Report on the

ENVIRONMENTAL ASPECTS
of a
SUPERTANKER PORT
on the
TEXAS GULF COAST

Prepared for

TEXAS A&M UNIVERSITY SEA GRANT COLLEGE PROGRAM

in the

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

by

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COVER: Satellite photo of the Texas coast from East Matagorda Bay in the upper left, to Galveston Bay in the lower right. The location of the two port sites considered in this study are shown on the photo. (Photo by NASA.)

ABSTRACT

The objective of this study was to conduct an evaluation of the environmental impact of a deep-sea port off the Texas coast. The study considered both the non-spill impact of construction and operation of the port and the potential oil spill impact on the coastal environment.

The time and financial constraints of the project limited the study to existing on-hand knowledge. The scope of this study was limited to two terminal locations, three designs of port facilities, and three sizes of oil spills. The study also considered the environmental impact of not constructing the port but expanding the present methods to meet the oil import needs of the area.

The two port sites considered in this study were Site 1, located 29 (47 km) statute miles southeast of Freeport, Texas in 95 feet (29 m) of water, and Site 2, located 11 statute miles (18 km) offshore in 60 feet (18 m) of water. The nearshore site would require dredging a 1000-ft (300 m) wide 13 statute mile (20 km) long channel to a depth of 90 ft (28 m).

The major physical, biological and cultural features of the Texas Coastal Zone that might be impacted by the supertanker activity were inventoried. Models were developed to predict where oil from potential offshore oil spills would go and which environmental features would be affected.

In this study of the impact of an accidental spill on the coastal area, the probability of occurrence was included in the evaluation. The probability that a specific environmental element will be impacted was taken as the product of the probability that the oil spill will occur times the probability that if it does occur it will reach that specific environmental element. A third factor that was included in this evaluation is the probability that if the impact did occur, that the concentration and contact time will be high enough to cause harm to the elements. Adequate information was not available from existing literature in many areas to accurately evaluate the impact on the environment. However, for the purpose of this preliminary environmental assessment, the methodology was developed, much of the missing data assumed, and the impact estimated.

This project was conducted through the Sea Grant Program in the National Ocean and Atmospheric Agency (NOAA) for the President's Council on Environmental Quality (CEQ). An interdisciplinary study team consisting of nine members was formed from various divisions of the University. The following conclusions and recommendations were developed by the team. It should be pointed out however, that the team does not unanimously support all the conclusions and recommendations.

1. Texas is fortunate in having barrier islands along much of the coast. These islands will tend to protect the bays and estuaries from the effects of a potential offshore oil spill.
2. Winds and sea conditions in the western gulf are such that oil spill containment and control are feasible much of the time.

3. If oil is spilled, it will require 2 to 3 days travel time to reach the shore.

4. The offshore supertanker port should reduce the potential for oil spills to occur within the estuaries.

5. Oil spill containment and control procedures must be a planned and integral part of the port activity.

6. The impact on the environment of construction for the offshore site (Site 1) will be minimal.

7. The impact of construction for the offshore port site (Site 1) will be less than the impact of the nearshore site (Site 2).

8. The locations selected for this study seem to be well chosen from an environmental standpoint.

9. The continuous, low-level operational oil spill will have minimal impact on the marine environment.

10. There is no reason that the spill volumes used in this study should be attained.

11. The annual 500-ton spill is not expected to affect the estuaries and oil spill control procedures could be expected to be affective most of the time.

12. The potential 30,000-ton oil spill could cause severe environmental damage, unless adequate control and containment procedures are included as a part of the port design and operation.

13. Proceed with caution. There is no environmental reason for not pursuing the project further with designs, better environmental studies and contingency plans. Environmental field studies are necessary to collect data lacking for this study and develop baseline data.

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CHAPTER I

INTRODUCTION

STATEMENT OF PROBLEM

The objective of this pilot study was to conduct an evaluation of the environmental impact of a deep-sea port off the Texas coast. The study considered both the non-spill impact of construction and operation of the port and the potential oil spill impact on the coastal environment.

The time and financial constraints of the project limited the study to on-hand knowledge. Expertise in ocean engineering, physical oceanography, petroleum engineering, industrial economics, marine biology, parks and recreation, and environmental engineering was called upon to accomplish the various task items of this project.

The scope of this study was limited to two terminal locations, three designs of port facilities, and three types of oil spills. The study also considered the environmental impact of not constructing the port but rather expanding the present methods to meet the oil import needs of the area.

This project was conducted through the Texas A&M Sea Grant College Program in the National Oceanic and Atmospheric Agency (NOAA) for the President's Council on Environmental Quality (CEQ). Information on the port sites, port facilities, oil spill frequency and volumes and type of oil was provided by the Council on Environmental Quality.

PORT FACILITIES

The two offshore port site locations that were considered in this study are shown in Figure I-1. Site Number 1 (latitude 28° 36', longitude 95°00) is located 29 statute miles (47 km) southeast of Freeport, Texas, in 95 feet (29 m) of water, while Site Number 2 (latitude 28°42', longitude 95°25') is located 11 statute miles (18 km) offshore in 60 feet (18 m) of water.

The five-nested single point mooring with the central platform as shown in Figure I-2 was considered for Site Number 1. The central platform would include pumping facilities and was considered approximately 200 feet by 250 feet (61 m X 77 m) in plan. Pipelines from the platform would extend to a shore based tank farm. Construction of the facility at Site Number 1 would not require any dredging and would take approximately three years according to the Council on Environmental Quality.

The nearshore site is located in 60 feet (18 m) of water, eleven statute miles (18 km) offshore and will require dredging of a 1,000-ft (300 m) wide channel, 13 statute miles (20 km) long to a depth of 90 feet (28 m). The assumed arrangement of the port facilities at Site 2 is shown in Figure I-3. A breakwater is included in the assumed design to provide shelter for the loading and unloading operations.

Two types of port facilities were considered at Site No. 2, a 200-acre island and a 200-ft by 250-ft (61 m X 77 m) platform. The island has the two alternatives for trans-shipment to shore of either a pipeline or small tankers. The pipeline is the only method

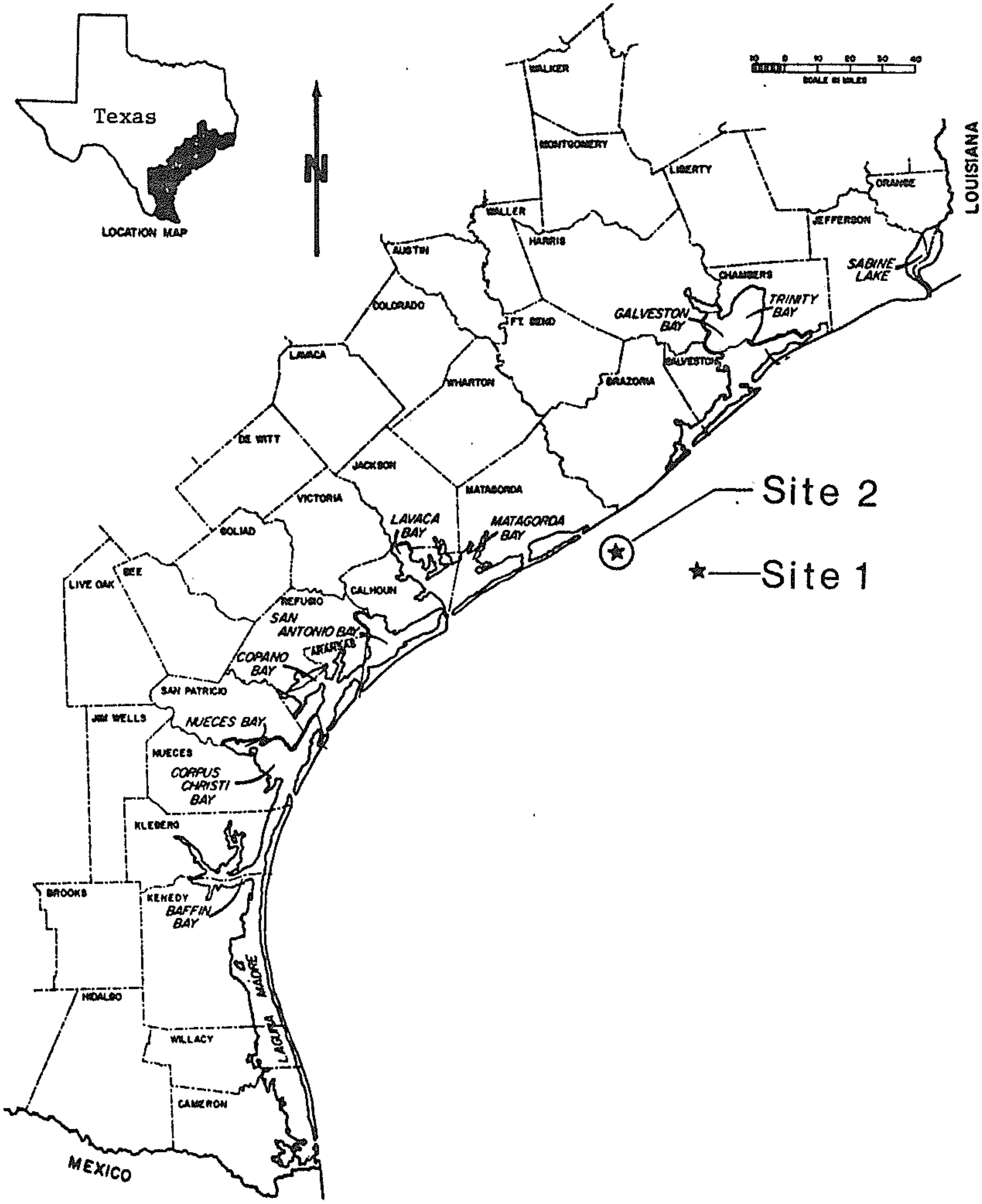


Figure I-1. Two Supertanker Port Locations.

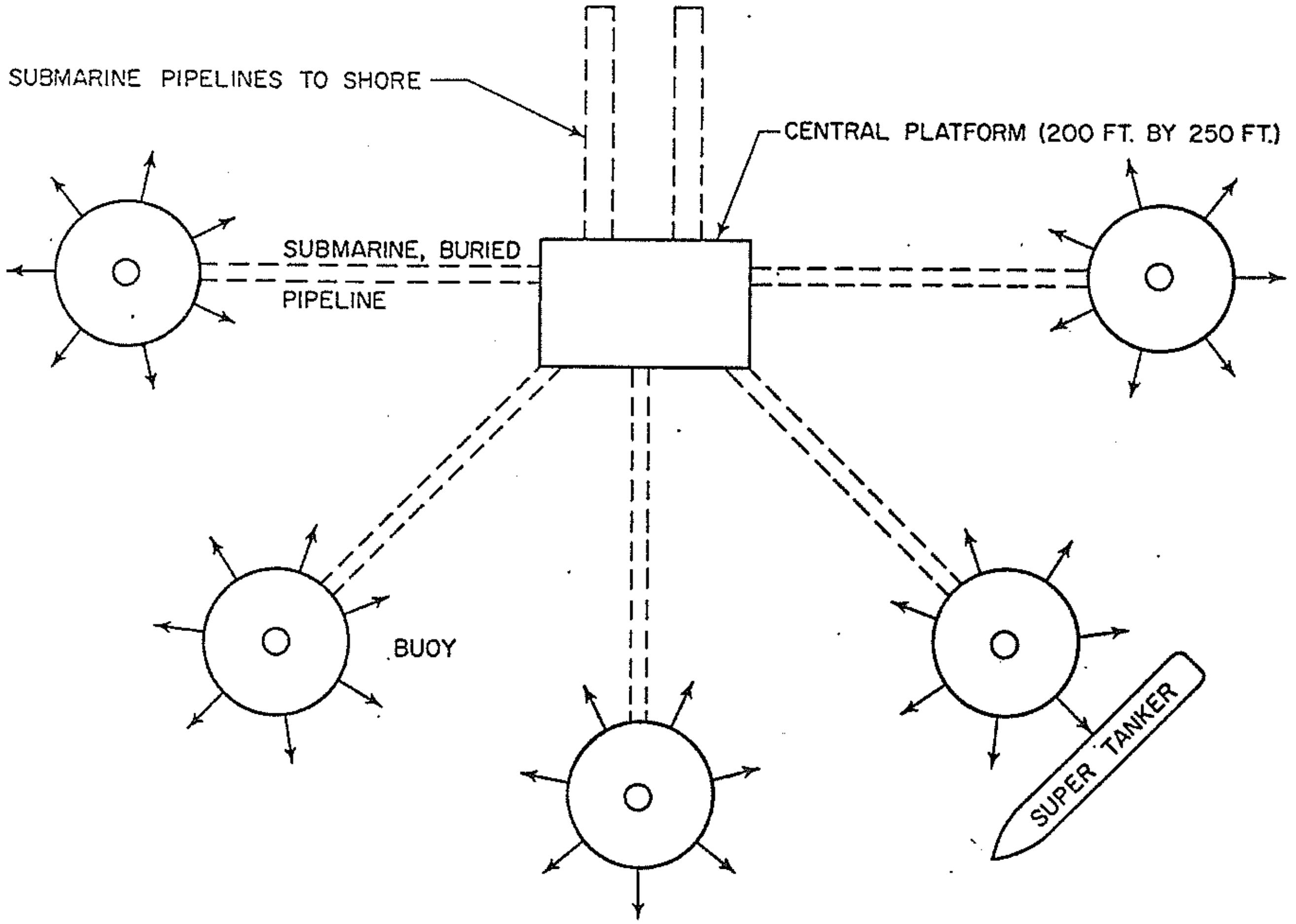


Figure I-2. Five-Nested SPM with Central Platform for Site 1.

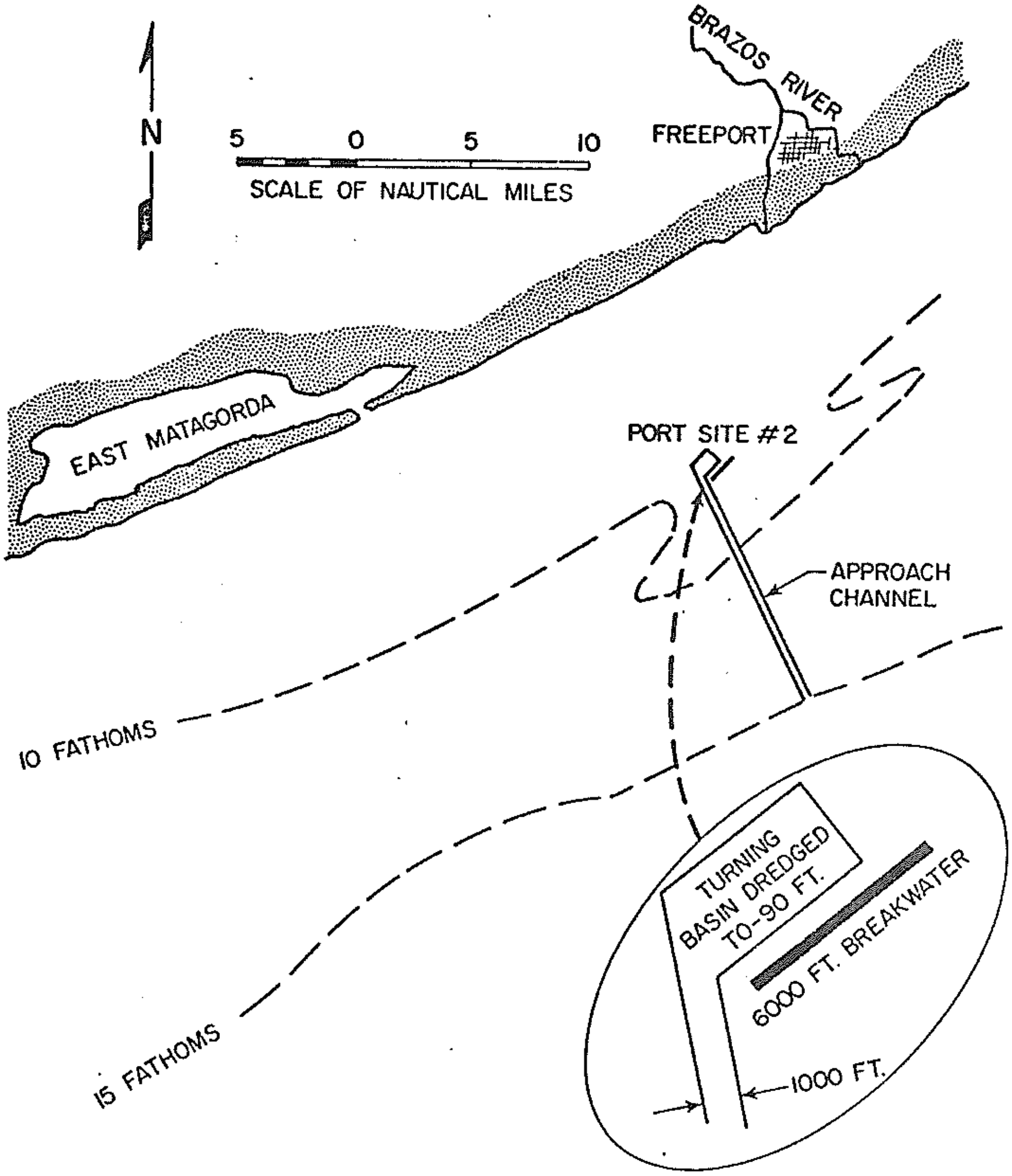


Figure I-3. Port Site and Approach Channel.

considered for trans-shipment with the platform. The port facility options for Site 2 are shown in Figure I-4.

OIL SPILL CHARACTERISTICS

It is not known that any oil will be discharged to the environment from the operation of an offshore facility. Similarly we do not know that people will be killed when a super highway will be built. We do note that human error and mechanical failure do cause highway deaths which can be statistically predicted and in a like manner human error and mechanical failure may lead to release of oil into the environment.

For this reason it is desirable to make an educated guess at spill volumes which might occur within given periods of recurrence and to hypothesize the fate and effect of such discharges. The spill volumes and frequencies used in this report were developed by the U.S. Coast Guard for the CEQ. It is assumed that they are based on records of oil releases from existing facilities and from known tanker release incidents.

The spill volumes and frequencies used in this study were a continuous or daily operational release, a 500-ton annual release and a 30,000-ton each 20 years. The fate and effect of a release is a function of the properties of the material being spilled. In this study it is assumed that the material is an African or Middle East crude with the properties shown in Table I-1. These values were provided by the CEQ.

