MY,1)
000646          CALL IOP (2HWB,20,UNIT(N),1)
000652     280  CONTINUE
000652     290  CONTINUE
          C
000655          CALL IOP (2HWF,20)
          C
000657     300  FORMAT (2A10,F5,2X,F6,22X,A1,2(/20X,F5,2X,F6,22X,A1))
000657     310  FORMAT (1X,2A10)
000657     320  FORMAT (3X*TOTAL POINTS SELECTED*I5)
000657     330  FORMAT (*    MULTIPLE POINTS REMOVED -- TRUE COUNT *I5//)
000657          END


PROGRAM LENGTH INCLUDING I/O BUFFERS
114706

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS
110    -  000012    120    -  000123    130    -  000133    140    -  000163
150    -  000402    160    -  000415    170    -  000430    180    -  000443
190    -  000456    200    -  000471    210    -  000504    220    -  000517
230    -  000532    240    -  000545    250    -  000550    260    -  000611
270    -  000615    280    -  000653    290    -  000653    300    -  000722
310    -  000730    320    -  000733    330    -  000740

BLOCK NAMES AND LENGTHS

VARIABLE ASSIGNMENTS
A      -  104565    B      -  104566    BLANK  -  104544    C      -  104567
D      -  057151    E1     -  056134    E2     -  056413    E3     -  056672
G      -  104545    I      -  104547    I1     -  104550    I2     -  104570
I3     -  104571    I4     -  104572    L      -  104546    M      -  104555
MM     -  104564    MX     -  104574    MY     -  104575    N      -  104573
NAME1  -  104556    NAME2  -  104557    UNIT   -  057154    X      -  001122
XDMAX  -  104552    XDMIN  -  104551    XMAX   -  104561    XMIN   -  104560
```

X1	-	054102	X2	-	054361	X3	-	054640	Y	-	026512
YDMAX	-	104554	YDMIN	-	104553	YMAX	-	104563	YMIN	-	104562
Y1	-	055117	Y2	-	055376	Y3	-	055655			

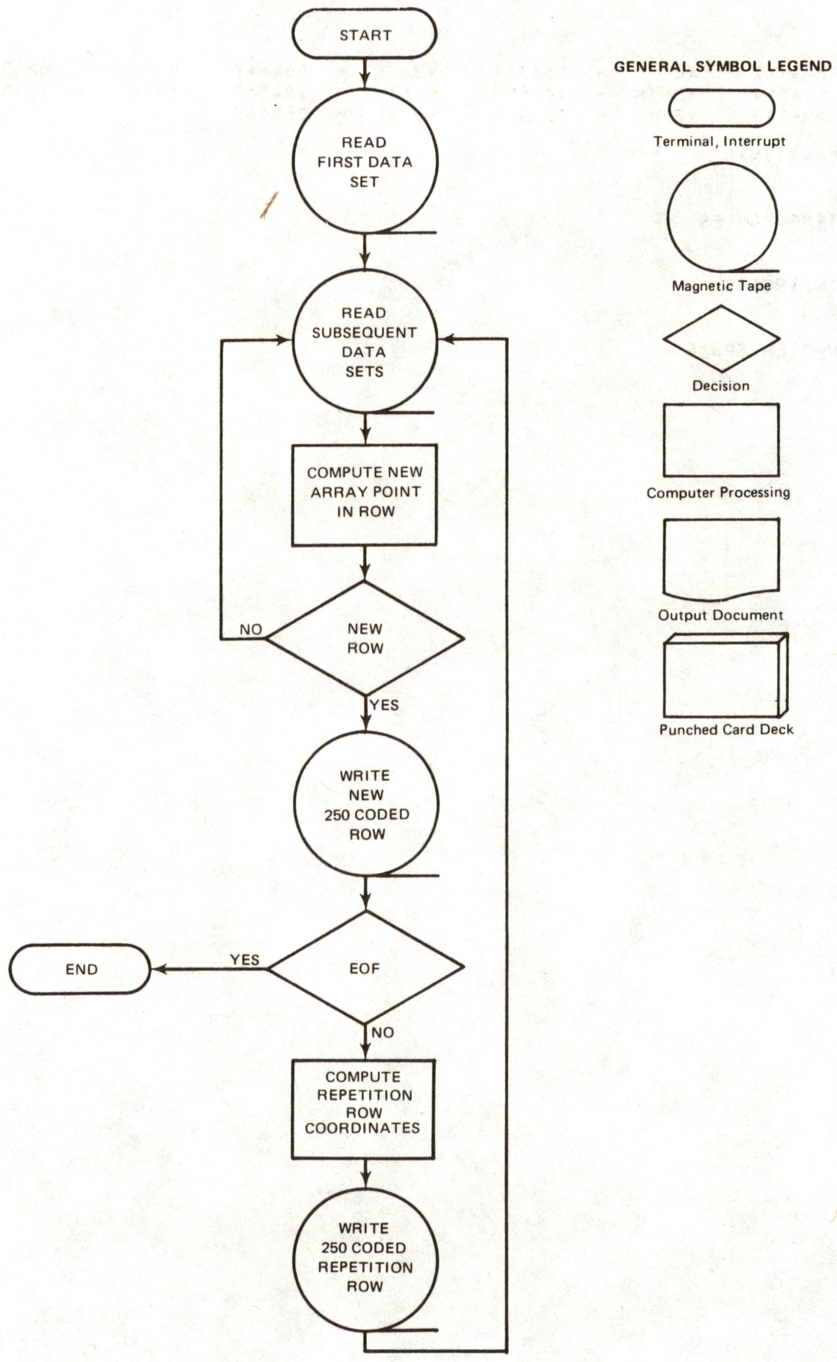
START OF CONSTANTS
000662

START OF TEMPORARIES
000747

START OF INDIRECTS
001037

UNUSED COMPILER SPACE
005000

Figure 16
Generalized Flow Chart for Program RCUCHG

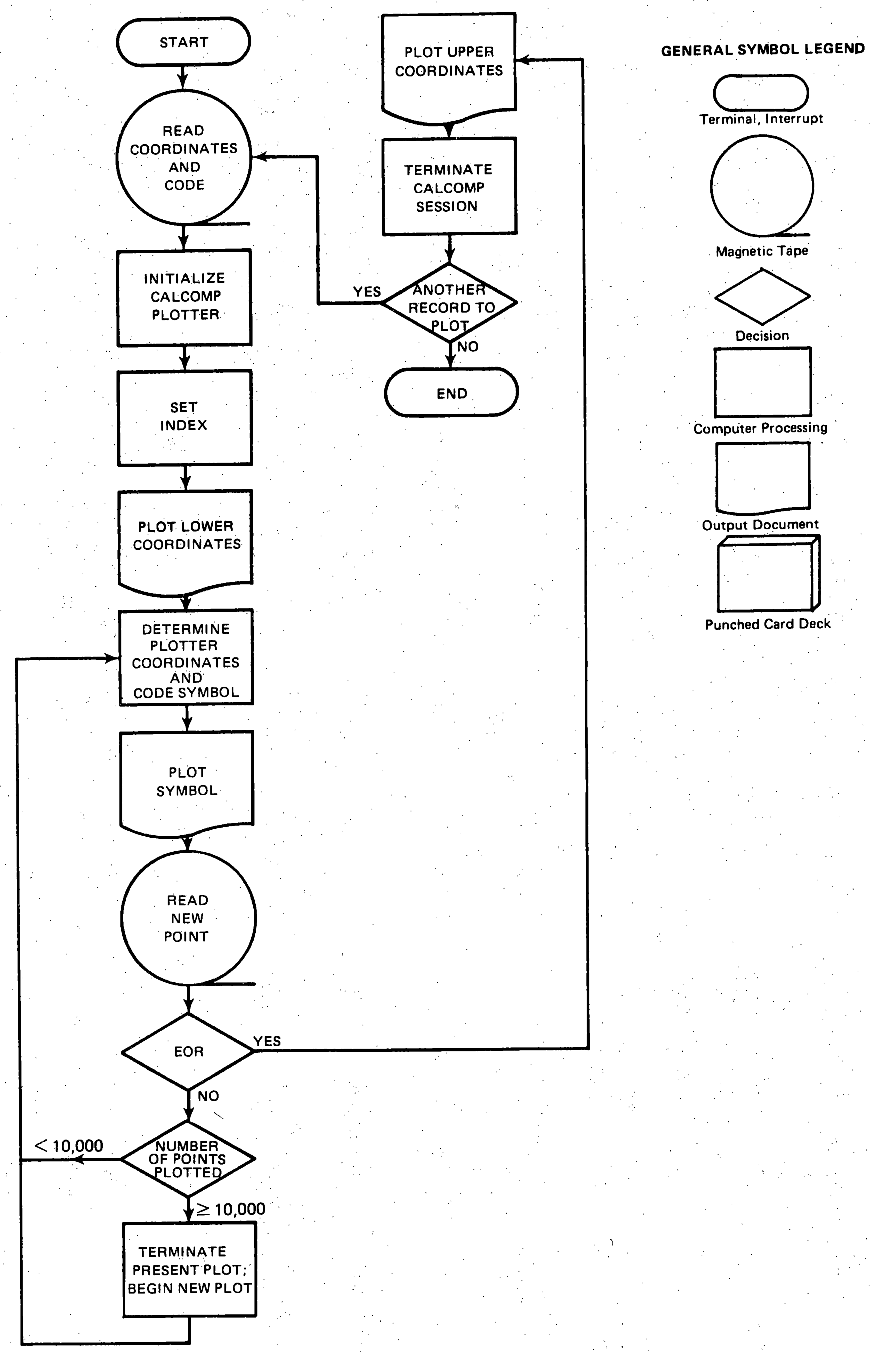