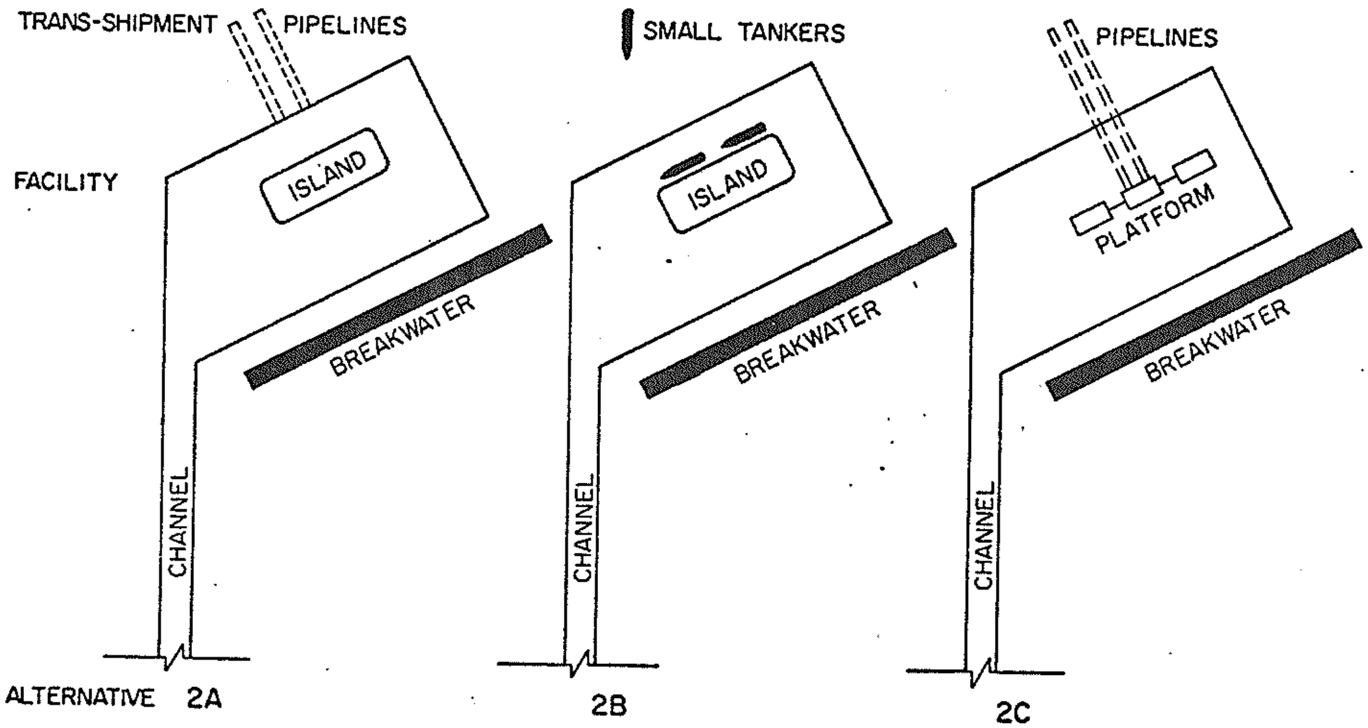


Figure I-4. Alternative Port Facilities at Site 2.

Table I-1. Composition of Crude.

Component	A	B
Sulfur, percent	0.14	1.30
Nitrogen, percent	0.083	0.042
Color	brown-black	brown-green
Specific gravity	0.858	0.840
API gravity	33.4	37.0
Light gasoline	2.4	7.3
Total gasoline and naptha	15.1	30.3
Kerosene distillate	13.1	9.9
Gas oil	10.3	15.2
Nonviscous lubricating distillate	14.8	11.3
Medium lubricating distillate	4.3	6.8
Viscous lubricating distillate	---	3.5
Residuum	42.2	19.4
Distillation loss	0.2	3.6
3, 4 benzpyrene	1320 μg/kg crude	400 μg/kg crude

Crudes A and B would also contain compounds such as 1, 2 benzanthracene, 1, 2 - benzphenanthrene, diphenylmethane, phenanthrene, and dibenzthiophene in the general proportions indicated by the benzpyrene content of each.

Source: Council on Environmental Quality.

The spills were considered to be caused by human errors and are not associated with any particular time of day or year or weather condition. While it seems highly unlikely, the return period of the major spills is the same for the two site locations. The origin of each spill was considered at or near the port site. The oil from the annual and twenty-year spills was released over a two-hour period. Flow volumes for the continuous spill are listed in Table I-2.

Table I-2. Flow Volume of Continuous Spill.

Site	Port Location	Port Facility	Tranship Shore	Flow Volume[1] Bbls./day 1980	2000
1	Offshore	5-SPM	Pipeline	1.2	4.2
2	Nearshore	Island	Pipeline	1.2	4.2
2	Nearshore	Island	Tanker	2.3	8.5
2	Nearshore	Platform	Pipeline	1.2	4.2

APPROACH

The general approach followed in this study was:

1. To identify and inventory the environmental elements which may be impacted by the various supertanker activities;
2. To analyze the interaction between the supertanker activities and the environmental elements; and

3. To evaluate and summarize the environmental impact of the deep sea port activities on the environment.

While the scope of the project was limited to two terminal locations and three types of spills, the methodology developed in the study is applicable to any port site on the Texas coast and any spill volume. Computerized procedures were utilized when possible and for these programs only the coordinates of the port site need to be changed to evaluate other locations. In nearly all areas these analyses were limited by lack of good experimental and environmental data.

CHAPTER II

ENVIRONMENTAL INVENTORY

TEXAS COASTAL ZONE

The Texas Coastal Zone, as defined by the Governor's Office of Texas, extends from the Sabine River at the Louisiana-Texas border on the north to the Rio Grande River at the Texas-Mexico border on the south. The Zone extends inland to include not only the 18 coastal counties but also an additional 18 adjacent counties, and extends outward to 10.35 miles in the Gulf of Mexico.

The Coastal Zone includes 25,394,003 acres, of which the Federal Government owns about 2 percent, the State of Texas 16 percent, local governments 2 percent, and private owners 80 percent. In the 18 counties adjoining the coast, there are an estimated 622 square miles of coastal marsh, 2,100 square miles of bays and estuaries, and 213 square miles of formally designated wildlife refuges.

Included in this chapter are the major physical, biological and cultural features that might be impacted by the supertanker activity. A more detailed description of the physical elements of the Coastal Zone and their interaction with the biological elements is given in Appendix A of this report.

Population Features

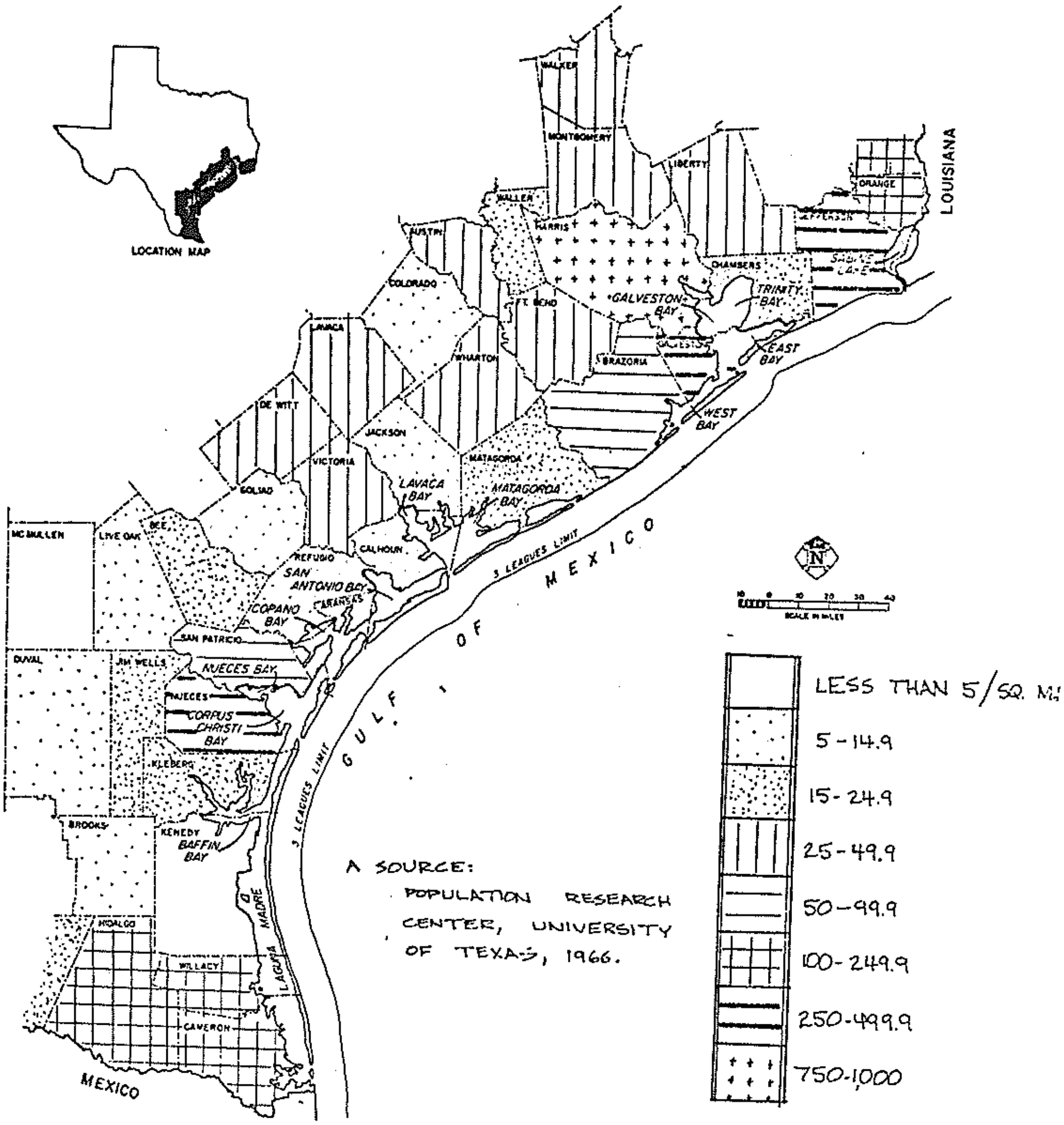
The 18 counties bordering the coast have a 1970 population of 2.95 million and an additional 0.55 million people lived in the 18 adjacent inland counties. Thus 3.5 million persons or nearly one out of every three Texans lived in the Coastal Zone in 1970. The Coastal

Zone is one of the most rapidly growing areas in the state, experiencing a 21.5 percent increase in population between 1960 and 1970 as compared with 16.9 percent for the state and 14.2 percent for the nation. This growth was not evenly distributed across the Coastal Zone, however. Seventeen of the Coastal Zone counties lost population between 1960 and 1970, but nineteen gained population. Included in the latter group were three counites which were among the eleven counties in the state experiencing a growth rate in excess of 40 percent over the decade.

The Coastal Zone region is largely urbanized with 84 percent of the population residing in cities of 2500 or more population, as compared with 80 percent for the state as a whole. Within the Coastal Zone, population is concentrated in a series of five Standard Metropolitan Statistical Areas (SMSA's) running from Beaumont-Port Arthur-Orange on the north to Houston, Galveston-Texas City, Corpus Christi, and Brownsville-Harlingen to the south. The growth in population between 1960 and 1970 in the Coastal Zone was almost entirely in these urbanized areas. Figure II-1 shows the population density for the Coastal Zone in 1966.

Weather

Texas is wedged between the warm waters of the Gulf of Mexico to the south and the high plateaus and mountain ranges to the north. The weather of the Texas Coastal Zone is dominated by the effects of the warm, moist air which flows in from the Gulf of Mexico. This tropical maritime air combines with an adequate rainfall to produce a generally humid subtropical climate in the Coastal Zone. The summers are long and warm to hot, and the winters are short and mild.



A SOURCE: POPULATION RESEARCH CENTER, UNIVERSITY OF TEXAS, 1966.

Figure II-1. Population Density of the Texas Coastal Zone.

The average annual temperature for the Texas Coastal Zone varies from 70°F in Jefferson County, in the northeast section of the coast, to 74°F in Cameron County near Mexico. The average annual precipitation for the same region varies from 55 inches of water per year in Jefferson County to 26 inches of water per year in Cameron County.

Hurricanes are a typical feature of the weather of the Texas Coastal Zone. Since 1900, on the average, one hurricane every two years has struck the Texas Coastal Zone. There seems to be no preferred location on the coastal zone which is more susceptible to hurricane landings. Hurricanes can inflict destruction due to their high winds, tornadoes, flood waters due to excessive amounts of rainfall, and high tides or a combination of all four. These hurricanes and tropical storms have stronger southerly winds in their right hand sector because of generally northward movement.

Physical Environmental Features of the Coast

High altitude, infrared color aerial photography at a scale of 1:120,000 was utilized to identify critical environmental elements along the coast. NASA photography from Mission 110 was obtained from the Earth Resources Research Data Faculty, Manned Spacecraft Center, Houston, Texas. Much of this information is summarized in a series of maps which extend from Corpus Christi Bay to Galveston Bay. The maps (Figures II-2 through II-9) show the general vegetation types up to the approximate hurricane high water line. U.S. Geological Survey maps at a scale of 1:125,000 provide the basic control for this survey of critical elements. Waterfowl along the Texas Coast are one of the critical elements that could be impacted by a potential oil spill.

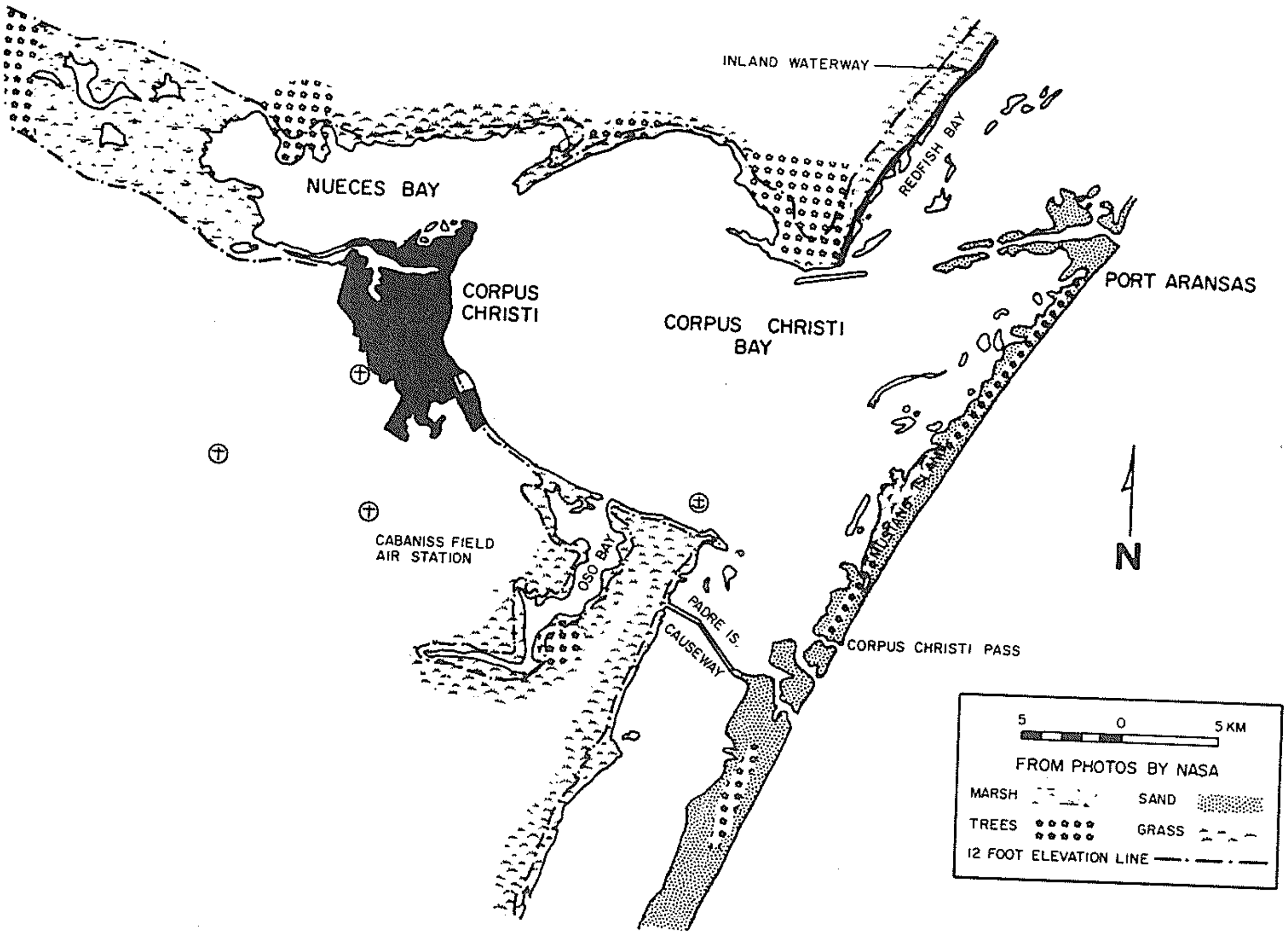


Figure II-2. Critical Environmental Elements of Corpus Christi Area.

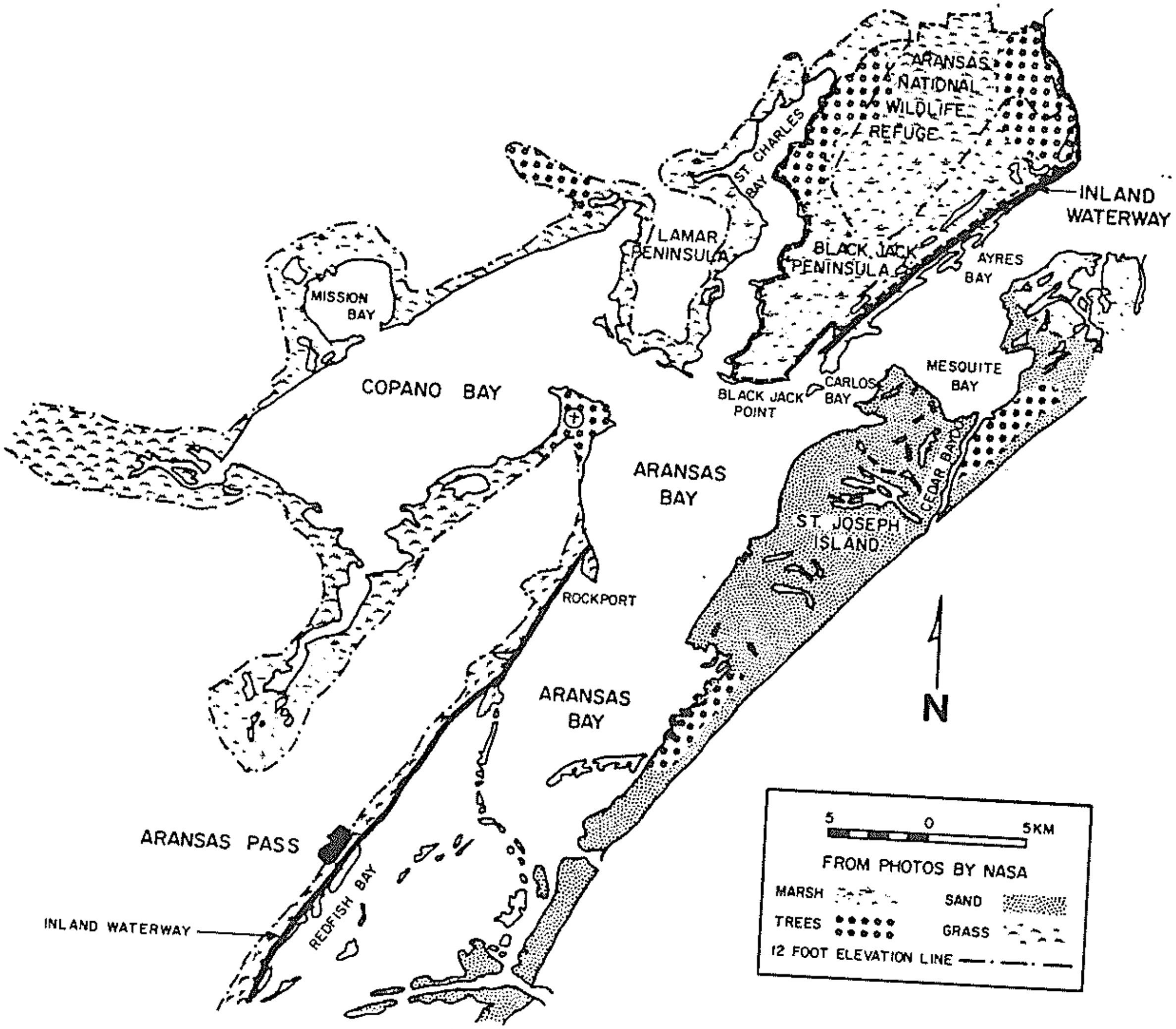


Figure II-3. Critical Environmental Elements of Copano-Aransas Area.

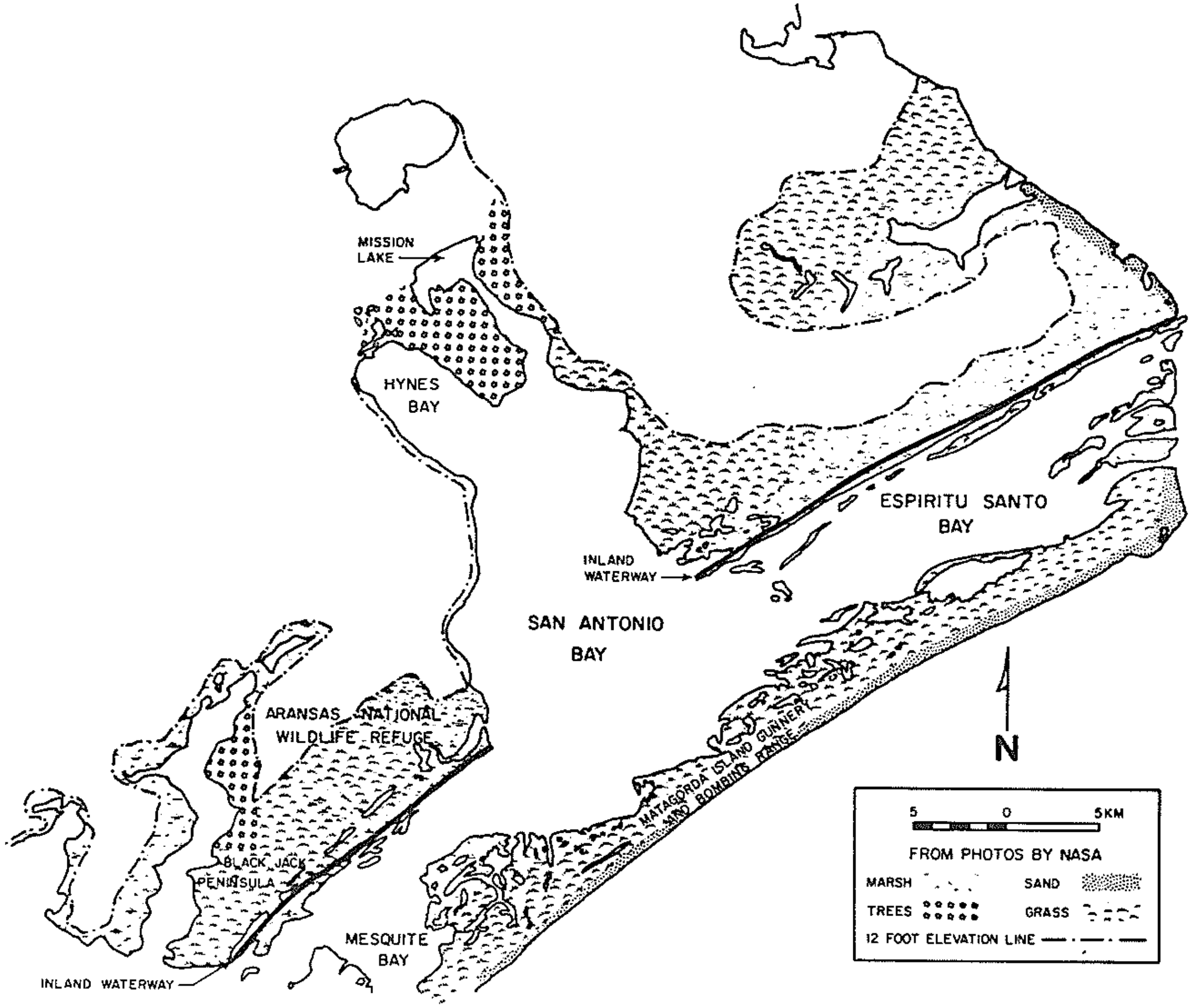


Figure II-4. Critical Environmental Elemtns of San Antonio Bay.

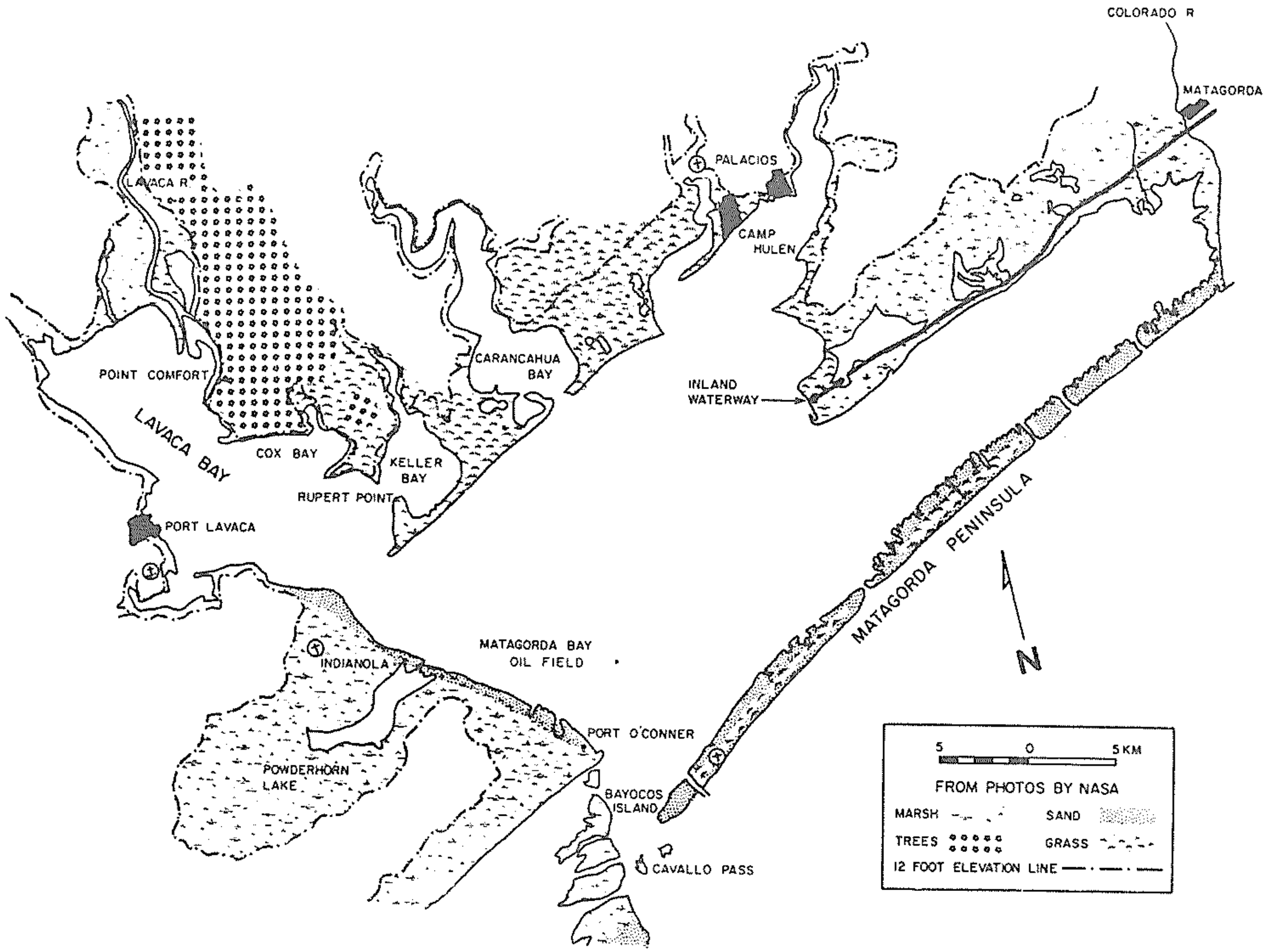


Figure II-5. Critical Environmental Elements of Matagorda Area.

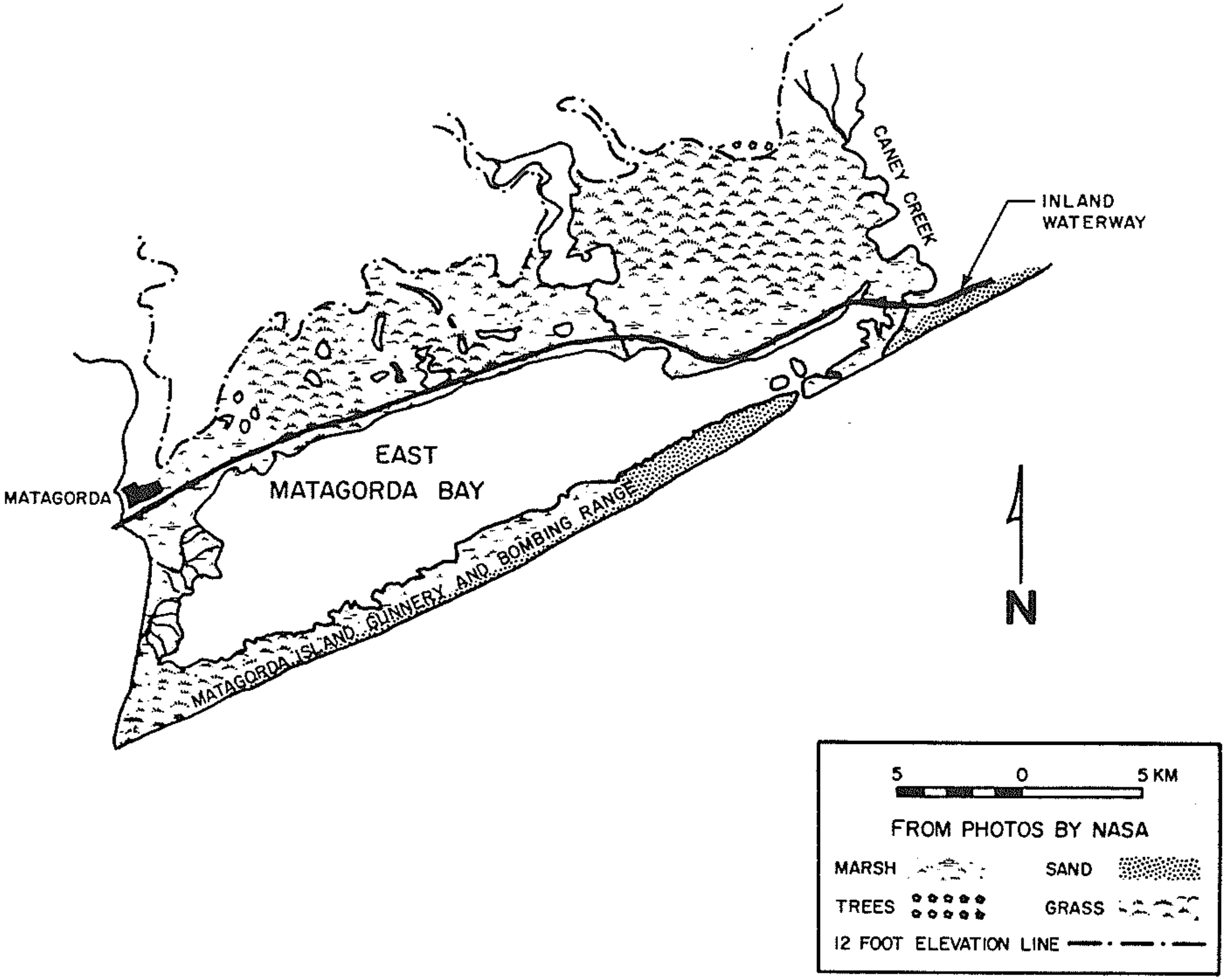


Figure II-6. Critical Environmental Elements of East Matagorda Area.

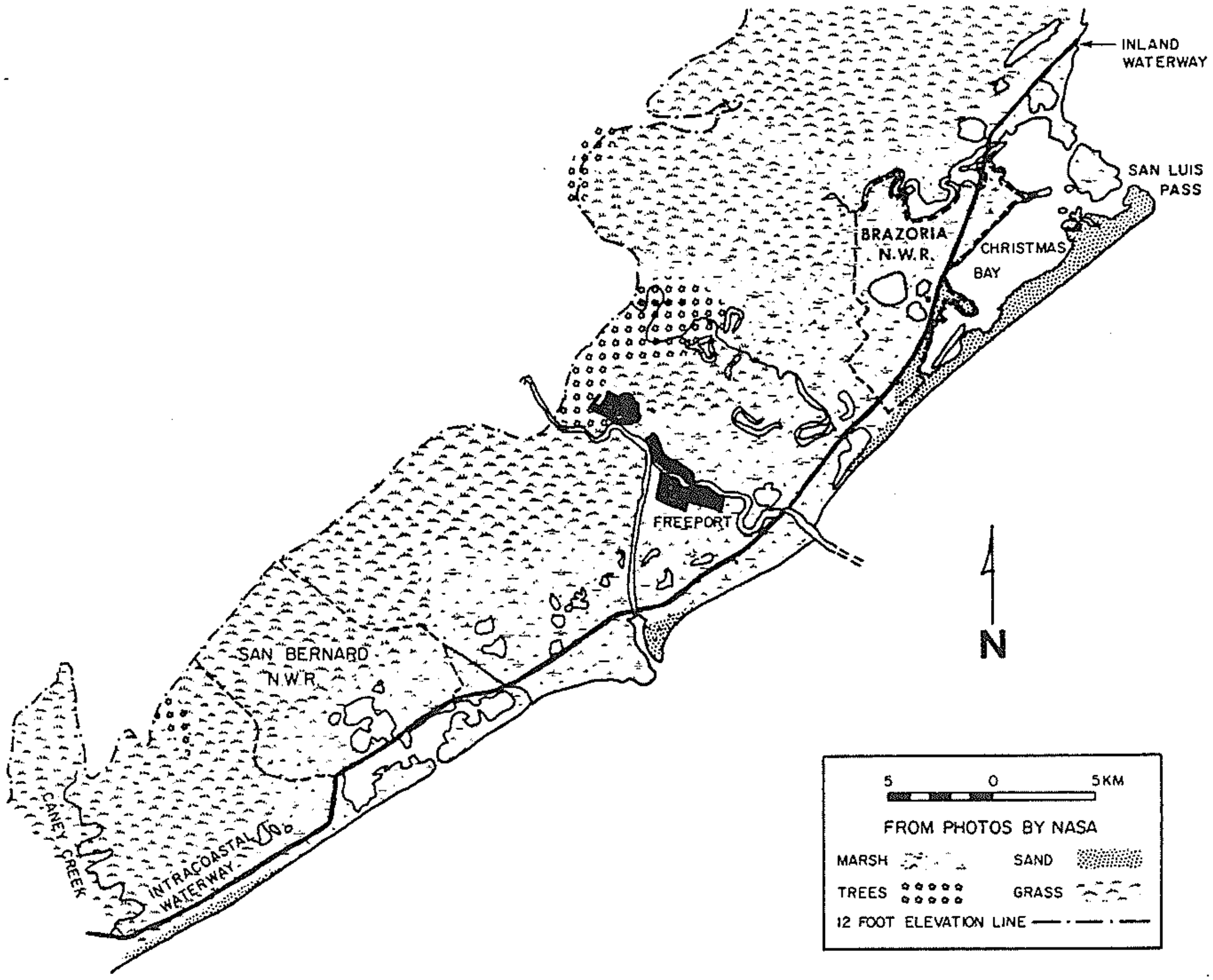


Figure II-7. Critical Environmental Elements of Freeport Area.

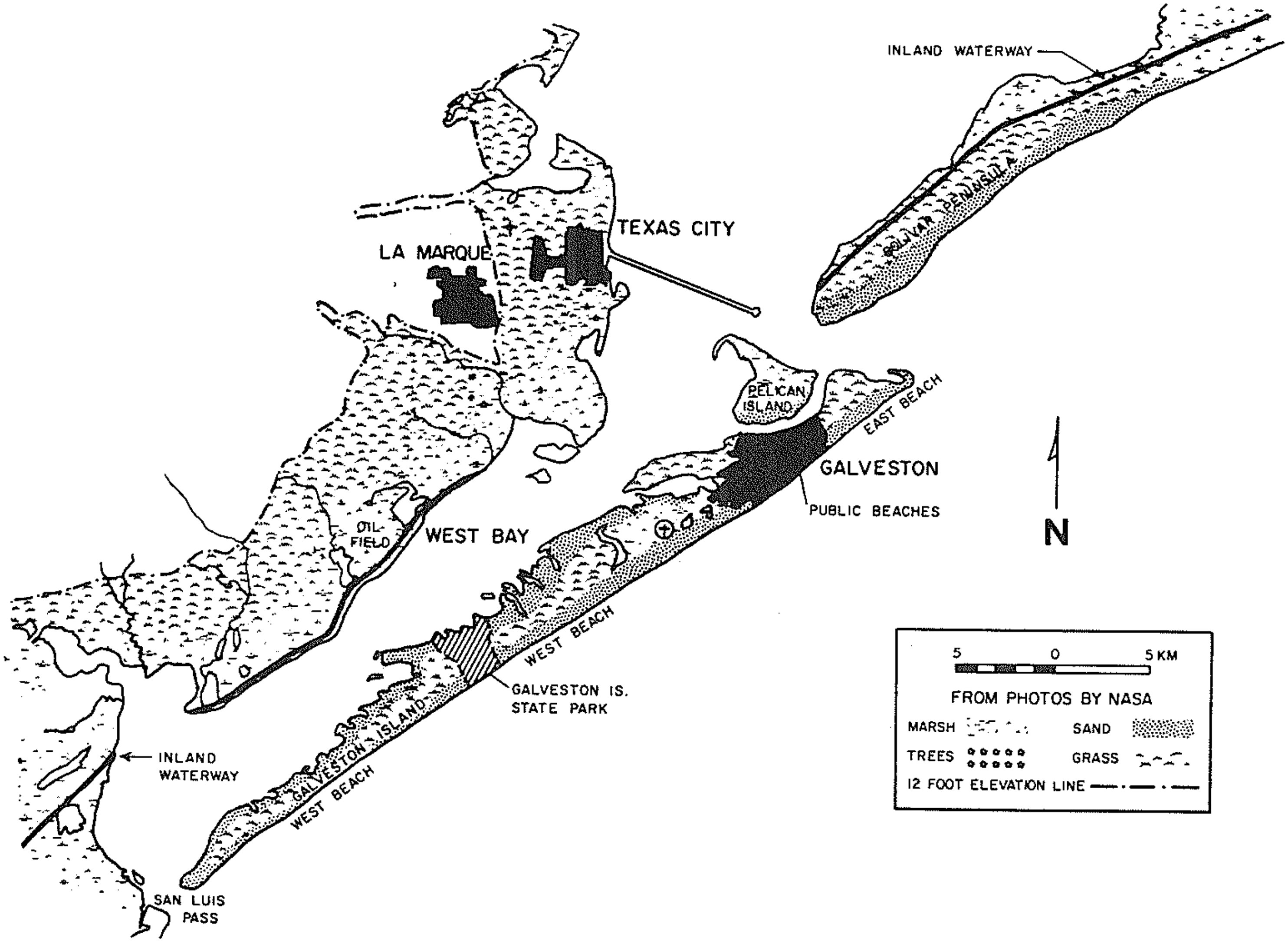


Figure II-8. Critical Environmental Elements of West Bay Area.