```
             C      ------------------------------------------------------------
                    PROGRAM RCUCHG(INPUT,OUTPUT,TAPE1=INPUT,TAPE2)
             C
             C      ------------------------------------------------------------
             C
             C         THIS PROGRAM CONVERTS THE MAP DIGITIZATION DATA BASE MADE AT
             C         500 METER SPACING TO A DATA BASE MADE ON 250 METER SPACING.
             C         THIS CONVERSION IS MADE BY REPEATING THE 500 CODE 250 METERS
             C         TO THE EAST AND REPEATING A ROW 250 METERS TO THE SOUTH.
             C         NO CONVERSION IS MADE ON THE EXTREME EASTERN COLUMN OR ON THE
             C         SOUTHERNMOST ROW.
             C
             C         THIS PROGRAM IS DESIGNED TO BE COMPILED BY CDC FORTRAN RUN
             C         60.2 COMPILER AND TO RUN ON THE UNIVERSITY OF TEXAS AT AUSTIN
             C         CDC 6400/6600 COMPUTER OPERATING UNDER THE UT-2D SYSTEM.
             C         SOME CODE MAY BE UNIQUE TO THE SYSTEM.
             C
             C
             C         TEXAS BUREAU OF ECONOMIC GEOLOGY--DLB--5/31/74.
             C
             C      ------------------------------------------------------------
             C
000002              INTEGER X(3),Y(3),R(3),IN(3),OUT(3000)
             C
             C      SET LIST = 1 FOR A LISTING
             C
000002              LIST=0
000003                 IF (LIST.EQ.1) PRINT 170
             C
             C         READ FIRST DATA SET -- IF EOF STOP
             C
000010              IF (IOP(2HRB,1,IN,3).NE.0) STOP
000016              X(1)=IN(1)
000017              Y(1)=IN(2)
000021              R(1)=IN(3)
000022              K=1
000024        110   CONTINUE
             C
             C         READ DATA SET
             C
000024              M=IOP(2HRB,1,IN,3)
             C
             C         CHECK FOR EOF
             C
000027                 IF (M) 120,120,130
000031        120   CONTINUE
000031              X(2)=IN(1)
000032              Y(2)=IN(2)
000034              R(2)=IN(3)
000036        130   CONTINUE
             C
             C         CREATE NEW POINT ON 250 SPACING
             C
000036              X(3)=X(1)+25
             C
             C         INTEGRATE NEW POINT INTO OUTPUT ARRAY
             C
000040              OUT(K)=X(1)
```