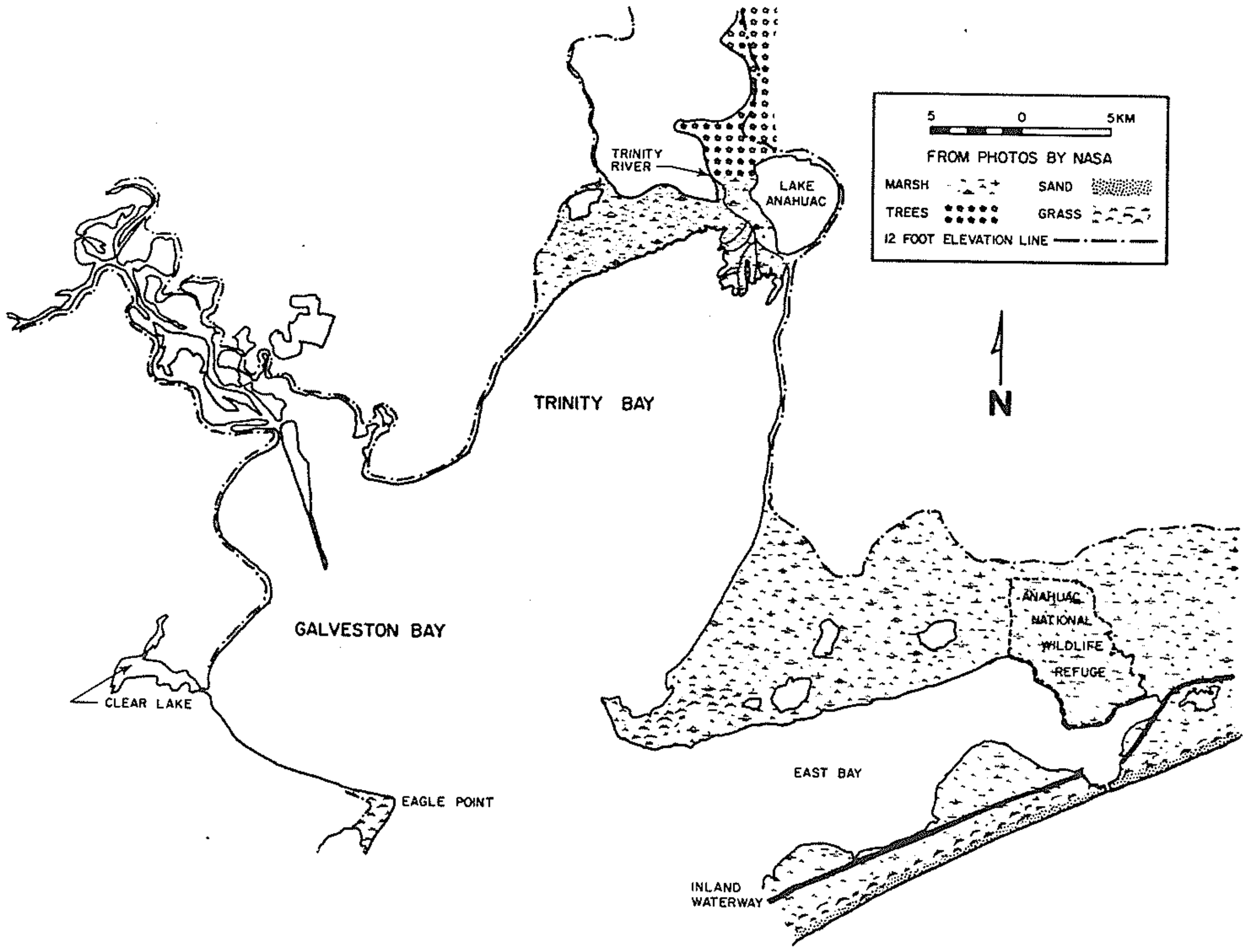


Figure II-9. Critical Environmental Elements of Galveston Bay.

While they can not be identified directly with aerial photography, waterfowl are generally associated with the marsh areas shown on the maps.

Texas Coastal Shoreline

In order to permit computerization of much of the data analysis, the inventory of the coastal area was indexed according to shoreline segments as shown in Figure II-10. Each section of the coast is three miles in length along the beach and extends from the ocean beach back to the approximate limit of hurricane high water which was assumed to be twelve feet elevation. The sides of each shoreline segment are normal to the general direction of the coastal beach. The segments are numbered consecutively starting with 1 at Brownsville in the southwest and ending at Sabine Pass on the northeast with number 124. Appendix B is a computer listing of the data tabulated to date using this indexing system.

A description of the Texas coastal shoreline by beach segments is listed below. Much of this information was obtained from the Texas Shores, a Regional Inventory Report of the National Shoreline Study of the U.S. Corps of Engineers, 1971.

Shoreline Segments 1-40: Padre Island, a barrier island between the Gulf of Mexico and Laguna Madre, extends south along the lower Texas coast for about 113 miles, ranging in width from a few hundred yards to about 3 miles. Padre Island has wide, clean, sandy beaches backed by sand dunes up to 40 feet high. Grass flats, smaller dunes, and mud flats make up the area between the primary dunes and Laguna Madre.

The long mainland shore of Laguna Madre, extending south about 117

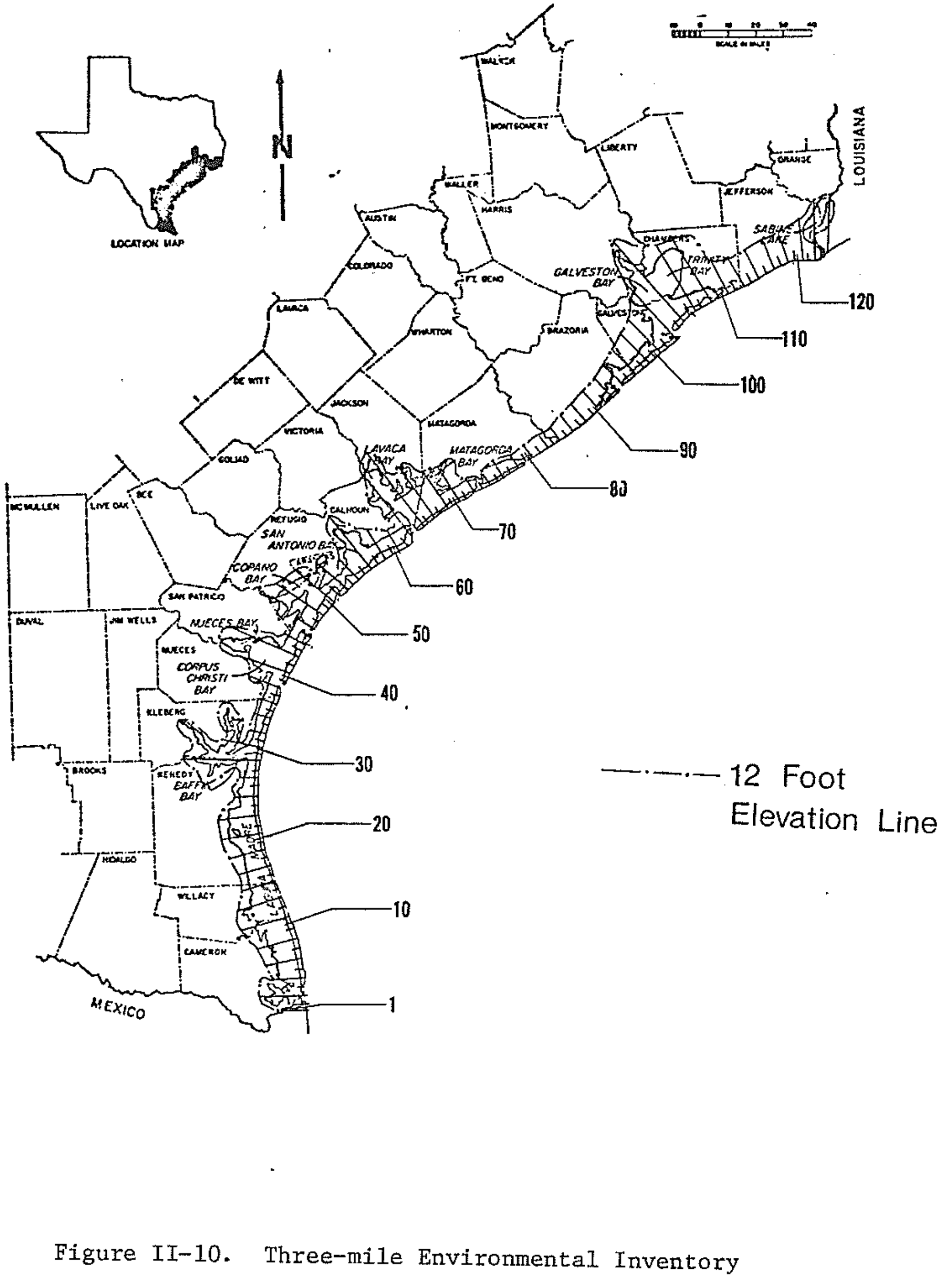


Figure II-10. Three-mile Environmental Inventory Shoreline Segments.

miles from Encinal Peninsula to Port Isabel, is essentially undeveloped privately owned land. The famed King Ranch occupies a substantial part of the shore along this reach. The area adjacent to the shore is largely unpopulated and has experienced less change during the past century than any other section of the Texas coast. Baffin Bay, about 30 miles south of Encinal Peninsula, has some private residences and recreational facilities along its west bank. Port Mansfield is a sport and commercial fishing center, with harbor facilities for fishing vessels and small craft. The community has a small number of permanent residents operating camps, motels, and businesses catering to tourists, hunters and fishermen. To the south, Laguna Atascosa National Wildlife Refuge borders a large portion of the Laguna Madre shore between the mouth of the Arroyo Colorado and a point about 8 miles north of Port Isabel. Between the wildlife refuge and Port Isabel, much of the area along the shore has been subdivided for permanent and summer homes. The Port Isabel waterfront is lined with hotels, motels, docks, piers, boat launching ramps and seafood handling and processing establishments.

Brazos Island and the South Bay area between Port Isabel and the Rio Grande are mostly undeveloped. The Gulf shore of Brazos Island, including a 2-mile strip dedicated as a state park, is used for public recreation. Some private housing and a few tourist service establishments are located along this southern extremity of the Texas coast.

Except for some public recreational and private residential and commercial developments at its northern and southern extremities, there are no other significant developments on Padre Island. The development at the north end includes a county park, fishing piers, several concession type businesses catering to bathers and beach users, an elaborate hotel complex and a subdivision for permanent and summer homes. A concrete seawall about 12 feet high protects the hotel. On the south end of Padre Island, along a length of about 5 miles, apartments, beach homes, motels, parks, restaurants and other tourist accommodations have been constructed.

The Federal navigation channel from the Gulf of Mexico to Port Mansfield extends through Padre Island about 38 miles north of Port Isabel. Most of the island north of the Port Mansfield Channel is occupied by the Padre Island National Seashore, a part 80.5 miles long dedicated to preserving that portion of the island in its natural state for the public's enjoyment. Each year its beaches provide recreation for a great number of people. Presently, there are camping and picnicking areas, an observation tower and a tourist center with additional facilities planned.

Shoreline Segments 41-51: The major portion of St. Joseph Island is used for ranching and private recreation. A small portion of the southern tip of the island, adjacent to the Aransas Pass Navigation Channel, is owned by the Federal Government. Mustang Island extends from the Aransas Pass Navigation Channel to Corpus Christi Pass, a distance of about 16 miles. The 16-mile long beach front is a very popular recreational center for the south Texas region. Sand dunes up to 25 feet in height lie behind the beach front, except for a small number of areas where dunes have been breached by hurricane tides. The island provides a rather high degree of protection against hurricane tides and waves for the inland areas around Corpus Christi Bay. The island has numerous beach homes and water-oriented recreational type facilities. Port Aransas, located on ther northern end of the island, is the only town on Mustang Island.

A causeway and ferry provide access to the northern end of the island, while the John F. Kennedy Causeway provides access to the south end. The north shore of Mesquite Bay and the east shore of Blackjack Peninsula are low and are part of the Aransas National Wildlife Refuge. The west bank of St. Charles Bay is undeveloped. The perimeter of Copano Bay has scattered developments of permanent-type homes, fishing and hunting camps, farm buildings, and oil field and supporting facilities. Most of the northwest shores of Aransas and Redfish Bays are well developed with permanent and summer homes. The cities of Rockport and Aransas Pass have many businesses catering to tourists, hunters, fishermen and other water-oriented recreationists. Much of the bay shore at Fulton and Port Ingleside is partially protected from erosion by several different types of privately constructed revetments. Oil fields and permanent and summer residences occupy the northeast shore of Corpus Christi Bay. The northwest shore of the bay, including the town of Portland, has several residential subdivisions on bluffs, which range up to 30 feet above sea level. Oil and gas wells, piers, and docks constitute the major development on the north shore of Nueces Bay. At the head of the bay, the shoreline is formed by the low, marshy delta lands at the mouth of the Nueces River. Much of the south shore of Nueces Bay is undeveloped and is used as a spoil area for dredging operations in the Corpus Christi Ship Channel.

Corpus Christi, the largest city on the Texas coast, fronts the west and south shores of Corpus Christi Bay with about 16 miles of highly developed and densely populated urban areas. Corpus Christi is an important seaport and industrial center for petroleum and agricultural products and is also a major tourist and convention center. Most of the 16-mile reach of shoreline is protected from erosion by breakwaters, seawalls, bulkheads, groins and riprap.

A large part of the Oso Bay shoreline is a tidal flat and not developed to any great extent. The University of Corpus Christi occupies an island connected to the mainland by a causeway at the mouth of Oso Bay. Encinal Peninsula lies between Oso Bay and the mainland shore of Laguna Madre. Part of the Corpus Christi Naval Air Station, the residential and tourist community of Flour Bluff and a number of small slips and wharves serving sport and commercial fishing interests and service facilities for the nearby oil and gas fields are located along the Encinal Peninsula shore. Many boating supply, bait, and fishing tackle businesses and launching ramps are located along the John F. Kennedy Causeway which connects the mainland with the north end of Padre Island and the south end of Mustang Island.

Shoreline Segments 52-61: Matagorda Island is a remote area accessible only by boat or aircraft. About 60 percent of the 30-mile long island is occupied by the Matagorda Island Air Force Base and Gunnery Range. The southwestern end of the island is devoted to ranching. Recreation on the island is limited to private interests and military personnel because of the limited accessibility and restricted areas. The shorelines of Espiritu Santo, San Antonio, Guadalupe and Hynes Bays are, for the most part, undeveloped. South of the town of Seadrift, the land is quite low and unsuitable for permanent-type structures. A low, concrete bulkhead protects about 3,700 feet of Seadrift's residential bay shore from wave erosion associated with strong south and southwest winds and minor tropical disturbances. Most of the upper part of San Antonio Bay is bordered by the low, marshy delta lands at the mouth of the Guadalupe River. Steep secondary banks up to 25 feet high rise above the river delta behind the normal shoreline. The west shore of San Antonio Bay is relatively high but undeveloped, except for the town of Austwell and a few scattered residences. The Aransas National WildlifeRefuge occupies the shore of San Antonio Bay from Webb Point to False Live Oak Point.

Shoreline Segments 62-73: Matagorda Peninsula has the only Gulf shore in this zone. The peninsula, accessible only by boat or aircraft, is used primarily for ranching and recreation. Overnight camping is quite popular in the area of good fishing near the Matagorda jetties. Two private airstrips are located on the peninsula. Most of the perimeter of Matagorda Bay is sparsely populated marshland devoted to grazing except for the town of Port O'Connor and other small communities on the western shore. The western shore generally has sand and shell beach areas which are used considerably for recreation where public access is available. The bay shore of Port O'Connor is protected from normal wave action by a concrete bulkhead about 4,200 feet long. Near Well Point, on the north shore of Matagorda Bay, about 1,200 feet of the shore is occupied by the Texas Parks and Wildlife Marine Biology Laboratory. Farm and ranch lands border a large portion of Tres Palacios Bay shoreline. The bay shore of the town of Palacios is partially protected by a concrete seawall, about 4.5 feet high and about 3/4 of a mile long. Twelve short groins extend from the seawall into the bay. The south part of the east shore of Lavaca Bay is low, undeveloped land. The remainder of the shore is comprised of banks and bluffs up to 25 feet high, except for some marsh areas at the mouths of several streams entering the bay. The city of Port Lavaca is the largest populated area on the bay. A considerable portion of the city's shore is protected against erosion from normal waves by bulkheads and rubble revetment.

Shoreline Segments 74-86: The northeasterly end of the Gulf shore in this area is undeveloped. It is a remote area and not easily accessible. The area is used for camping, bathing, and fishing when beach travel conditions permit. The Cedar Lakes area is undeveloped. Some small Gulf shore areas near the mouth of Caney Creek are subdivided for beach homes. Matagorda Peninsula, southwest of the mouth of Caney Creek, is used mostly for grazing. Numerous summer homes are located in the more accessible areas near the mouth of the Colorado River, where the beach is excellent for bathing and surf fishing. The shores of Matagorda Bay, east of the Colorado River are generally undeveloped.

Shoreline Segments 87-90: Shoreline development of the eastern half of this zone consists of permanent and summer homes and recreation-oriented businesses which cater to the many fishermen and bathers who visit the beach. The city of Freeport and its adjacent heavily industrialized area are located here. The area westward of the Freeport Harbor navigation entrance is mostly undeveloped, since it is accessible only by a single road and pontoon bridge across the Gulf Intracoastal Waterway. The beach does, however, receive some recreational use.

Shoreline Segments 91-111: This zone includes the largest concentrations of shoreline development along the Texas coast. The large Galveston Bay system, comprising Galveston Bay, East Bay, Trinity Bay, West Bay and several smaller bay arms, lies behind the barrier formations of Bolivar Peninsula, Galveston Island and Follets Island. A considerable part of Bolivar Peninsula is occupied by permanent and summer residences and numerous commercial establishments. The city of Galveston occupies about the easterly one-third of Galveston Island and the westerly two-thirds of the island has many permanent and summer-home type residential development. A number of similar developments are located on Follets Island, west of San Luis Pass. The westerly shore of Galveston Bay is occupied by almost continuous urban type development from Texas City on the south to La Porte and Baytown on the north. Seabrook, Kemah, San Leon and a number of unincorporated communities front the bayshore in this reach. The city of Anahuac is located on the easterly shore of Trinity Bay near the mouth of the Trinity River. The Anahuac National Wildlife Refuge borders about 6.5 miles of the north shore of East Bay.