```
000042          OUT(K+1)=Y(1)
000044          OUT(K+2)=R(1)
000045          OUT(K+3)=X(3)
000047          OUT(K+4)=Y(1)
000050          OUT(K+5)=R(1)
000052          K=K+6
          C
          C        CHECK FOR ARRAY OVERSTORE
          C
000053          IF (K.GT.3000) STOP 1
          C
          C        CHECK FOR LAST CARD FLAG
          C
000057             IF (M.NE.0) GO TO 140
          C
          C        CHECK TO SEE IF NEXT POINT IS ON THE SAME ROW
          C
000060             IF (Y(1).NE.Y(2)) GO TO 140
          C
          C        UPDATE POINTS
          C
000062          X(1)=X(2)
000063          Y(1)=Y(2)
000064          R(1)=R(2)
000066             GO TO 110
000066      140 CONTINUE
          C
          C        DROP EASTERN MOST POINT
          C
000066          K=K-4
000070             IF (LIST.EQ.1) PRINT 190
000075             IF (LIST.EQ.1) PRINT 180, (OUT(N),N=1,K)
000106             IF (LIST.EQ.1) PRINT 200, M,K
          C
          C        WRITE 250 METER CODED ROW
          C
000120          CALL IOP (2HWB,2,OUT,K)
          C
          C        CHECK FOR SOUTHERN MOST ROW
          C
000123             IF (M.NE.0) GO TO 160
000124             IF (LIST.EQ.1) PRINT 190
          C
          C        CHANGE N-S COORDINATES BY 250 METERS FOR REPETITION ROW
          C
000132          DO 150 L=2,K,3
000140          OUT(L)=OUT(L)-25
000141      150 CONTINUE
000142             IF (LIST.EQ.1) PRINT 180, (OUT(N),N=1,K)
          C
          C        WRITE 250 METER CODED REPETITION ROW
          C
000152          CALL IOP (2HWB,2,OUT,K)
          C
          C        RESET COUNTER AND SET UP NEW ROW
          C
000155          K=1
000156          X(1)=X(2)
```

```
000157          Y(1)=Y(2)
000161          R(1)=R(2)
000163             GO TO 110
000163     160  CONTINUE
          C
          C        WRITE EOF
          C
000163          CALL IOP (2HWF,2)
          C
000165     170  FORMAT (1H1)
000165     180  FORMAT (1X,R(I5,1X,I6,1X,A3,1X))
000165     190  FORMAT (1H0)
000165     200  FORMAT (*0 RETURN CODE=*I2* NUMBER OF WORDS=*I4)
000165          END


PROGRAM LENGTH INCLUDING I/O BUFFERS
014251

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS
110    -  000025    120    -  000032    130    -  000037    140    -  000067
160    -  000164    170    -  000222    180    -  000224    190    -  000230
200    -  000232

BLOCK NAMES AND LENGTHS

VARIABLE ASSIGNMENTS
IN     -  000263    K      -  006157    I      -  006162    LIST   -  006156
M      -  006160    N      -  006161    OUT    -  000266    R      -  000260
X      -  000252    Y      -  000255

START OF CONSTANTS
000170

START OF TEMPORARIES
000240

START OF INDIRECTS
000244

UNUSED COMPILER SPACE
006600
```

Figure 17
Generalized Flow Chart for Program CENCODE



```
      C     ------------------------------------------------------------
            PROGRAM CENCODE(INPUT,OUTPUT,TAPE20=INPUT)
      C
      C     ------------------------------------------------------------
      C
      C        THIS PROGRAM PLOTS DIGITIZATION CODE ON THE CALCOMP PLOTTER AT
      C        A SCALE OF 1:125000, USING SPECIAL SYMBOLS FOR RCU CODE AND
      C        LETTERS FOR LU CODE.
      C
      C        THIS PROGRAM IS DESIGNED TO BE COMPILED BY CDC FORTRAN RUN
      C        60.2 COMPILER AND TO RUN ON THE UNIVERSITY OF TEXAS AT AUSTIN
      C        CDC 6400/6600 COMPUTER OPERATING UNDER THE UT-2D SYSTEM.
      C        SOME CODE MAY BE UNIQUE TO THE SYSTEM.
      C
      C
      C        TEXAS BUREAU OF ECONOMIC GEOLOGY--DLB--5/31/74.
      C
      C     ------------------------------------------------------------
      C
000002      INTEGER DUM(3),CODE(47),C
      C
000002      DATA CODE/2HA1,2HA2,2HA3,2HA4,2HA5,2HA6,2HA7,2HA8,2HA9,3HA10,
           1     3HA11,3HA12,3HA13,2HB1,2HB2,2HB3,2HB4,2HC1,2HC2,2HC3,
           2     2HC4,2HC5,2HD1,2HD2,2HD3,2HE1,2HE2,2HF1,2HF2,2HF3,2HF4,
           3     2HF5,2HF6,2HF7,2HF8,2HF9,3HF10,3HF11,1HG,2HI1,2HI2,2HNP,
           4     1HR,2HSP,1HU,1HW,1HX/
      C
000002  110 CONTINUE
      C
      C        INITIAL BINARY DATA READ--IF EOF ENCOUNTERED ABORT
      C
000002      IF (IOP(2HRB,20,DUM,3).NE.0) STOP 1
      C
      C        INITIALIZE CALCOMP FOR 12-INCH BALLPOINT PLOT
      C
000010      CALL BGNPLT (4LPLOT,100.,100,10)
000013      CALL PLT (16.,0.5,-3)
      C
      C        INITIALIZE INDEX AND PAGE WIDTH
      C
000016      K=0
000017      YSET=0.
000017      Y=DUM(1)
000021      X=DUM(2)
      C
      C     PLOT LOWER COORDINATES
      C
000023      CALL NUMBER (-2.,0.,.14,X,0.,-1)
000027      CALL NUMBER (-1.,0.,.14,Y,0.,-1)
      C
000033         GO TO 140
      C
000034  120 CONTINUE
      C
      C        INCREMENT NUMBER OF POINTS PLOTTED INDEX
000034      K=K+1
      C
      C        READ NEW DATA POINT
```