The East Bay shoreline of Bolivar Peninsula is extensively used for recreational boating and fishing. The north shore of East Bay is mostly unoccupied except for residential development on Smith Point. The shores of Trinity Bay are mostly undeveloped excepting the Anahuac vicinity and the vicinity of Umbrella Point and Houston Point on the north shore, where numerous homes, boating and fishing camps, and some oil industry facilities are located. The upper end of Galveston Bay near Baytown is highly developed. Most of the shores are occupied by industrial, commerical and residential properties. The Galveston Bay shoreline from Morgan Point to Texas City, including the shore of Clear Lake and some of Dickinson Bay, is extensively developed with permanent and summer residences and some commercial establishments. The shoreline outside of the Texas City Hurricane Flood Protection System is, for the most part, undeveloped. A few recreation-oriented businesses are located in the unprotected area. The northerly shores of West, Bastrop and Christmas Bays are undeveloped except for a few summer home type subdivisions.

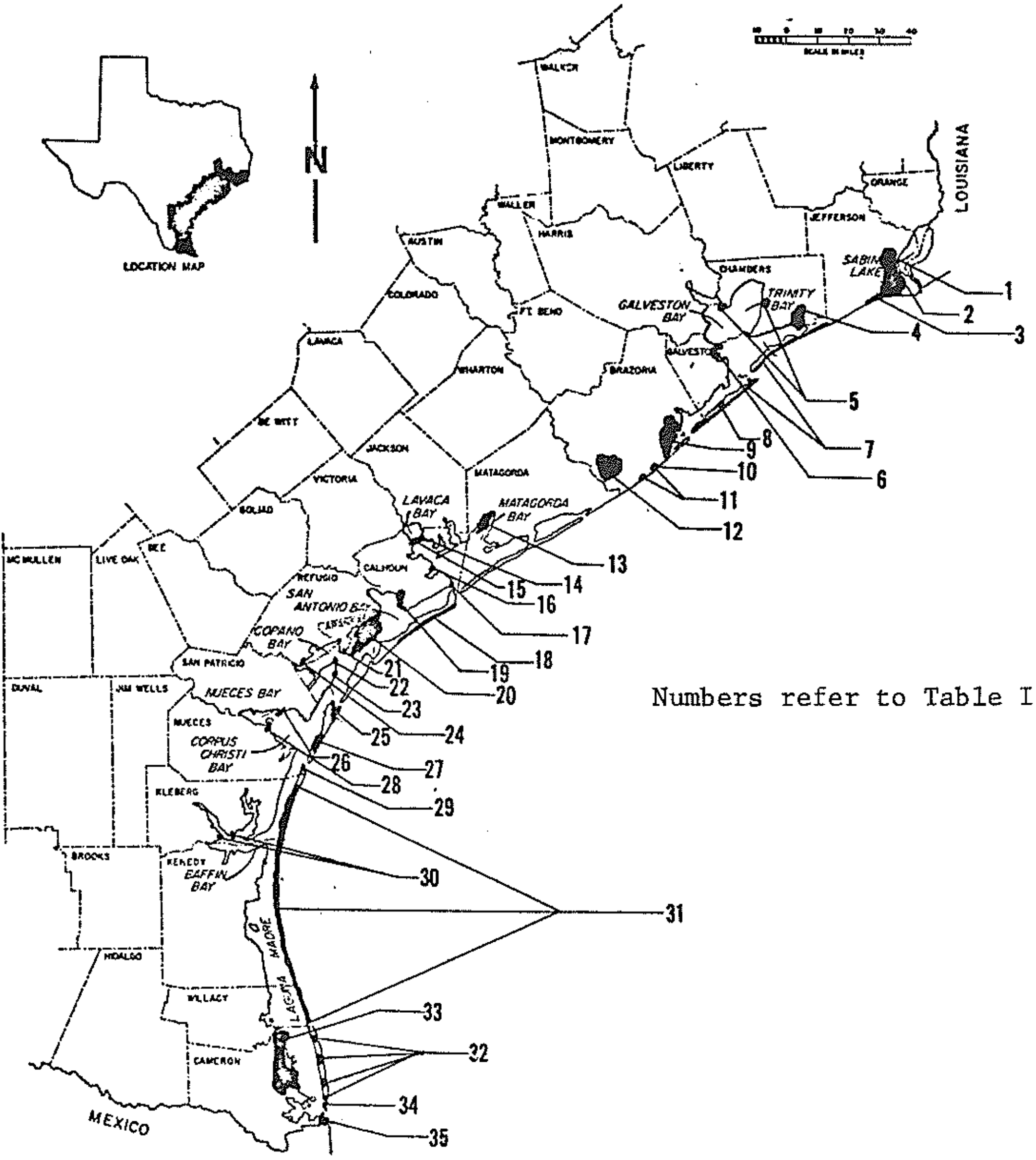
Galveston Island has about 32 miles of Gulf shoreline which is used heavily for recreation. About 10 miles of the Gulf shore of the city of Galveston is protected by a massive concrete seawall. Most private property along the seawall is highly developed with hotels, motels, apartments, restaurants, tourist attractions and other businesses. A few permanent residences are located immediately behind the seawall. Some beach bathing facilities, motels, concessions, amusements and a trailer park are situated on the unprotected part of the beach in front of the seawall at the east end of the island. The north portion of the city of Galveston and the south shore of nearby Pelican Island are occupied by marine and industrial facilities related to the deep-water harbor, and by businesses related to fishing, shipping and offshore oil exploration. The westerly two-thirds of Galveston Island is unprotected from hurricane surges. The area is rapidly changing from sparsely settled grazing lands to subdivisions for summer and permanent homes. Follet's Island, west of San Luis Pass, is about 9 miles long and is occupied by many permanent and summer homes.

Shoreline Segments 112-124: The shores of this most easterly zone are mostly undeveloped. Within the city limits of Port Arthur on the northwest shore of Sabine Lake, there are some recreational developments, principally for boating and boat racing. Two small towns are located near the Gulf south of Port Arthur. The westerly portion of the Gulf shore in Zone A is used extensively for public recreation, although virtually no facilities have been provided for public use or access.

PARKS, RECREATION AREAS, AND WILDLIFE REFUGES

The Texas gulf coast has 1081 miles of shoreline, of which 421 miles are bluffshore, 359 miles are of marsh shore, and 301 miles are of beach (Outdoor Recreation Resources Review Commission, 1962). Barrier islands, broken infrequently by entrances to bays and lagoons, parallel the mainland shore except at Sabine Pass and the Brazos River delta. These barrier islands include Padre Island (the longest of the barrier islands -- 113 miles in length), Matagorda Island, Matagorda Peninsula, St. Josephs Islands, Galveston Island, and Bolivar Peninsula. These barrier islands, which range in width from a few hundred yards to three miles, are separated from the mainland by shallow coastal lagoons, three to five miles wide (Miloy and Copp, 1970) (U.S. Army Engineer District, 1970). The terrain, climate and weather of the Texas gulf coast region are generally favorable for year-round recreation and contribute to a high potential for development.

The major part of the recreational and tourism growth is occurring around the urban centers, with pockets of development spotted along the coast. Large areas of the coastline, which have been designated by the Coastal Resources Management Program of the Office of the Governor as recreational beaches, are still used primarily for cattle grazing (Bureau of Economic Geology, the University of Texas at Austin, 1970). The major parks and recreational areas along the Texas coast are listed in Table II-1 and are shown in Figure II-11.



Numbers refer to Table II-1.

Figure II-11. Major Park and Recreation Areas of the Coastal Zone.

Table II-1. Major Parks and Recreation Areas Along the Texas Coast.

NUMBER[1]	PARKS AND RECREATION AREAS
1.	J.D. Murphree Wildlife Management Area
2.	Proposed Texas State Park in Jefferson County
3.	Public Beach, Jefferson County
4.	Anahuac National Wildlife Refuge
5.	Chambers County Parks
6.	Galveston County Parks
7.	Public Beach, Galveston County
8.	Galveston Island State Park
9.	Brazoria National Wildlife Refuge
10.	Velasco State Park
11.	Brazoria County Parks
12.	San Bernard National Wildlife Refuge
13.	Public Fishing Pier, Palacious
14.	Port Lavaca Causeway State Park
15.	Pulbic Fishing Piers, Port Lavaca
16.	Indianola Park, Calhoun County
17.	City Park, Port O'Connor
18.	Matagorda Island Bombing and Gunnary Range
19.	City Park, Seadrift
20.	Aransas National Wildlife Refuge
21.	Goose Island State Park
22.	Copano Bay State Park
23.	City Parks, Rockport
24.	City Park and Pier, Bayside
25.	Port Aransas Park, Nueces County
26.	San Patricio County Park
27.	Proposed Mustang Island State Park
28.	Corpus Christi City Parks
29.	Nueces County Parks

Table II-1. Major Parks and Recreation Areas Along the Texas Coast.(Con't)

NUMBER	PARKS AND RECREATION AREAS
30.	Kleberg County Parks
31.	Padre Island National Seashore
32.	Cameron County Parks
33.	Laguna Atascosa National Wildlife Refuge
34.	Port Isabel Lighthouse State Park
35.	Brazos Island State Park

[1] The numbers refer to Figure II-11.

Federally owned lands along the coast are administered by the Department of the Interior (National Parks Service and Bureau of Sport Fisheries and Wildlife) and the Defense Department (Department of the Air Force). These federally owned lands (317,500 acres) include land set aside for both conservation and recreation.

Padre Island National Seashore, administered by the National Park Service, occupies 80 miles and 132,200 acres of Padre Island. Besides being one of the last natural seashores in the nation, Padre Island is a wintering area for migratory waterfowl. The island offers numerous recreational activities including swimming, camping, surfing, surf fishing, hiking, birdwatching, beachcombing, scuba diving and sunbathing. In 1971, Padre Island had 904,365 visitors and 105,300 campers (National Park Service, 1971).

The Bureau of Sport Fisheries and Wildlife, administers five National Wildlife Refuges on the Texas coast (see Figure II-12). These refuges furnish wintering areas for thousands of migratory waterfowl,

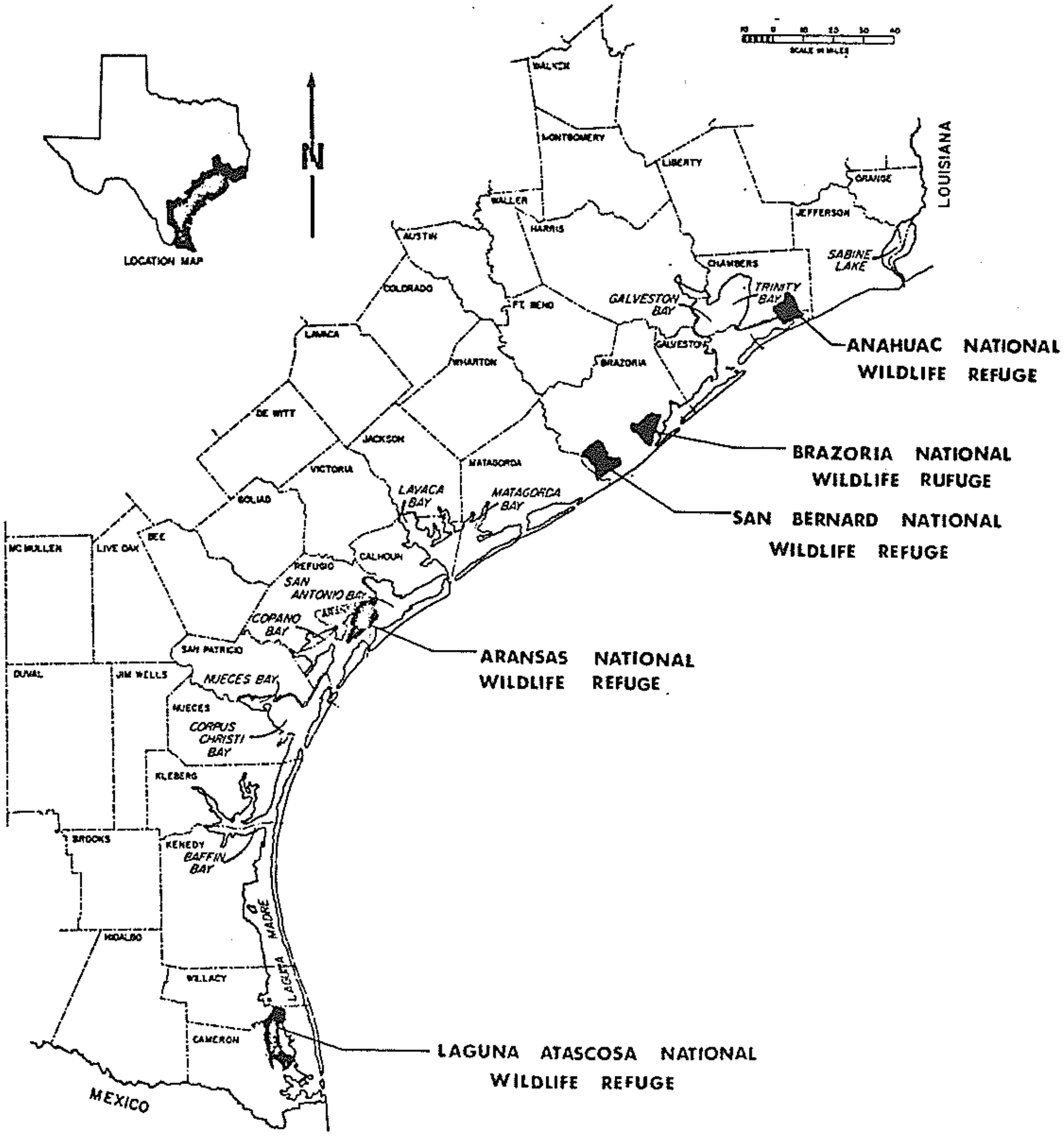


Figure II-12. Wildlife Refuges of the Coastal Zone.

water birds, shorebirds, and numerous other species of wildlife. They also offer numerous recreational opportunities for birdwatching, photography, fishing, hiking, picnicking, and camping. The National Wildlife Refuges located on the Texas coast are: Anahuac, Aransas, Brazoria, Laguna Atascosa, and San Bernard National Wildlife Refuges (Reed and Reid, 1969)(U.S. Fish and Wildlife Service, 1972).

Anahuac National Wildlife Refuge, which is located on East Bay of Galveston Bay, occupies 9,940 acres in Chambers County. The primary species for this refuge are: Lesser Canada, snow, and blue geese; mottled ducks; masked ducks; canvasbacks; yellow rails; red wolves; alligators; bald eagles; and peregrine falcons. Visitors to Anahuac National Wildlife Refuge numbered 11,580 in 1970 and participated in nature observation, photography, and sightseeing (U.S. Fish and Wildlife SErvice, 1971)(U.S. Fish and Wildlife Service, 1969)(U.S. Fish and Wildlife Service, 1972).

Aransas National Wildlife Refuge, the wintering ground for the rare whooping crane, occupies 54,830 acres in Calhoun, Aransas, and Refugio Counties. The primary species on the Aransas Refuge are: whooping cranes, sandhill cranes, roseate spoonbills, egrets, herons, peregrine falcons, geese, ducks, turkeys, shorebirds, deer, peccaries, caracaras, white-tailed hawks, Texas red wolves and alligators. The refuge has several miles of roads which allow visitors to observe and photograph the wildlife in a variety of habitats. There are also trails for hiking, picnic areas, and camping areas (by permission of the refuge manager and for organized groups only). The Aransas National Wildlife Refuge is the largest on the Texas coast, and receives the highest visitation -- 94,000 people visiting the refuge in 1970 (U.S. Fish and Wildlife Service, 1971)(U.S. Fish and Wildlife Service, 1971, Aransas National Wildlife Refuge)(U.S. Fish and Wildlife Service, 1972).

Brazoria National Wildlife Refuge, located on the Coastal Plain of southeast Texas (17 miles southeast of Angleton) contains 9,530 acres of coastal marsh and prairies in Brazoria County. Three-fourths of the refuge is less than four feet in elevation, and spoil bank knolls and windbreak plantings are the only break in the marsh vegetation. The primary species of this refuge are: geese, ducks, red wolves, alligators, and muskrats. The refuge offers public hunting and fishing in limited areas, sightseeing, birdwatching, and nature photography. The refuge office, which also administers the San Bernard National Wildlife Refuge, is located in Angleton, Texas. Brazoria National Wildlife Refuge is the smallest refuge on the Texas coast and had 524 visitors in 1970 (U.S. Fish and Wildlife Service, 1971)(U.S. Fish and Wildlife Service, 1965)(U.S. Fish and Wildlife Service, 1972).

Texas' second largest wildlife refuge, Laguna Atascosa National Wildlife Refuge, occupies 45,150 acres in Cameron County. Located twenty-five miles northeast of San Benito, this refuge was established in March of 1946 to serve as a wintering and feeding ground for migrating ducks and geese. The primary species for Laguna Atascosa National Wildlife Refuge are: geese, ducks, herons, ibises, shorebirds, gulls, terns, doves, cranes, white-tailed hawks, and white-tailed kites. The refuge offers a variety of habitat including coastal prairies, salt flats, and low wooded ridges. Subtropical forms, such as the ocelot and the jaguarundi, occur along with species from the northern latitudes. Tour roads, hiking trails, and blinds are provided for visitors to use in sightseeing, nature study, and photography. Camping is permitted in designated areas, and saltwater fishing and boating are allowed in the Intracoastal Canal. Laguna Atascosa National Wildlife Refuge received 39,850 visitors in 1970 (Reed and Reid, 1969)(U.S. Fish and Wildlife Service, 1971)(U.S. Fish and Wildlife Service, 1965, Mammals of the Laguna Atascosa National Wildlife Refuge)(U.S. Fish and Wildlife Service, 1972).

San Bernard National Wildlife Refuge, which was established in November of 1968, is Texas newest wildlife refuge. The refuge contains 14,920 acres in Brazoria and Matagorda counties and is currently administered by the Angleton office of the U.S. Fish and Wildlife Service. The primary species for this refuge are: geese, ducks, wading birds, shorebirds, and red wolves. The waterfowl population averages about 3,000 Canadian geese, 74,000 blue and snow geese, and less than 20,000 ducks. Because the refuge was not staffed until September, 1972, estimates of the populations for other wildlife species are not available. In 1970, the San Bernard National Wildlife Refuge received 538 visitors (U.S. Fish and Wildlife Service, 1971) (U.S. Fish and Wildlife Service, 1972).

Attendance by activities at the National Wildlife Refuges along the Texas coast are listed in Table II-2. It can be seen that the refuge with the most visitors is Aransas National Wildlife Refuge with 80,000 visitors and Laguna Atascosa Natural Wildlife Refuge is second with 40,000 visitors.

The United States Air Force administers Matagorda Island Gunnery and Bombing Range, which occupies 51,000 acres in Aransas County. The

Table II-2. Attendance by Activities at the National Wildlife Refuges Along the Texas Coast.

ACTIVITY	ATTENDANCE	
	1970	1971
Anahuac National Wildlife Refuge [1]		
Fishing: Saltwater	6,051	5,550
Wildlife Photography	133	204
Wildlife Observation	5,077	5,739
Wildlife Tours/Routes	200	264
Picnicking	5,605	6,162
Miscellaneous Wildlife	140	25
Camping	21	8
Actual Visits	11,576	18,552
Aransas National Wildlife Refuge [2]		
Total Registered Visitors	48,300	40,700
Visitors Using the Intra-Coastal Canal	8,200	13,100
Camping (groups)	103: 3,400	89: 3,500
Wildlife Tours	3,000	2,000
Commercial Visitors	22,600	24,000
Official Visitors	1,300	1,100
Total Visitors	94,000	80,000
Brazoria National Wildlife Refuge [3]		
Fishing: Saltwater	212	315
Environmental Education	11	15
Wildlife Photography	2	1
Wildlife Observation	40	41
Wildlife Tours/Routes	3	6
Miscellaneous Wildlife	77	145
Miscellaneous Non-Wildlife	117	127
Hunting	0	92
Actual Visits	524	797
San Bernard National Wildlife Refuge [4]		
Fishing: Saltwater	407	353
Environmental Education	7	0

Table II-2. (Cont.)

Wildlife Observation	21	14
Miscellaneous Wildlife	15	32
Miscellaneous Non-Wildlife	88	109
Actual Visits	538	508
Laguna Atascosa National Wildlife Refuge [5]		
Hunting	1,440	1,848
Fishing: Saltwater	24,605	20,916
Environmental Education	298	1,520
Wildlife Photography	315	63
Conducted Programs	0	123
Wildlife Trails	1,086	624
Wildlife Tours/Routes	11,428	13,170
Visitor Contact Stations	41	288
Camping	521	1,375
Picnicking	3,055	1,800
On-Site Programs	826	693
Miscellaneous Wildlife	498	176
Group Camping	467	588
Horseback Riding	2	3
Bicycling	16	99
Miscellaneous Non-Wildlife	125	637
Actual Visits	39,846	40,002

[1] From the Recreational Use Reports of the 1970 and 1971 Annual Narrative Reports of Anahuac National Wildlife Refuge.

[2] From the Recreational Use Reports of the 1970 and 1971 Annual Narrative Reports of Aransas National Wildlife Refuge.

[3] From the Recreational Use Reports of the 1970 and 1971 Annual Narrative Reports of Brazoria National Wildlife Refuge.

[4] From the Recreational Use Reports of the 1970 and 1971 Annual Narrative Reports of San Bernard National Wildlife Refuge.

[5] From the Recreational Use Reports of the 1970 and 1971 Annual Narrative Reports of Laguna Atascosa National Wildlife Refuge.

Gunnery and Bombing Range contains about 43,000 acres suitable for grazing, and has 8.5 miles of shoreline. An area of about 27,000 acres has been set aside as a recreation area for armed forces personnel, and numerous activities are offered, including: fishing, swimming, and hunting. White-tailed deer, quail, turkey, dove, ducks, and geese are hunted on the recreation area. The Air Force cooperates with the conservation efforts of the nearby Aransas National Wildlife Refuge and halts bombing at certain times during the year (Personal Communications, U.S. Air Force, 1972).

The State of Texas currently owns seven parks containing 3510 acres of designated park lands on the Gulf coast (Texas Parks and Wildlife Department, 1970). Two other areas totaling 17,720 acres have been proposed as additional state parks (a site in Jefferson County having 14,360 acres and a site on Mustang Island having 3,360 acres (Personal Communications, 1972). With the addition of these two proposed parks, the total state-owned areas of designated park lands would come to 21,230 acres. The State of Texas claimed public ownership of all lands between mean low water and mean high water by the Open Beach Law of 1959, which also claimed public access to these lands. However, the policies and principles concerning public and private rights to use the beaches of Texas are still considered uncertain and explanatory legislation and litigation are needed. Public ownership of all beaches makes several thousand more acres of beach available for recreational purposes. One state-owned wildlife management area, the J. D. Murphee Wildlife Management Area, is also located adjacent to the coast and offers opportunities for recreation (Texas Parks and Wildlife Department, 1970).

The Texas Parks and Wildlife Department administers all State Parks and Wildlife Management areas. Those areas which are located along the coast are: Brazos Island State Scenic Park, Copano Bay Causeway State Recreation Park, Galveston Island State Recreation Park, Port Isabel Lighthouse State Historic Site, Port Lavaca Causeway State Recreation Park, and Velasco State Park. The size, nature, and facilities of these parks differ greatly, and they are therefore considered separately here (Texas Parks and Wildlife Department, 1970)(Reed and Reid, 1969).

Brazos Island State Scenic Park, located on the top of Brazos Island in Cameron County, contains 217 acres. The park has no facilities and consists of undeveloped Gulf beach. Surfing, camping, fishing, picnicking, nature study, and swimming are the main activities.

Copano Bay Causeway State Recreation Park, located five miles north of Rockport in Aransas County, contains a total of six acres. This park consists of two fishing piers, totaling 8,700 feet in length, and concession facilities at each end of the causeway. Saltwater fishing is the primary activity, and picnicking is permitted.

Galveston Island State Recreation Park occupies 1,950 acres on Galveston Island. The park is currently closed to the public, pending development of the facilities.

Goose Island State Recreation Park, which is located on St. Charles and Aransas Bays, contains 307 acres in Aransas County. The park provides facilities for camping, boating, fishing, swimming, nature study, and picnicking.

Velasco State Park actually is a state park in name only. The

Texas Parks and Wildlife Department maintains no facilities there and owns no land, other than the land between mean-low and mean-high tides which is claimed under the Open Beach Law. Public access is provided, but the area is not proposed as a site for future land acquisition or operations.

The attendance figures for the Texas State Parks are summarized in Table II-3.

Municipal park and recreation areas are scattered along the Texas shores of the Gulf of Mexico. These areas are usually located near the population centers of the coastal zone and vary in size and abundance from county to county. Although there are over 5,000 acres of county and city parks, most (92%) of the total acreage is located in five counties (Brazoria, Calhoun, Cameron, Galveston, and Nueces). The conditions and facilities at these city and county parks vary greatly, ranging from primitive conditions with no facilities whatsoever, to areas having only restrooms, to areas which offer modern facilities and conveniences including restrooms with flush toilets, cabanas, concession areas, electrical hook-ups, barbecue grills, and lighted fishing piers (Texas Highway Department, Texas - Land of Contrast)(Texas Highway Department, Texas Public Campground Guide). The county and city parks are tabulated in Table II-4. The locations of the parks are shown in Figure II-13. The park number listed in the table corresponds to the park number given in the figure.

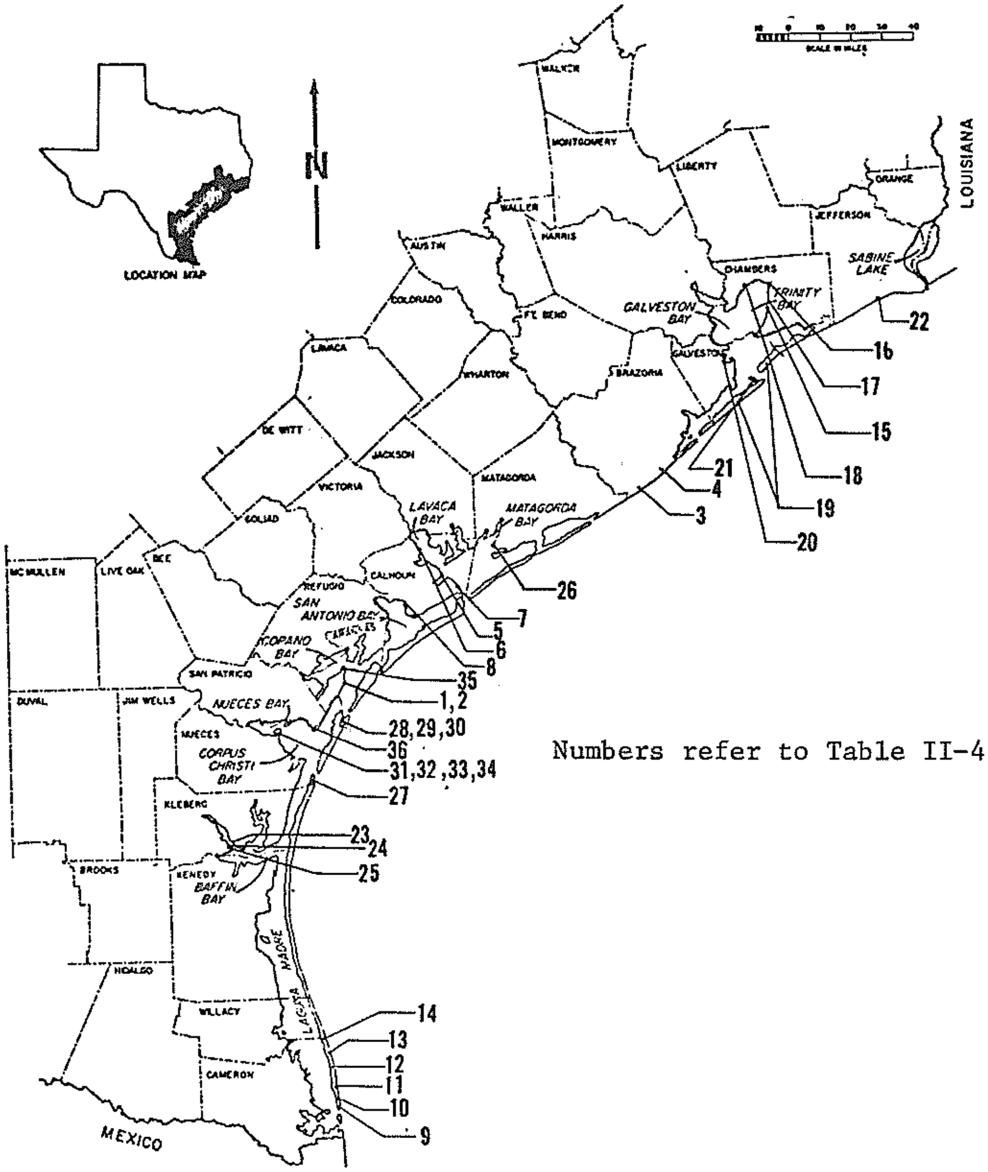
Wildlife in the Beach Zones

The beach zones of the Texas Gulf Coast provide feeding grounds, resting areas, and even nesting sites for several transient species of

Table II-3. 1970-71 Attendance at Texas State Parks on the Gulf Coast [1].

STATE PARK	OVERNIGHT	DAY USE	TOTAL
Brazos Island	1,409	5,946	7,355
Copano Bay	0	12,359	12,359
Galveston Island	5,002	53,442	58,444
Goose Island	24,902	192,939	217,841
Port Isabel	0	26,827	26,827
Port Lavaca	0	9,359	9,359
Velasco	140,000	410,000	550,000

[1] Estimates of attendance obtained from the Texas Parks and Wildlife Department.



Numbers refer to Table II-4.

Figure II-13. County and City Parks Along the Texas Coast.

Table II-4. County and City Parks Along the Texas Coast.

PARKS AND RECREATION AREAS BY COUNTY	WATERFRONTAGE	ACREAGE	ACTIVITIES AND FACILITIES
Aransas County [2] [3]	1.0 miles	[1]	
** 1 Rockport Beach		67 acres	2, 3, 5, 7, 8, 9
2 Navigation District #2		4 acres	2, 4, 5, 6, 8
Brazoria County [3]	[1]	[1]	
3 Quintana-Bryan Beach		157 acres	5, 6
4 Surfside Beach		304 acres	5, 6
Calhoun County [3] [7] [10]	2.6 miles	378 acres	
5 Indianola Park	1.0 miles	351 acres	1, 2, 3, 4, 5
City Parks	[1]		
6 Port Lavaca Fishing Pier		18 acres	1, 3, 4, 6, 8
7 Port O'Connor Park		5 acres	2, 4, 5
8 Seadrift Bayfront City Park		4 acres	2
Cameron County [3] [8]	1.0 miles	[1]	
9 Isla Blanca Park No. 1		148 acres	1, 2, 3, 4, 5, 7, 8, 9
10 Andy Bowie Park No. w		225 acres	1, 2, 3, 4, 5
11 Access Road and Parking Area No. 1		11 acres	1, 2, 3, 4, 5
12 Access Road and Parking Area No. 2		14 acres	1, 2, 3, 4, 5
13 Access Road and Parking Area No. 3		14 acres	1, 2, 3, 4, 5
14 Access Road and Parking Area No. 4		14 acres	1, 2, 3, 4, 5
Chambers County [3] [2] [10]	1,900 feet	[1]	
15 Double Bayou Park		20 acres	1, 2, 3, 4, 6, 8
16 Fort Anahuac Park		26 acres	1, 2, 3, 4, 5, 6, 8
17 Job Beason Park		12 acres	1, 2, 3, 4, 8
18 McCollum Park		[1]	1, 2, 3, 4, 5, 6, 8
Galveston County [4] [6]	app. 60.0 miles	[1]	
19 Public Beach		1300 acres	1, 2, 3, 4, 5, 8
20 Bay Shore Park		35 acres	1, 2, 3, 4, 5
21 Pelican Island and Seawolf Park		40 acres	1, 2, 3, 4, 5

Table II-4. (Continued.)

Jefferson County [5]			
22 Public Beach	5.0 miles	75 acres	1, 2, 3, 4, 5, 8
Kleberg County [2] [6] [10]	.7 miles	[1]	
23 Kleberg County Park		[1]	1, 2, 3, 4, 8
24 Loyola Beach		25 acres	1, 2, 3, 4, 8
25 Riviera Beach		[1]	1, 2, 3, 4, 8
Matagorda County [2] [6]	1,200 feet	[1]	
26 Palacios Park and Fishing Piers		[1]	1, 3, 4
Nueces County [2] [3] [10]		[1]	
County Parks	39,000 feet	[1]	
27 Padre Island Park		358 acres	1, 2, 4, 5, 7, 8
28 Port Aransas Park		137 acres	1, 2, 4, 5, 7, 8
29 Municipal Harbor (Port Aransas)		6 acres	3, 8
30 County Fishing Piers (2) (Port Aransas)		3 acres	4, 8
31 Breakwater Park		1 acre	4, 8
32 OSO Pier		1 acre	4, 7, 8
Corpus Christi City Park	3.0 miles	[1]	
33 Bayfront Park		11 acres	4, 5, 7
34 Cole Park		28 acres	4, 6
Refugio County [2] [3]	1,500 feet	[1]	
35 Bayside Park and Pier		4 acres	2, 4
San Patricio County [2] [9]	[1]	[1]	
36 County Park		4 acres	2, 3, 4, 5
City Parks	1,200 feet	[1]	
Willacy County [2]	800 feet	[1]	[1]

Table II-4. (Continued)

[1] Incomplete

[2] From Land Ownership Patterns by Mike McKann, 1970.

[3] From Inventory of Recreation Areas and Facilities by the Texas Parks and Wildlife Department, 1970.

[4] From personal communication, County Judge, Galveston County, 1972.

[5] From personal communication, County Judge, Jefferson County, 1972.

[6] From Texas-Land of Contrast, Texas Highway Department.

[7] From personal communication, Texas Parks and Wildlife Department, 1972.

[8] From personal communication, County Judge, Cameron County, 1972.

[9] From personal communication, County Judge, San Patricio County, 1972.

[10] From Texas Public Campground Guide, Texas Highway Department.

*Codes For Activities and Facilities.

Code Number	Activity or Facility
1	Camping
2	Picnicking
3	Boating and Water Skiing
4	Fishing
5	Swimming and Surfing
6	Playgrounds
7	Concessions (Restaurant, Bait Shops, Etc.)
8	Restrooms
9	Miscellaneous Park Facilities

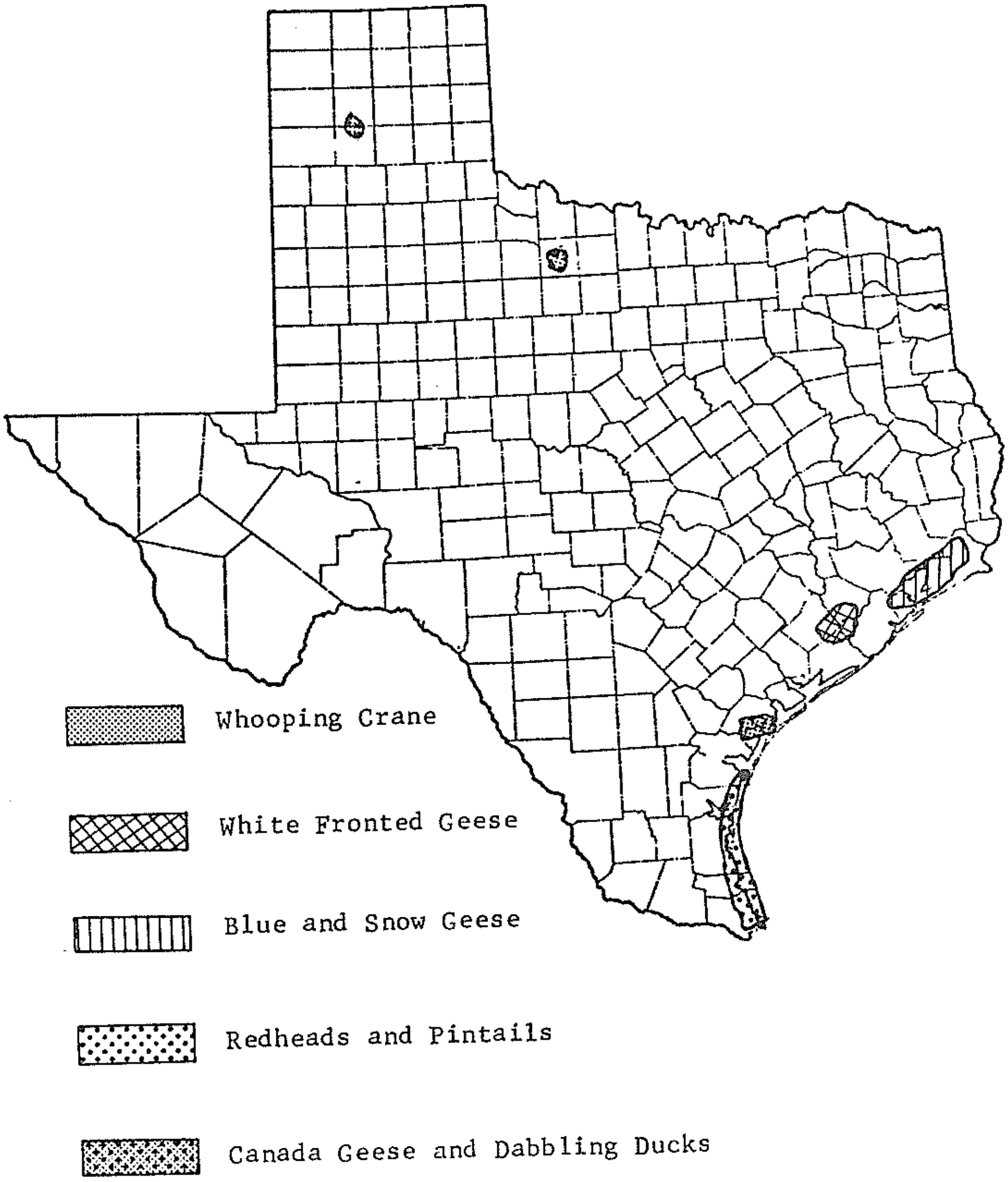
** Numbers refer to Figure II-13.

wildlife. The most numerous of these transients are the pelicans, shorebirds, gulls, and terns which feed and rest along the beaches. A few predatory mammals (coyotes, skunks, badgers, foxes, and raccoons) also visit the beaches in search of food. In addition, sea turtles come to the Texas coast to build their nests, lay eggs, and then retreat to the Gulf.