```
       C
000036           IF (IOP(2HRB,20,DUM,3).NE.0) GO TO 190
       C
       C         CHECK FOR SYSTEM DEPENDENT PLOTTER TIME ALLOTMENT
       C
000042           IF (K.GE.10000) GO TO 130
       C
000045           GO TO 140
       C
000045   130   CONTINUE
       C
       C         REINITIALIZE CALCOMP FOR NEW PLOT
       C
000045         CALL ENDPLT
000046         CALL BGNPLT (4LPLOT,100.,100,10)
000051         CALL PLT (16.,0.5,-3)
000054         YSET=YMAX
000055         K=0
       C
000056   140   CONTINUE
       C
       C         SET SYMBOL CODES TO INITIAL CONDITIONS
       C
000056         C=0
000057         H=-.06
       C
       C         CALCULATE PLOTTER COORDINATES
       C
000060         XPAGE=(DUM(2)-X)/317.500635
000064         YPAGE=(DUM(1)-Y)/317.500635
       C
       C         DETERMINE MAXIMUM WIDTH OF PLOTTER CORDINATES
       C
000067         YMAX=AMAX1(YPAGE,YMAX)
000072         YPAGE=YPAGE-YSET
       C
       C         CHECK FOR Y-PLOTTER GREATER THAN 10.4 INCHES
000073           IF (ABS(YPAGE).GT.10.4) GO TO 130
       C
       C         DETERMINE PLOTTING SYMBOL FOR CODE
       C
000077         DO 150 I=1,47
       C
000103           IF (DUM(3).EQ.CODE(I)) GO TO 160
       C
000105   150   CONTINUE
       C
       C         EXTRANEOUS CODE ERROR MESSAGE
       C
000107         PRINT 200, DUM
       C
000114           GO TO 120
       C
000115   160   CONTINUE
       C
000115           IF (I.LE.38) GO TO 170
       C
000120         H=-1.*H
```

```
000121          IF (I.EQ.39) C=23
000124          IF (I.EQ.40) C=44
000127          IF (I.EQ.41) C=45
000132          IF (I.EQ.42) C=30
000135          IF (I.EQ.43) C=34
000140          IF (I.EQ.44) C=35
000143          IF (I.EQ.45) C=37
000146          IF (I.EQ.46) C=39
000151          IF (I.EQ.47) C=40
          C
000154             GO TO 180
          C
000155      170 CONTINUE
          C
000155          IF (I.GT.12) C=C+3
000161          IF (I.GT.21) C=C+2
000165          IF (I.GT.22) C=C+1
000171          IF (I.GT.33) C=C+1
000175          IF (I.GT.35) C=C+4
000201          C=C+I
          C
000202      180 CONTINUE
          C
          C     PLOT CODE
          C
000202          CALL SYMBOL (XPAGE,YPAGE,H,C,0.,-1)
000206          B=DUM(1)
000207          A=DUM(2)
          C
000211             GO TO 120
          C
000212      190 CONTINUE
          C
000212          XPAGE=XPAGE+1.
          C
          C     PLOT UPPER COORDINATES
          C
000214          CALL NUMBER (XPAGE,YPAGE,.14,A,0,-1)
000220          XPAGE=XPAGE+1.
000222          CALL NUMBER (XPAGE,YPAGE,.14,B,0,-1)
          C
000226          CALL ENDPLT
          C
          C        CHECK FOR ANOTHER RECORD TO BE PLOTTED
          C
000227             IF (IOP(2HRR,20).EQ.0) GO TO 110
          C
000232      200 FORMAT (* ++++++++CODING ERROR+++++++++/*0*2I10,5X,A5)
000232          END

PROGRAM LENGTH INCLUDING I/O BUFFERS
004474

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS
```

110	-	000003	120	-	000035	130	-	000046	140	-	000057
150	-	000106	160	-	000116	170	-	000156	180	-	000203
190	-	000213	200	-	000307						

BLOCK NAMES AND LENGTHS

VARIABLE ASSIGNMENTS

A	-	000427	B	-	000426	C	-	000414	CODE	-	000335
DUM	-	000332	H	-	000422	I	-	000425	K	-	000415
X	-	000420	XPAGE	-	000423	Y	-	000417	YMAX	-	000421
YPAGE	-	000424	YSET	-	000416						

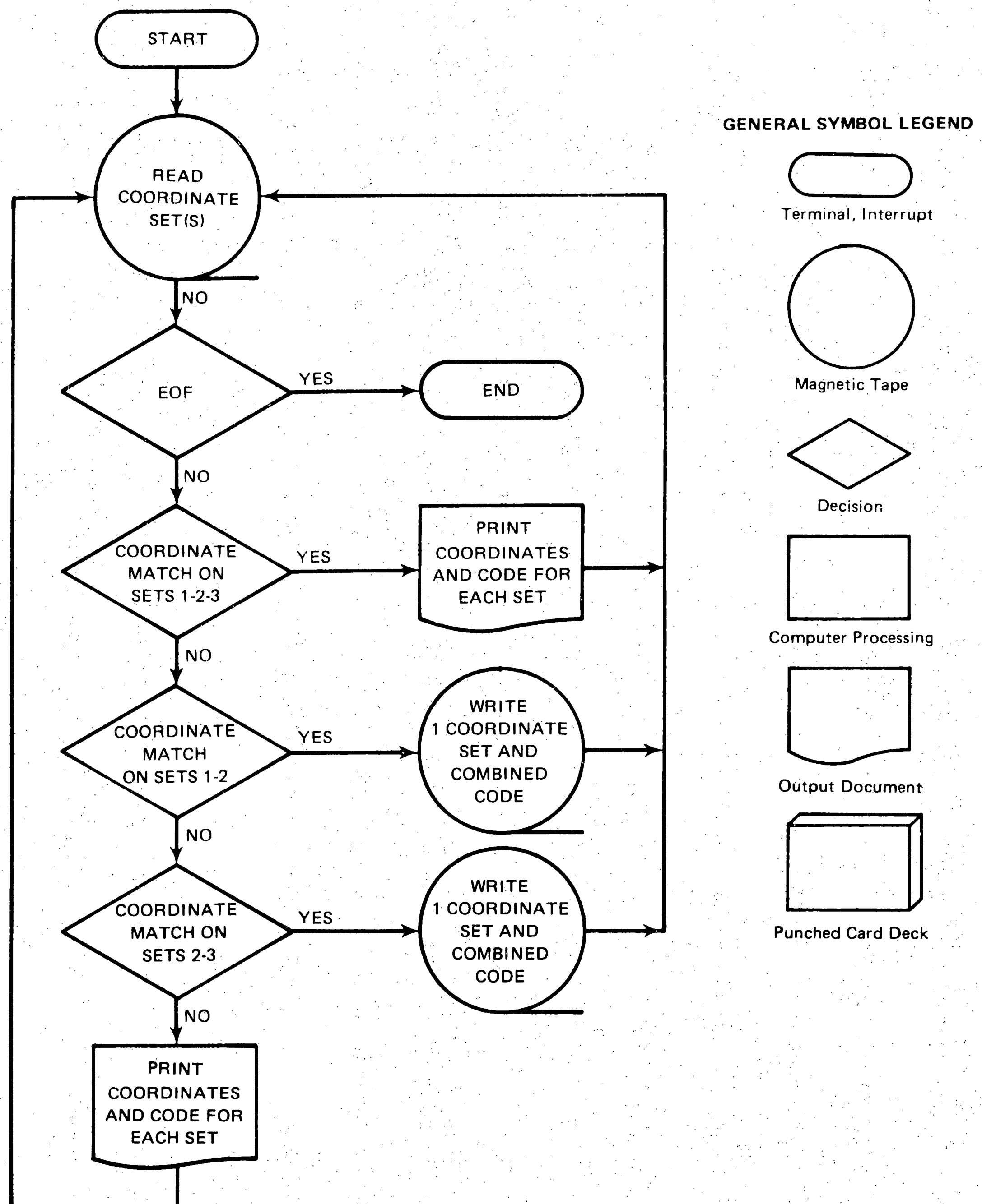
START OF CONSTANTS
000235

START OF TEMPORARIES
000315

START OF INDIRECTS
000327

UNUSED COMPILER SPACE
006300

Figure 18
Generalized Flow Chart for Program COMBINE



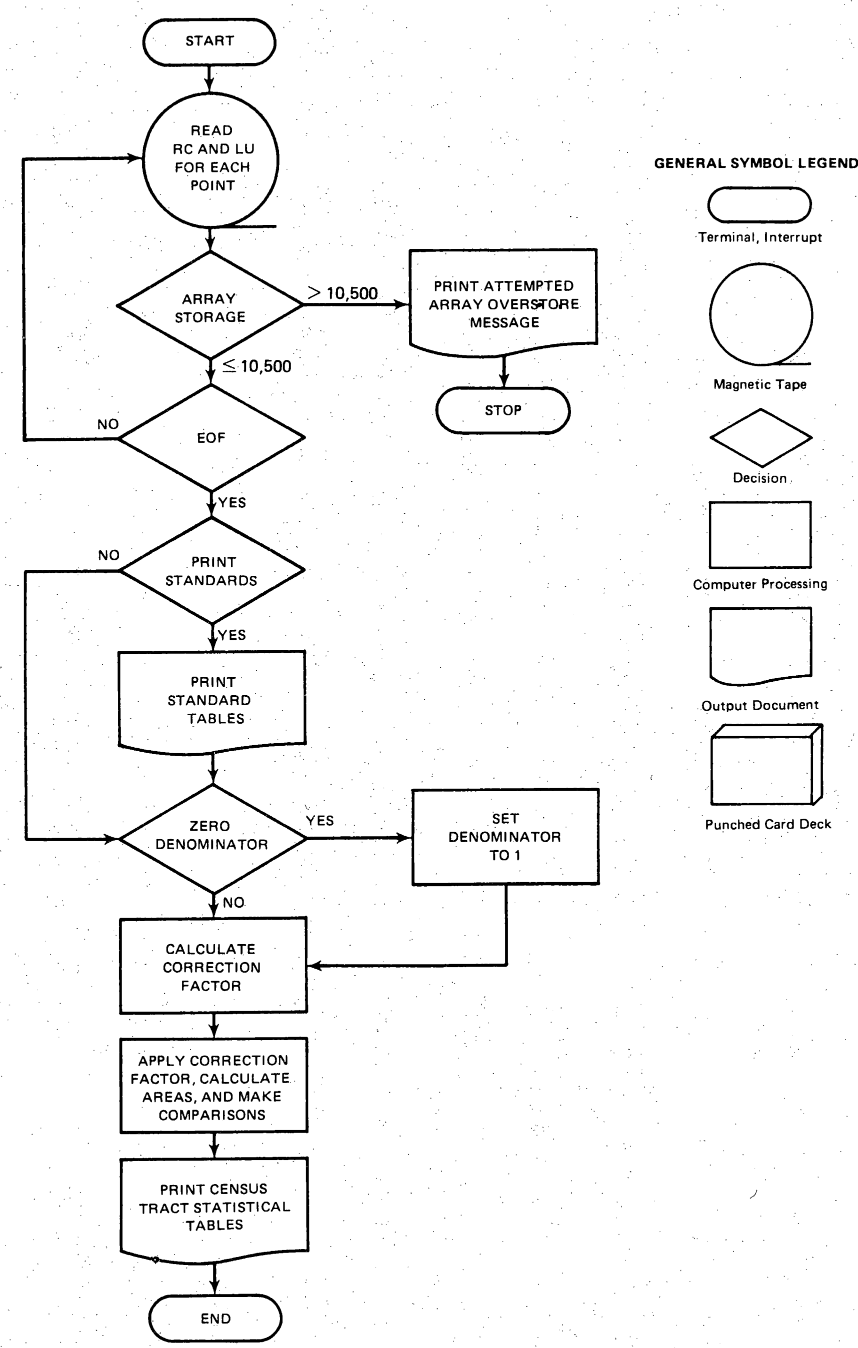
```
C      ----------------------------------------------------------------
            PROGRAM COMBINE(INPUT,OUTPUT,TAPE1,TAPE5=INPUT)
C
C      ----------------------------------------------------------------
C
C         THIS PROGRAM COMBINES THE LAND USE AND THE RESOURCE CAPABILITY
C         DATA BASES.  WHEN COORDINATES OF THE TWO BASES MATCH THE CODES
C         ARE COMBINED.  WHEN NO MATCH OCCURS AN UNMATCHED LIST IS
C         COMPILED FOR MANUAL CORRECTION.
C
C         THIS PROGRAM IS DESIGNED TO BE COMPILED BY CDC FORTRAN RUN
C         60.2 COMPILER AND TO RUN ON THE UNIVERSITY OF TEXAS AT AUSTIN
C         CDC 6400/6600 COMPUTER OPERATING UNDER THE UT-2D SYSTEM.
C         SOME CODE MAY BE UNIQUE TO THE SYSTEM.
C
C         TEXAS BUREAU OF ECONOMIC GEOLOGY--DLR--5/31/74.
C
C      ----------------------------------------------------------------
C
000002      INTEGER DUM(3),CODE(3)
000002      REAL X(3),Y(3)
000002      IFLAG=0
C
C         READ FIRST COORDINATE SET
C
000003      IF (IOP(2HRB,2,DUM,3).GT.0) GO TO 180
000011      X(1)=FLOAT(DUM(1))
000012      Y(1)=FLOAT(DUM(2))
000013      CODE(1)=DUM(3)
C
000015  110 CONTINUE
C
C         READ NEXT COORDINATE SET
C
000015      IF (IOP(2HRB,2,DUM,3).GT.0) GO TO 180
000023      X(2)=FLOAT(DUM(1))
000024      Y(2)=FLOAT(DUM(2))
000025      CODE(2)=DUM(3)
C
C         READ NEXT COORDINATE SET
C
000027      IF (IOP(2HRB,2,DUM,3).GT.0) GO TO 120
000035      X(3)=FLOAT(DUM(1))
000036      Y(3)=FLOAT(DUM(2))
000037      CODE(3)=DUM(3)
C
C         CHECK FOR COORDINATE SETS 1-2-3 MATCH
C
000041      IF
           1      (X(1).EQ.X(2).AND.X(2).EQ.X(3).AND.Y(1).EQ.Y(2).AND.Y(2)
           2      .EQ.Y(3)) GO TO 140
C
000061         GO TO 130
C
000061  120 CONTINUE
C
000061      IFLAG=1
C
```