Wildlife in the Estuaries and Coastal Marshes

The estuaries and coastal marshes, which are perhaps the most productive areas in the world, provide habitat for numerous species of wildlife. Texas' 359 miles of coastal marshes and 1,526,389 area-surface acres are considered to "harbor some of the finest waterfowl concentrations on the continent" (Peterson, 1967; Beasley, 1967; Outdoor Recreation Resources Review Commission, 1962). These areas, which annually draw about two million birds to Texas, also contain large numbers of mammals, reptiles, and amphibians (see Tables B-1 through B-10 and B-12 of Appendix B).

Although there are several species of predatory birds, aquatic birds are the most numerous form of wildlife in the estuaries and coastal marshes. Over 140 species of aquatic birds (waterfowl, water and shore birds, gulls, terns, and waders) have been reported in the National Wildlife Refuges along the Texas coast (see Tables B-1 through B-5 of Appendix B). The locations of the peak concentrations of these birds varies for each species, according to their habits, food, and temperature preferences. For example, blue and snow geese prefer the northern areas of the Texas coast while red head and pintail ducks winter in the more southerly Laguna Madre area.



Source: U. S. Study Commission - Texas, 1962.

Figure II-14. Major Waterfowl Wintering Areas.

Table II-5. Midwinter Waterfowl Populations.

Species	Coastal Areas		Inland Areas of Texas		
	Louisiana to Matagorda Bay	Matagorda Bay to Mexico	Southwest	Northwest	Northeast
Ducks: (Dabblers)					
Mallard	40,827	117	35,025	992,506	129,700
Black Duck	--	--	--	--	--
Mottled Duck	41,863	107	--	--	--
Gadwall	265,216	845	22,105	25,790	8,100
American Widgeon	140,794	12,370	24,180	146,545	9,400
Green-winged teal	353,777	3,847	10,810	90,104	16,350
Blue-winged teal	66,439	351	1,730	--	--
Cinnamon teal	--	--	85	1	--
Shoveler	247,602	2,259	1,490	6,127	2,450
Pintail	555,364	67,255	62,525	665,867	6,350
SUBTOTAL: (Dabblers)	1,711,882	87,151	157,950	1,926,940	172,350
Ducks: (Divers)					
Redhead	6,615	102,459	555	1,697	850
Canvasback	11,540	579	1,665	1,532	700
Scaup	33,393	4,541	550	1,052	8,550
Ring-necked duck	4,907	15	1,695	1,030	--
Goldeneye	131	10	170	991	--
Bufflehead	1,084	847	945	2,459	1,200
Ruddy Duck	1,018	163	85	5,136	--
SUBTOTAL: (Divers)	58,688	108,614	5,665	13,897	11,300
Mergansers	728	103	80	4,327	--
Unident. & misc. ducks	175	210	6,460	20,157	--

Table II-5. Page 2

Geese:					
Snow geese	197,841	9,357	5	1,727	250
Blue geese	89,387	4,010	--	--	--
Ross' geese	--	--	--	1	--
White-fronted geese	17,588	3,304	--	--	--
Canada geese:					
Gt. Basin	--	--	--	--	--
Large	213	506	--	--	--
S. G. Pr.	--	--	--	108,160	8,000
T. G. Pr.	13,248	8,099	--	--	12,200
Mixed	--	--	--	5,750	--
Total Canada Geese	13,461	8,605	30	113,910	20,200
TOTAL GEESE	318,277	25,276	35	115,638	20,450
Whistling Swan	--	--	6	--	--
Trumpeter Swan	--	--	--	--	--
Coot	128,865	20,607	7,720	10,684	85,800
TOTAL WATERFOWL	2,218,615	241,961	177,910	2,091,643	289,900

Source: 1971 - 1972 Midwinter Waterfowl Survey, U.S. Fish and Wildlife Service and the Texas Parks and Wildlife Department.

Most of the mammals which inhabit the estuaries and coastal marshlands are terrestrial species, although a few aquatic or marine species do occur there. Numerous rabbits and rodents inhabit the coastal marshlands, including three large aquatic rodents (beaver, muskrat, and nutria) which have been observed in the National Wildlife Refuges (see Tables B-7 through B-10 of Appendix B). The large rodent population of rats and mice makes up a large part of the diet of the many predators found there. Raccoons, skunks, coyotes, bobcats, and other predatory mammals are found throughout the coastal zone and are numerous in the coastal marshes (see Tables B-7 through B-10 of Appendix B). Dolphins (or porpoise) are the most numerous marine mammal observed in the estuaries; however, they seem to be decreasing in numbers. The other marine mammals reported along the Texas coast (see Tables B-6 and B-11 of Appendix B) are considered rare, endangered, or extinct -- for example, the West Indian Seal, which has not been seen in many years.

Many species of reptiles and amphibians may be found in the coastal marshes (see Table B-12 of Appendix B). Freshwater ponds offer nearly ideal habitats for aquatic and semi-aquatic species, while the large expanses of marsh grasslands are inhabited by terrestrial reptiles. In some areas, venomous snakes, especially rattlesnakes and water moccasins, which are widespread along the entire coastal zone, reach dangerous proportions. Most of these animals, except the venomous snakes and the American alligator (an endangered species) receive little attention from the human population.

Wildlife on the Barrier Islands and Uplands

Wildlife is plentiful on the barrier islands and coastal uplands of the Texas coast. Hundreds of birds, along with many mammals, reptiles, and amphibians, can be found in these areas (see tables B-1 through B-12 of Appendix B). Most of these species are common to both the barrier islands and the uplands, as well as being permanent or transient inhabitants of the intervening marshlands. Although some species of wildlife normally range only along certain sections of the Texas coast, most can be found along its entire length.

The birds, which are numerous all along the coast, are the predominant life form on the barrier islands and uplands. Songbirds and predaceous birds are most abundant in the uplands and are joined by numerous aquatic species on the barrier islands (see Table B-1 and Figures B-1 through B-10.

In addition, numerous mammals (including white-tailed deer and javelina) live in the uplands and on the barrier islands. With the exceptions of the cougar, jaguar, and some tropical species, the same predators appear all along the coast. Rodents and rabbits occur in both areas, but are probably more numerous on the uplands (see Tables B-6 through B-11 of Appendix B).

Although mostly the same species of reptiles and amphibians are found along the entire coast, concentrations of specific species vary with local conditions (see Table B-12 of Appendix B). Aquatic species are few or lacking along some stretches of the coast but reappear in other areas. Rattlesnakes, copperheads, coral snakes and water moccasins, the only venomous species found in North America, are numerous here.

HYDROGRAPHY OF CONTINENTAL SHELF OFF TEXAS

Temperature, Salinity and Oxygen

Temperature, salinity and oxygen distributions on the continental shelf of Texas were studied by several authors of the Institue of Marine Sciences, University of Texas, and of Galveston Marine Laboratory of Bureau of Commercial Fisheries in connection with biological studies.

Several observations southeast off Port Aransas to 25 n miles (46 km) offshore in 1962 to 1963 indicate that the thermocline develops only from May to September beyond 10 n miles (18 km) from the coast at about 10 to 30 m depths with gradients of temperature from 0.5°F per meter to 2°F per meter with thickness of 3 to 20 meters (Jones, Copeland and Hoese, 1965). In winter time however, surface salinity and temperature are low within 10 miles (18 km) of the coast, and thus the pycnocline is formed at 10 to 20 m depths.

Farlund (1963) measured temperature and salinity on the beach at one-mile intervals along Mustang Island in 1959 and 1960 almost weekly. Temperature varies from 12°C in January and February to 32° in July and August and salinity varies rather randomly from 28°/oo to 38°/oo with summertime generally high above 32°/oo. Oxygen is between 5 and 9 mg/liter and in general high in November to March and low in summer season when both the effect of high temperatures and salinities reduce the saturation dissolved oxygen level.

There are no turbidity data but Cuzon de Rest (1963) reported measurements of turbidity in 1959 to 1960 on the Louisiana coast.

The data indicate that turbidity was higher from January to April whereas the low values are recorded during the early summer and fall when the sea is relatively calm and the freshwater runoff low.

Waves

Information concerning waves in the Gulf region was obtained from climatological and oceanographic Atlas of Mariners Volume I - North Atlantic Ocean. In general, the seas are calm in the summer and early fall and moderate during the winter and early spring. Waves greater than 5 ft (2 m) occur about 20% of the time during the year. Table II-6 lists the occurrence of wave height for each season of the year.

Table II-7 lists the wave characteristics for the different wind conditions. The minimum fetch and duration to obtain fully developed seas are also listed. Approximately 80% of the time the wave period will be less than 8 seconds and the wave length less than 300 ft (100 m). The last column in Table II-7 was included in the report to show that extremely long waves can be generated and could cause movement of sediments at depths of 60 ft (20 m). Waves become shallow water waves at depths of about 1/20 their wave lengths. Table II-8 lists the percentage frequency of wave heights and frequency off the Galveston Coast. Wave periods greater than 13 seconds seldom occur and the wave heights are generally less than 16 ft.

Winds

The oil on the water surface will mainly move with the wind and the resulting motion of the oil slick will be the vector sum of the

Table II-6. Occurrence of Waves in the Gulf.

WAVE HEIGHT RANGE Feet	METERS	SEASON SUMMER	FALL	WINTER % of time	SPRING	AVERAGE
< 2	< 1	50	30	30	40	37
2-5	1-2	40	45	45	45	44
5-10	2-3	9	24	23	14	18
> 10	> 3	1	1	2	1	1

Source: Climatological and Oceanographic Atlas for Mariners.

Table II-7. Conditions in Fully Developed Seas (from Bascom, 1964).

Wind Velocity		Fetch		Duration	WAVE CHARACTERISTICS					Shoaling Depth(4		Shallow water Wave Depth(5		Breaking Depth	
					Height(1		Period(2	Length(3							
(kts)	(m/s)	(miles)	(km)	(hours)	(ft)	(m)	(sec)	(ft)	(m)	(feet)	(m)	(ft)	(m)	(ft)	(m)
10	5	10	18	2.4	1.4	0.4	4	80	25	40		4	1.2	2.0	0.6
15	8	34	60	6.0	3.5	1.0	6	180	55	90		9	2.7	5.0	1.5
20	10	75	140	10.0	8.0	2.4	8	320	100	160		16	4.9	11	3.3
25	13	160	300	16.0	14.0	4.3	10	500	150	250		25	7.7	19	5.8
30	15	280	520	23.0	22.0	6.7	12	740	230	370		37	11	29	8.8
40	21	710	1300	42.0	44.0	13.4	16	1300	400	650		65	20	55	17.
50	26	1420	2600	69.0	78.0	24.	20	2000	600	1000		100	30	100	30.

(1 Average of highest 1/3.

(2 Period (T) where most of the energy is concentrated.

(3 $L(ft) = 5.12\ T^2$

(4 Wavelength/2

(5 Wavelength/20

Table II-8. Percent Frequency of Wave Height and Period - Galveston

PERIOD (Seconds)	HEIGHT (feet)							
	< 1	1-2	3-4	5-6	7	8-9	10-11	12-16
< 6	1.7	19.0	25.9	9.0	2.7	1.3	0.2	0.2
6-7	0	2.0	5.7	10.5	4.6	2.5	0	0.2
8-9	0	0.8	0.5	1.6	2.0	0.6	0.6	0.5
10-11	0	0.6	0.3	0	0.6	0.3	0.2	0
12-13	0	0	0.2	0	0	0	0	0
> 13	0	0	0.3	0.2	0	0	0	0

Source: Summary of Synoptic Meteorological Observations, North American Coastal Marine Areas, Vol. 6.

wind and the water current. The oil slick velocity is generally taken as 3 to 4 percent of the wind speed. The percentage frequency of wind direction and velocity are listed in Table II-9 for the Galveston and Corpus Christi Coastal areas. It can be seen that the most frequently occurring directions are from the E-SE-S with 55 percent of the winds from this quadrant off Galveston and 61 percent from this quadrant off Corpus Christi. Only about 15 percent of the time does the wind have an eastward component.

Surface Currents off Texas Coasts

Table II-10 is an excerpt from the charts "Central American Waters: Current Charts", H. O. Misc., No. 10, 690-1 (1942). The table indicates mean velocity (in knots), direction and number of observations at five 1° squares off the Texas coast. In segments I and II, the current velocity is 0.2 to 0.8 knots with direction mostly west or WNW. In segments III to V velocity is small and directions vary though often currents move coastwards. Values given in the table are based on a small number of observations, mainly ship drift which would include a wind component. Since the wind and the current would tend to be in the same direction, these values are probably higher than the actual water currents.

Littoral Transport

Much of the information listed below as littoral transport is from U.S. Corps of Engineers 1971 report on the National Shoreline Study. Throughout most of the year the prevailing winds along the Texas coast are from the south and southeast. From the Louisiana border, the coastline extends generally southwest to the coastal bend

Table II-9. Percent Frequency of Wind Direction and Velocity.

WIND DIRECTION	Galveston Area PERCENT FREQUENCY	Galveston Area MEAN SPEED Knots	Galveston Area MEAN SPEED M/Sec	Corpus Christi Area PERCENT FREQUENCY	Corpus Christi Area MEAN SPEED Knots	Corpus Christi Area MEAN SPEED M/Sec
N	7.4	14.6	7.5	7.8	17.4	9.0
NNE	4.2	14.1	7.2	4.9	15.5	8.0
NE	8.2	12.8	6.6	7.3	12.8	6.6
ENE	4.7	12.9	6.6	4.6	12.2	6.3
E	11.8	11.5	5.9	10.9	10.8	5.6
ESE	7.8	11.4	5.8	8.8	12.2	6.3
SE	15.8	11.4	5.8	19.3	12.4	6.4
SSE	8.5	12.0	6.2	11.3	13.4	6.9
S	11.0	10.9	5.6	11.1	12.4	6.4
SSW	3.2	10.6	5.4	2.4	11.7	6.0
SW	3.3	9.5	4.9	1.9	10.1	5.2
WSW	1.4	9.6	4.9	0.6	9.9	5.1
W	2.7	10.3	5.3	1.3	10.0	5.0
WNW	1.7	12.4	6.4	0.9	12.8	6.6
NW	3.3	13.7	7.0	2.5	14.6	7.5
NNW	2.3	15.0	7.7	2.5	16.7	8.6

Source: Summary of Synoptic Meteorological Observations - North American Coastal Marine Areas, Vol. 6.

Table II-10. Currents off the Texas Coast.[1]

Item[2]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
I.	ϕ > 29°, λ 93-94° Off Sabine											
Vel.	·82	·75	·73	·62	·78	·48	·39	·52	·64	·62	·68	·59
Dir.	W	W	W	W	WNW	W	WNW	WNW	W	WNW	WNW	WNW
No. 0	119	147	211	194	248	262	243	390	240	217	191	169
II.	ϕ > 29°, λ 94-95° Off Galveston											
Vel.	·35	·38	·37	·44	·38	·27	·18	·30	·36	·41	·25	·35
Dir.	W	W	W	W	W	W	NNW	WNW	W	WSW	W	W
No. 0	113	127	159	169	181	177	152	179	156	139	157	114
III.	ϕ 28-29°, λ 95-96 Off Freeport-Matagorda											
Vel.	·06	·29	·15	·17	·27	·26	·23	·10	·13	·25	·19	·17
Dir.	WSW	SW	NE	N	NNE	NNW	NE	SW	W	NW	SSW	
No. 0	6	16	13	16	16	16	23	20	15	15	10	7
IV.	ϕ 27-28°, λ 96-97° Off Corpus Christi											
Vel.	·14	·21	·19	·30	·21	·25	·20	·28	·24	·22	·20	·35
Dir.	WNW	WSW	WNW	NW	NNW	WNW	N	NW	W	NNW	WNW	SW
No. 0	24	33	46	15	45	54	59	60	58	29	39	34
V.	ϕ 26-27°, λ 95-97° Off Mansfield											
Vel.	·26	·57	·16	·12	·24	·53	·85	---	---	----	·59	
Dir.	N	NNE	NNW	N	NNW	NNE	NNE	---	---	---	N	
No. 0	3	10	5	2	6	5	6	---	---	---	3	

---

[1] Based on "Control American Waters: Current Charts." H.O. Misc. No. 10, 690-1, 1942, Data to 1935.

[2] ITEM

I.	Segment
Vel.	Knots
Dir.	Towards
No. 0	No. of observations

area in the Corpus Christi vicinity, and from that point generally south to the Mexican border. With this shoreline configuration, the waves generated by the south to southeast winds produce a net littoral transport from northeast to southwest along the upper coast, and from south to north along the lower coast. Frequently during the winter months, and occasionally during other seasons, changes in wind directions reverse the directions of littoral transport for short periods of time. The general littoral movements of beach and shore materials along the Gulf shore are interrupted both by artificial structures and by tidal currents through passes between the Gulf and inland bays. Major natural passes exist at Sabine Pass, Galveston Bay entrance, San Luis Pass, Pass Cavallo, Aransas Pass and Brazos Santiago Pass. Four of these - Sabine Pass, Galveston Bay entrance, Aransas Pass and Brazos Santiago Pass - have been improved for deep-draft navigation and have stone jetties extending considerable distances into the Gulf of Mexico. Similar jetties have been provided for improved navigation channels at the old Brazos River entrance near Freeport, Matagorda Ship Channel entrance through Matagorda Peninsula near Port O'Connor and the Port Mansfield Channel entrance through Padre Island north of Port Isabel. In addition to those mentioned above, there are permanent openings in the shoreline at the mouth of the Brazos River Diversion Channel, San Bernard River and the Colorado River. An authorized navigation improvement of the mouth of the Colorado River will provide jetties extending into the Gulf. Rollover Pass, a former intermittent or wash-over pass through Bolivar Peninsula, has been improved for tidal exchange and passage of fish between East Bay and the Gulf and is now permanently open. A number of other intermittent passes at various locations are opened when hurricanes cross the coast. Following the storm, these passes may remain open for periods ranging from a few weeks to several years before being closed by natural shore processes. Two of the more permanent passes of this nature are Brown Cedar Cut and Greens Bayou, both connecting Matagorda Bay with the Gulf through Matagorda Peninsula. The natural and man-made passes and channels disrupt the normal longshore drift by increasing the deposition adjacent to and in the passes. All of the navigation entrances are maintained periodically by hopper dredges, with the excavated material being deposited in deeper water several miles offshore in the Gulf. Other factors affecting the rate and volume of littoral transport are the sediments carried to the Gulf by the major rivers along the coast and the longshore currents affecting movement of materials within the littoral zone. For the most part, nearshore currents parallel the coast and move from the upper coast toward the lower coast. Farther offshore, the Gulf stream moves in the opposite direction. Along the upper coast, the Sabine, Neches and Trinity Rivers carry mostly fine sediments to the coast and do not supply significant volumes of sands to the beaches and shore. The Brazos, Colorado and intervening rivers southward to the Rio Grande carry larger percentages of sandy materials and during flood periods, contribute considerable sand to the Gulf and its shore processes. In the coastal bend area between Pass Cavallo and Aransas Pass, littoral transport is subject to reversal more frequently than along the remainder of the coast and at times, fine materials are probably lost directly offshore in those reaches where the approach direction of prevailing waves is approximately normal to the shoreline.