```
000062    130  CONTINUE
          C
          C       CHECK FOR COORDINATE SET 1-2 MATCH
          C
000062            IF (X(1).EQ.X(2).AND.Y(1).EQ.Y(2)) GO TO 150
000072            IF (IFLAG.EQ.1) GO TO 170
          C
          C       CHECK FOR COORDINATE SET 2-3 MATCH
          C
000074            IF (X(2).EQ.X(3).AND.Y(2).EQ.Y(3)) GO TO 160
          C
          C       PRINT UNMATCHED SET 1
          C
000103         PRINT 200, X(1),Y(1),CODE(1)
000114         X(1)=X(3)
000115         Y(1)=Y(3)
000117         CODE(1)=CODE(3)
          C
000121            GO TO 110
          C
          C       PRINT UNMATCHED SETS 1,2,3
          C
000121    140  CONTINUE
000121         PRINT 200, (X(I),Y(I),CODE(I),I=1,3)
000137            IF (IOP(2HRB,2,DUM,3).GT.0) GO TO 180
000145         X(1)=FLOAT(DUM(1))
000146         Y(1)=FLOAT(DUM(2))
000147         CODE(1)=DUM(3)
          C
000151            GO TO 110
          C
000152    150  CONTINUE
          C
          C       COMBINE CODE ON MATCHED SET 1-2
          C
000152         ENCODE (6,190,WORD) CODE(1),CODE(2)
          C
          C       WRITE SET
          C
000164         WRITE (1,200) X(1),Y(1),WORD
000176         X(1)=X(3)
000177         Y(1)=Y(3)
000201         CODE(1)=CODE(3)
          C
000203            GO TO 110
          C
000203    160  CONTINUE
          C
          C       PRINT UNMATCHED CODE SET 1
          C
000203         PRINT 200, X(1),Y(1),CODE(1)
          C
          C       COMBINE CODE ON MATCHED SET 2-3
          C
000215         ENCODE (6,190,WORD) CODE(2),CODE(3)
000227         WRITE (1,200) X(2),Y(2),WORD
000241            IF (IOP(2HRB,2,DUM,3).GT.0) GO TO 180
000247         X(1)=FLOAT(DUM(1))
```

```
000250            Y(1)=FLOAT(DUM(2))
000251            CODE(1)=DUM(3)
           C
000253               GO TO 110
           C
000254       170  CONTINUE
           C
           C         PRINT UNMATCHED END AND SET 1-2
000254            PRINT 200, (X(I),Y(I),CODE(I),I=1,2)
           C
000272       180  CONTINUE
           C
000272       190  FORMAT (A3,A3)
000272       200  FORMAT (1X,F5,F7,1X,A6)
000272            END
```

```
PROGRAM LENGTH INCLUDING I/O BUFFERS
006457

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS
110     -  000016    120     -  000062    130     -  000063    140     -  000122
150     -  000153    160     -  000204    170     -  000255    180     -  000273
190     -  000323    200     -  000325

BLOCK NAMES AND LENGTHS

VARIABLE ASSIGNMENTS
CODE    -  000355    DUM     -  000352    I       -  000367    IFLAG   -  000366
WORD    -  000370    X       -  000360    Y       -  000363

START OF CONSTANTS
000275

START OF TEMPORARIES
000330

START OF INDIRECTS
000352

UNUSED COMPILER SPACE
006500
```

Figure 19
Generalized Flow Chart for Program CENSTAT



```
        C      -----------------------------------------------------------------
               PROGRAM CENSTAT(INPUT,OUTPUT,TAPE11=INPUT,TAPE10)
        C
        C      -----------------------------------------------------------------
        C
        C         THIS PROGRAM COMPUTES THE AREAS OF EACH RESOURCE CAPABILITY
        C         UNIT AND EACH LAND USE FROM THE DATA SELECTED FOR CENSUS TRACT
        C         BY PREVIOUS PROGRAMS.  THE AREAS ARE COMPARED TO STANDARDS
        C         GENERATED BY OTHER PROGRAMS AND THESE COMPARISONS ARE
        C         PRESENTED IN TABULAR FORM.
        C
        C         THIS PROGRAM IS DESIGNED TO BE COMPILED BY CDC FORTRAN RUN
        C         60.2 COMPILER AND TO RUN ON THE UNIVERSITY OF TEXAS AT AUSTIN
        C         CDC 6400/6600 COMPUTER OPERATING UNDER THE UT-2D SYSTEM.
        C         SOME CODE MAY BE UNIQUE TO THE SYSTEM.
        C
        C         TEXAS BUREAU OF ECONOMIC GEOLOGY--DLB--5/31/74.
        C
        C      -----------------------------------------------------------------
        C
000002         REAL CTNAME(2),RCODE(10500),LCODE(10500),AREA(9,38)
000002         REAL PERCTLU(9),PERCOLU(9),PERSMLU(9),PERRGLU(9)
000002         REAL PTLUCO(9),PTLUSM(9),PTLURG(9)
000002         REAL PERCULU(9,38),PERTRCT(9,38),PERTRCO(9,38),PERTRSM(9,38)
000002         REAL PERTRRG(9,38),RCUAREA(38),LU(9),RCU(38),LCAREA(9)
000002         REAL LSMSA(9),RSMSA(38),LCOUNTY(2,9),RCOUNTY(2,38)
000002         REAL LREGION(9),RREGION(38)
000002         REAL CAREA(9,38),USE(9)
000002         REAL CTAREA,COAREA(2),SMSAREA,REGAREA,YEAR
000002         INTEGER PCODE
000002         DATA RCU/2HA1,2HA2,2HA3,2HA4,2HA5,2HA6,2HA7,2HA8,2HA9,3HA10,3HA11,
              1      3HA12,3HA13,2HB1,2HB2,2HB3,2HB4,2HC1,2HC2,2HC3,2HC4,
              2      2HC5,2HD1,2HD2,2HD3,2HE1,2HE2,2HF1,2HF2,2HF3,2HF4,2HF5,
              3      2HF6,2HF7,2HF8,2HF9,3HF10,3HF11/
000002         DATA LU/1HR,1HG,1HU,1HW,2HI1,2HI2,2HSP,2HNP,1HX/
000002         DATA USE/10HRANGELAND ,10H CROPLAND ,10H URBAN     ,10HUNASSIGNED,
              1      10HG.W.IRRIG.,10HS.W.IRRIG.,10HSTATE PARK,10HNATL. PARK,
              2      10HINDUS.PARK/
000002         DATA COAREA/444865.,721729./
        C
        C         SET PARAMETERS
        C
000002         N=0
000003         TOTAL=0.
000003         SMSAREA=1163742.
000005         REGAREA=2011542.
        C
        C         READ DATA HEADER CARD-- CENSUS TRACT NUMBER, AREA IN ACRES,
        C         LAND USE YEAR, COUNTY CODE, STANDARDS PRINT CODE.
        C
000007         READ (11,290) (CTNAME(I),I=1,2),CTAREA,YEAR,M,PCODE
        C
        C         READ RESOURCE AND LAND USE CODES
        C
000024     110 CONTINUE
        C
000024         N=N+1
000026         READ (11,300) RCODE(N),LCODE(N)
```

```
        C
        C        STORAGE LIMIT CHECK
        C
000035           IF (N.GT.10500) GO TO 120
000041           IF (EOF,11) 130,110
        C
000043   120  CONTINUE
        C
000043        PRINT 310, N
        C
000051        STOP
        C
000053   130  CONTINUE
        C
        C        READ IN STANDARDS FOR COMPUTATION
        C
000053        READ (10,320) (LSMSA(I),I=1,9)
000061        READ (10,320) (RSMSA(I),I=1,38)
000067        READ (10,320) ((LCOUNTY(I,J),J=1,9),I=1,2)
000105        READ (10,320) ((RCOUNTY(I,J),J=1,38),I=1,2)
000123        READ (10,320) (LREGION(I),I=1,9)
000131        READ (10,320) (RREGION(I),I=1,38)
000137           IF (PCODE.EQ.0) GO TO 140
        C
        C        PRINT STANDARDS
        C
000140        PRINT 330
000144        PRINT 340
000150        PRINT 350, (USE(I),LSMSA(I),I=1,9)
000164        PRINT 360
000170        PRINT 370, (RCU(I),RSMSA(I),I=1,38)
000204        PRINT 380
000210        PRINT 350, (USE(I),LCOUNTY(1,I),I=1,9)
000225        PRINT 390
000231        PRINT 350, (USE(I),LCOUNTY(2,I),I=1,9)
000246        PRINT 400
000252        PRINT 370, (RCU(I),RCOUNTY(1,I),I=1,38)
000267        PRINT 410
000273        PRINT 370, (RCU(I),RCOUNTY(2,I),I=1,38)
000310        PRINT 420
000314        PRINT 350, (USE(I),LREGION(I),I=1,9)
000330        PRINT 430
000334        PRINT 370, (RCU(I),RREGION(I),I=1,38)
        C
000350   140  CONTINUE
        C
        C        COMPUTE LU AREAS, RCU AFFECTED BY EACH LU.
        C        CORRECT AREAS TO INPUTTED C.T. AREA, AND COMPARE CORRECTED
        C        AREAS TO STANDARDS.
        C
000350        ZEROSET=1.
000352        DO 160 I=1,9
000354        IF (LSMSA(I).EQ.0.) LSMSA(I)=ZEROSET
000356        IF (LREGION(I).EQ.0.) LREGION(I)=ZEROSET
000360        DO 150 J=1,2
000362        IF (LCOUNTY(J,I).EQ.0.) LCOUNTY(J,I)=ZEROSET
000367   150  CONTINUE
        C
```

```
000372     160  CONTINUE
           C
000374          DO 180 I=1,38
000377          IF (RSMSA(I).EQ.0.) RSMSA(I)=ZEROSET
000401          IF (RREGION(I).EQ.0.) RREGION(I)=ZEROSET
000403          DO 170 J=1,2
000405          IF (RCOUNTY(J,I).EQ.0.) RCOUNTY(J,I)=ZEROSET
000412     170  CONTINUE
           C
000415     180  CONTINUE
           C
000417          DO 210 K=1,9
000421          DO 210 I=1,N
000422             IF (LCODE(I).NE.LU(K)) GO TO 210
000425          DO 190 J=1,38
000426             IF (RCODE(I).NE.RCU(J)) GO TO 190
000433          AREA(K,J)=AREA(K,J)+15.44375
000435          RCUAREA(J)=RCUAREA(J)+15.44375
000436             GO TO 200
           C
000437     190  CONTINUE
           C
000441     200  CONTINUE
000441          TOTAL=TOTAL+15.44375
           C
000443     210  CONTINUE
           C
000450          DO 220 J=1,38
000451          IF (RCUAREA(J).EQ.0.) RCUAREA(J)=ZEROSET
           C
000454     220  CONTINUE
           C
000457          CFACTOR=CTAREA/TOTAL
000461          DO 250 K=1,9
000463          DO 230 J=1,38
000472          CAREA(K,J)=CFACTOR*AREA(K,J)
000473          LCAREA(K)=LCAREA(K)+CAREA(K,J)
           C
000474     230  CONTINUE
           C
000500          PERCTLU(K)=LCAREA(K)/CTAREA*100.
000503          PERCOLU(K)=LCAREA(K)/COAREA(M)*100.
000505          PERSMLU(K)=LCAREA(K)/SMSAREA*100.
000507          PERRGLU(K)=LCAREA(K)/REGAREA*100.
000511          PTLUCO(K)=LCAREA(K)/LCOUNTY(M,K)*100.
000513          PTLUSM(K)=LCAREA(K)/LSMSA(K)*100.
000515          PTLURG(K)=LCAREA(K)/LREGION(K)*100.
000517          IF (LCAREA(K).EQ.0.) LCAREA(K)=ZEROSET
000522          DO 240 J=1,38
000537          PERCULU(K,J)=CAREA(K,J)/LCAREA(K)*100.
000541          PERTRCT(K,J)=CAREA(K,J)/(RCUAREA(J)*CFACTOR)*100.
000544          PERTRCO(K,J)=CAREA(K,J)/RCOUNTY(M,J)*100.
000546          PERTRSM(K,J)=CAREA(K,J)/RSMSA(J)*100.
000550          PERTRRG(K,J)=CAREA(K,J)/RREGION(J)*100.
           C
000551     240  CONTINUE
           C
000553     250  CONTINUE
```

```
          C
          C        PRINT TABLE FOR EACH LAND USE IN CENSUS TRACT
          C
000555          DO 280 K=1,9
000557             IF (LCAREA(K).LE.1.) GO TO 280
000562          PRINT 440, (CTNAME(I),I=1,2)
000567          PRINT 450, YEAR
000575          PRINT 460, USE(K)
000603          PRINT 470
000607          PRINT 480, LCAREA(K),PERCTLU(K),PERCOLU(K),PERSMLU(K),PERRGLU(K),
               1        PTLUCO(K),PTLUSM(K),PTLURG(K)
000633          PRINT 490
000637          PRINT 500
000643          PRINT 510
000647          PRINT 520
000653          DO 270 J=1,38
000655             IF (CAREA(K,J).EQ.0.) GO TO 260
000660          PRINT 530, RCU(J),CAREA(K,J),PERCULU(K,J),PERTRCT(K,J),PERTRCO(K,
               1       J),PERTRSM(K,J),PERTRRG(K,J)
          C
000715      260 CONTINUE
          C
000715      270 CONTINUE
          C
000717          PRINT 540, CFACTOR,CTAREA
000727          PRINT 550
          C
000733      280 CONTINUE
          C
000735      290 FORMAT (2A10,F6,F4,2I1)
000735      300 FORMAT (14X,A3,A2)
000735      310 FORMAT (* STORAGE LIMIT(*I6*) EXCEEDED*)
000735      320 FORMAT (F6)
000735      330 FORMAT (*1 STANDARD AREA VALUES CHECK*/)
000735      340 FORMAT  (*0 LAND USE AREAS IN SMSA*/)
000735      350 FORMAT  (* *A10,F10)
000735      360 FORMAT  (//*0 RESOURCE AREAS IN SMSA*/)
000735      370 FORMAT  (* *A3,F11)
000735      380 FORMAT  (//*0 LAND USE AREAS IN SAN PATRICIO COUNTY*/)
000735      390 FORMAT  (//*0 LAND USE AREAS IN NUECES COUNTY*/)
000735      400 FORMAT  (//*0 RESOURCE AREAS IN SAN PATRICIO COUNTY*/)
000735      410 FORMAT  (//*0 RESOURCE AREAS IN NUECES COUNTY*/)
000735      420 FORMAT (//*0 LAND USE AREAS IN 4 COUNTY REGION*/)
000735      430 FORMAT  (//*0 RESOURCE AREAS IN 4 COUNTY REGION*/)
000735      440 FORMAT  (*1*55X,2A10/)
000735      450 FORMAT (*0*61X,F4/)
000735      460 FORMAT (*0*55X*LAND USE: *A10/)
000735      470 FORMAT (*0*35X*PERCENT     PERCENT     PERCENT     PERCENT     PERCENT
               1     PERCENT      PERCENT*/ 25X*LU*11X*OF           OF CO.       OF
               2    OF 4       OF TOTAL     OF TOTAL    OF TOTAL*/ 23X*ACREAGE*5X* C
               3T AREA        AREA        SMSA         COUNTY      LAND USE     LAND USE
               4 LAND USE*/ 70X*AREA          IN CO.       IN SMSA       IN 4 CO.*//)
000735      480 FORMAT (23X,F6,8X,F5.1,7X,F4.1,6X,F4.1,7X,F4.1,3(8X,F4.1))
000735      490 FORMAT  (*0*/60X,4(5X*PERCENT*))
000735      500 FORMAT (31X*RCU*10X*RCU*7X*PERCENT*4(4X*OF TOTAL*))
000735      510 FORMAT (28X*AFFECTED BY   ACREAGE*7X*OF*3X,4(4X*RCU AREA*))
000735      520 FORMAT  (29X*LAND USE*5X*AFFECTED*4X*LU AREA*5X*IN CT*7X*IN CO.*
               1  5X*IN SMSA*5X*IN 4 CO.*//)
```