Bottom Topography and Sediments of the Texas Shelf

Information concerning the topography and sediments of the Texas shelf may be found in Lynch (1954), Nienaber (1963), Shepard, et al., (1960), and Stetson and Trask (1953). Between Galveston and the Rio Grande the Texas shelf is essentially a featureless plain varying in width from 100 miles on the northeast to about 50 miles on the southwest. The slope, though gradual, is not uniform, being greatest beyond the 50-fathom contour. The monotony of the shelf plain is broken by a string of coral heads in 6-8 fathoms of water off the Brazos River (Mattison, 1948) and by another group of coral heads in 30-40 fathoms off Corpus Christi (Smith, 1948).

In marked contrast with the shelf, the continental slope, beyond 100 fathoms, is steeper and of highly irregular contour. Knobs, ridges, domes, and canyons are characteristic of this zone.

Nearshore surface sediments, out to 6-10 miles from shore, are mostly coarse grain sands which are worked and reworked by waves and longshore currents. This zone is broken periodically by sedimentary fans of predominantly clay-silt off the mouths of rivers and passes. Beyond the 5-fathom contour the grain size of the sand tends to decrease, and the sands become mixed with clays and silts. In deeper water, especially to the west, the silts and clays predominate. The tendency toward reduced particle size with depth is accompanied by a general tendency toward increasing organic content, calcium carbonate content, and water content of the surface sediments (see Figures II-15, II-16).

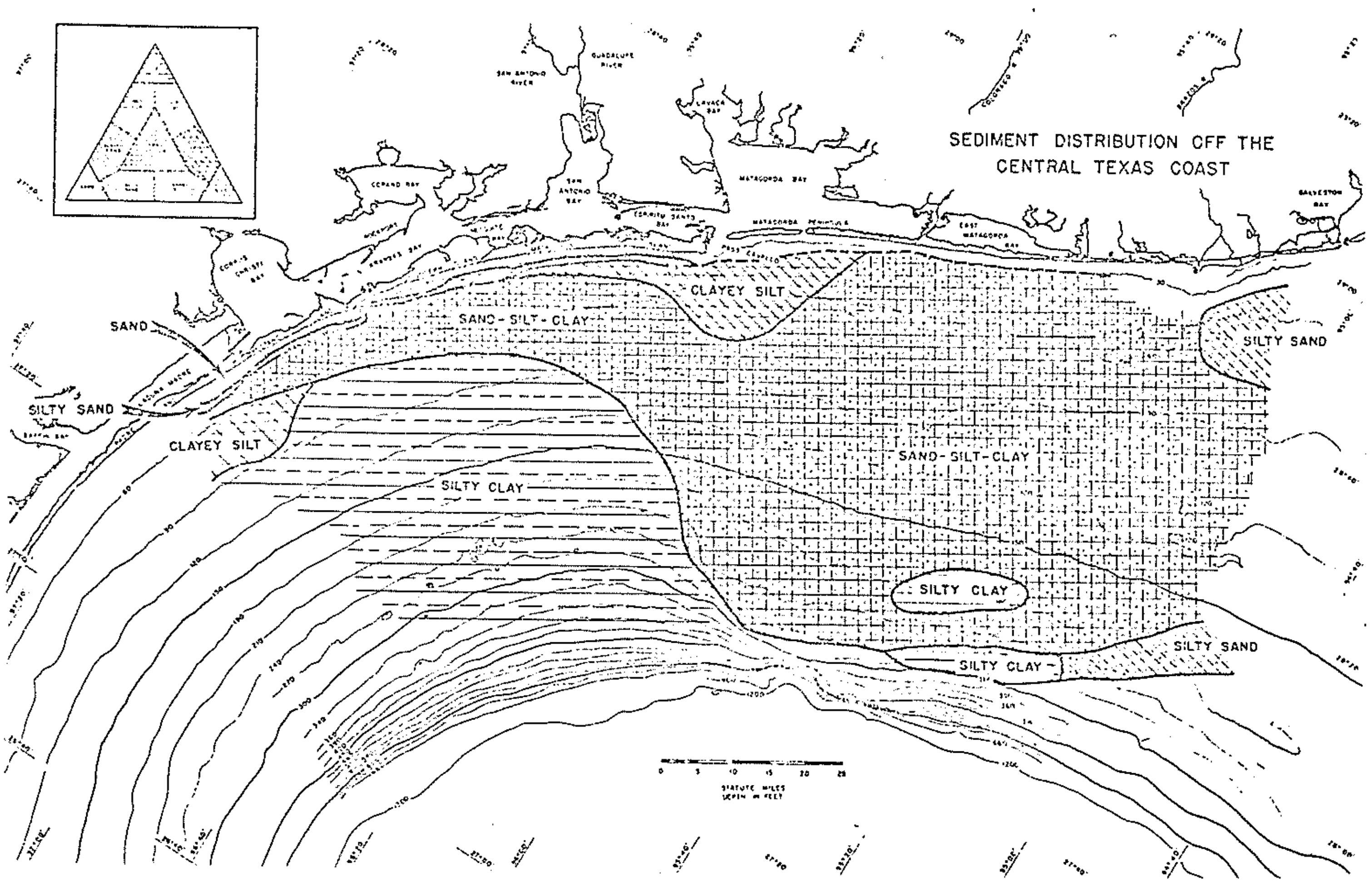


Figure II-15. Sediment Distribution, Continental Shelf Off Central Texas (after Stetson and Trask).

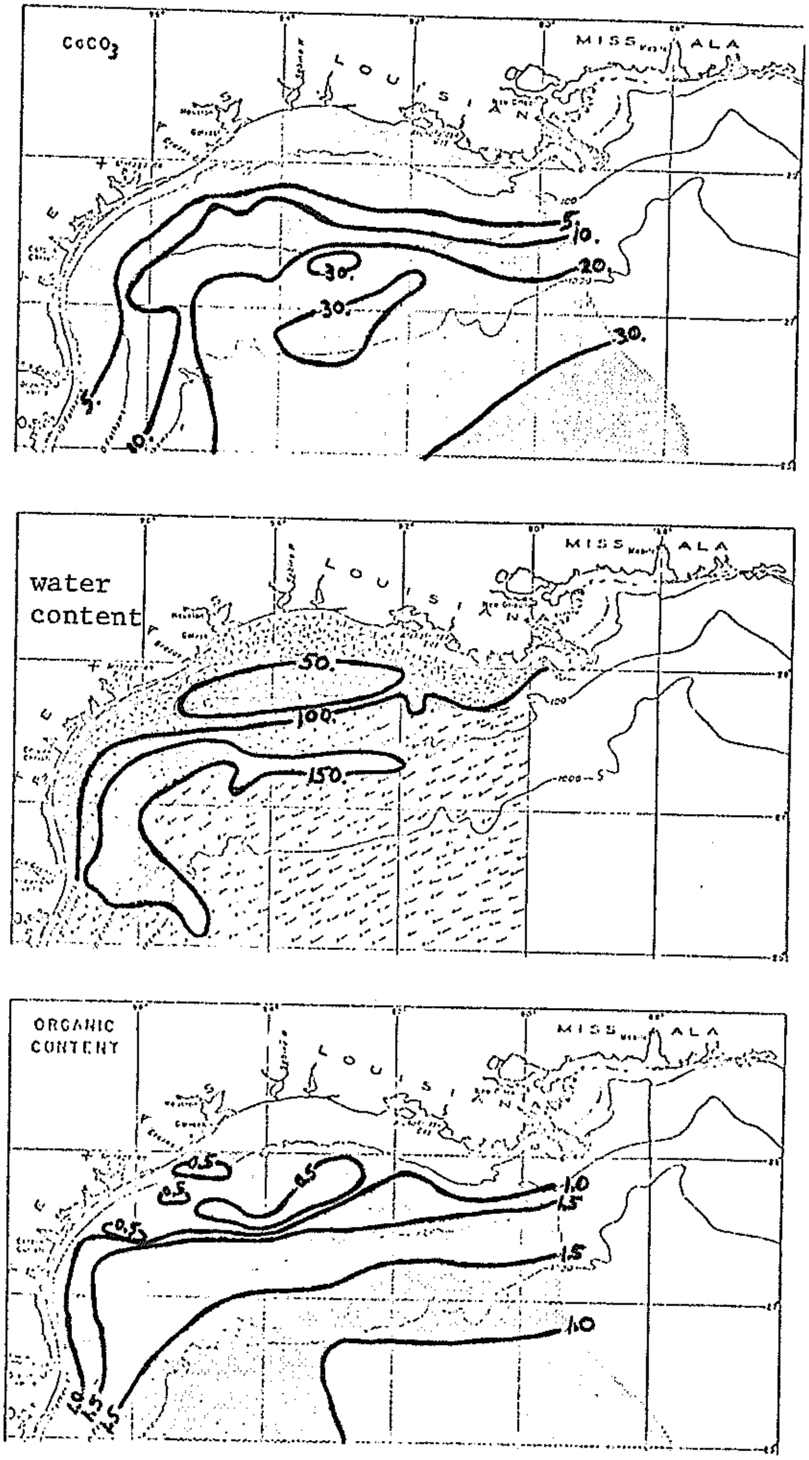


Figure II-16. Distribution of Organic Matter, Calcium Carbonate, and Water Content (expressed as percentages) in the Surface Sediments of the Northwestern Gulf of Mexico (after Stetson and Trask).

BIOLOGY OF THE TEXAS COAST

Benthic Algae

Humm and Hildebrand (1962) reported 116 species of benthic and attached algae from the south Texas coast, but most of these were taken from lagoonal waters. Some groups were apparently limited by the low habitat diversity and by the low winter temperatures of the Texas lagoons. The relative scarcity of rocks and other hard substrata severely restricts the diversity and abundance of attached algae in the shallow waters of the Gulf proper.

Phytoplankton

Apparently no papers have been published on the phytoplankton of Texas shelf waters, although Freese (1952) and Wood (1963) reported on the diatom flora of south Texas bays. Therefore, information concerning the phytoplankton flora and productivity of Texas marine waters must be inferred from the few studies carried out in the eastern Gulf. These include primarily the papers of Balech (1967a, b), Curl (1959), El Sayed (1967), Kabanova (1966), Marshall (1956), Odum and Hoskin (1956), Riley (1937), Simmons and Thomas (1962), and Steele (1964).

From these studies it may be presumed that the phytoplankton of the Texas shelf is relatively rich, consisting chiefly of diatoms with lower representation of dinoflagellates and other phytoplankton groups. Primary diatom genera should include _Nitzschia_, _Thallasiothrix_, _Thalassionema_, _Skeletonema_, _Chaetoceros_, and _Asterionella_. It is probable that the Texas marine phytoplankton reaches an annual maximum in the early spring months, followed by an annual low period in late summer and early fall. Average annual primary productivity should fall around 20-30 mg C/m^3/day.

Zooplankton and Micronekton

Knowledge of the zooplankton and micronekton of the entire Gulf of Mexico is quite scanty, and except for a few nearshore areas of the eastern Gulf, it is limited largely to taxonomic studies of particular groups (chaetognaths, pteropods, and copepods being the best known). A bibliography of much of this work is available but will not be included here. Only a few of these studies have considered the Texas shelf in any detail, and no quantitative zooplankton studies have been carried out here except for the Russian work of Khromov (1965). This worker studied the distribution of zooplankton biomass in the northwestern Caribbean Sea as well as in most of the Gulf of Mexico. His data indicate a zone of low zooplankton density (0.5 g/m^3) east of Galveston, but southwest of Galveston the nearshore density exceeds 0.5 g/m^3 in the shallow coastal waters with lower densities seaward.

Extrapolating from the taxonomic studies of the eastern Gulf and considering the few Texas zooplankton collections which have been examined, it is reasonable to conclude that the Texas shelf waters are quite rich in the same species found elsewhere in the Gulf.

Zooplankton of the Texas bays and lagoons have received some attention, and the data indicate a relatively rich and diverse fauna dominated by the euryhaline copepod *Acartia tonsa*.

Benthic Invertebrates

A rather detailed picture of the distribution and seasonal abundance of macro-invertebrates in the Texas coastal bays and lagoons is provided by the studies of Conte and Parker (1971); Gunter (1950, 1956); Gunter, Christmas, and Killebrew (1964); Hedgpeth (1950, 1953, 1954); Ladd (1951); Ladd, Hedgpeth, and Post (1957); Parker (1960); Simmons (1957); and other workers. In addition, a semi-quantitative view of the distribution of benthic macro-invertebrates of the Texas shelf out to a depth of 29 fathoms (the practical limit of shrimp trawling) is provided in the works of Harper (1970), Hildebrand (1954) and others.

From these studies one may distinguish twenty faunal assemblages in the coastal freshwater, lagoonal, Gulf margin, and open Gulf environments of Texas (Table II-11). Details of these faunal assemblages are presented in Appendix B, and only a generalized sketch of the salient points will be presented here.

The low-lying coastal freshwater environments have not been well studied, but it is clear that the fauna consists of a mixture of rather specialized coastal species and local representatives of wider-ranging freshwater species. This important habitat has been largely overlooked by coastal investigators who have tended to concentrate their attention in the brackish waters.

The lagoonal environment, which has been fairly well studied, is ecologically quite diverse and is represented by eleven recognizable faunal assemblages. The long Texas coast is ecologically transitional between the cooler, well-watered east where flushing rates are high, and the warmer, arid southwest where evaporation may exceed precipitation and runoff during much of the year, resulting in highly saline lagoonal environments. Thus, the variety and relative abundance of faunal assemblages encountered in any lagoon tend to vary from the upper to the lower Texas coast, the lower-salinity assemblages being more prominent on the upper coast and the hypersaline assemblages being limited to the lower coast.

In the Gulf margin environment two assemblages are recognized primarily from the works of Hedgpeth (1950, 1953, 1954) and Parker (1960). The surf zone and sand beach assemblage extends along the entire coast and is the native marine edge fauna of the state. The open gulf jetty assemblage is a hybrid fauna derived from a variety of habitats to populate the artificial substrate of stone and concrete which makes up the coastal jetties.

Six open Gulf faunal assemblages are recognized on the continental shelf and upper continental slope of the Texas coast, and this number would undoubtedly be larger if the area were more thoroughly studied. For present purposes the inner shelf (2-12 fathoms) and intermediate shelf (12-35 fathoms) assemblages are most important. Hildebrand (1954) found about equal numbers of invertebrate species in the inner and intermediate areas and he noted a broad overlap in species composition, both being especially rich in penaeid shrimp and portunid crabs. He found the two areas to differ somewhat in the dominant organisms, the inner shelf being characterized by *Renilla mulleri*, *Pitar texasiana*, *Penaeus setiferus*, and *Callinectes danae*, whereas the intermediate shelf was dominated by *Pitar cordata*, *Busycon contrarium*, *Astropecten*

Table II-11a. Types of Benthic Macro-faunal Assemblages Represented in the Coastal Area of the Northwestern Gulf of Mexico.

A. <u>FRESHWATER</u>

1. Freshwater assemblage

B. <u>LAGOONAL</u>

2. Marine influenced river assemblage
3. River influenced low-salinity bay assemblage
4. Freshwater and low salinity marsh assemblage
5. Enclosed bay or inter-reef assemblage
6. Lower bay shallow and bay margin assemblage
7. Lower bay and open sound center assemblage
8. Lower salinity oyster reef assemblage
9. High salinity oyster reef assemblage
10. Tidal pass and inlet assemblage
11. Hypersaline lagoon assemblage
12. Open hypersaline lagoon, near inlet, assemblage

C. <u>GULF MARGIN</u>

13. Open Gulf jetty assemblage
14. Surf zone and beach assemblage

D. <u>OPEN GULF</u>

15. Inner shelf assemblage
16. Intermediate shelf
17. Outer shelf assemblage

Table II-11a. Page 2

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18. Northern Gulf calcareous bank assemblage

19. Northern Gulf epifaunal assemblage

20. Upper continental slope assemblage

Table II-11b. Macro-invertebrate Collections from the Central Texas Continental Shelf, May-June, 1971.

Organisms	Stations									
	inner shelf				intermediate shelf					
	29	30	27	14	20	15	13	17	19	21
	10.4	10.4	11.5	12.0	15.3	19.7	20.8	20.8	21.8	21.8
Cnidaria										
Hydrozoa										
hydroids (unident.)	+					+	+		+	
Anthozoa										
anemones (unident.)	++				+	+			+	
Leptogorgia (?) sp.						+				
Renilla sp.	++		++		+					
Anellida										
polychaete tubes					+					
Mollusca										
Gastropoda										
Busycon contrarium					+					
Crepidula fornicata							+			
Distorsio clathrata						+				
Pleurobranchia hedgpethi				++	++			+		
Polystira albida							+			
Strombus alatus								+		
Bivalvia										
Chione clenchi						+	+	+		
Laevicardium laevigatum						+				
Ostrea frons						+				
Cephalopoda	++	++		+			+	++	+	+
Crustacea										
Stomatopoda										
Squilla empusa				+	+	++	+		+	
Decapoda: Natantia										
Penaeus aztecus					+		+		+	+
P. setiferus				+++	++	++	+		+	++
P. aztecus + *P. setiferus*	+		++	+++	+			+	+++	
Sycionia brevirostris				+		+	+	+		+
Sycionia dorsalis				++	++	+		+	+	++
Trachypenaeus constrictus								+		

Decapoda: Reptantia										
Calappa sulcata							+	+		
Callinectes ornatus				+++		++	++	+++	+++	
Callinectes + Portunus	+		++		+					
Hepatus epheliticus		+	+	+					+	
Leiolambrus nitidus				+		+		+	+	
Libinia emarginata		+		+						
Parthenope serrata								+		
Persephone p. aquilonaris	+	+								
Petrochirus diogenes									+	
Podochela sidneyi		+								
Porcellana sayana	+					+	+		++	
Portunus gibbesi			+					+		
Portunus sayi										+
Portunus spinicarpus						++		+	++	
Portunus spinimanus			+			+	+	+	+	+
Stenocionops f. coelata									+	
Echinodermata										
Asteroidea										
Astropecten sp.				+	+++	+	++	++	++	++
Luidia clathrata				++		+		+		+
Echinoidea										
Sea biscuit							+			
Ophiuroidea										
Ophiolepis sp.				+			+			
Chordata										
tunicates					+	+				

By R. M. Darnell (Id. by R. Defenbaugh). All collections were standard 15-min. drags with a 20-ft. otter trawl. Station locations (13-30_ are given in Figure II-16. Water depth (in fathoms) is listed for each station designation. Abundance of living individuals in each collection is indicated by logarithmic designation (+ = 1 - 9, ++ = 10 - 99, +++ = 100 or more).

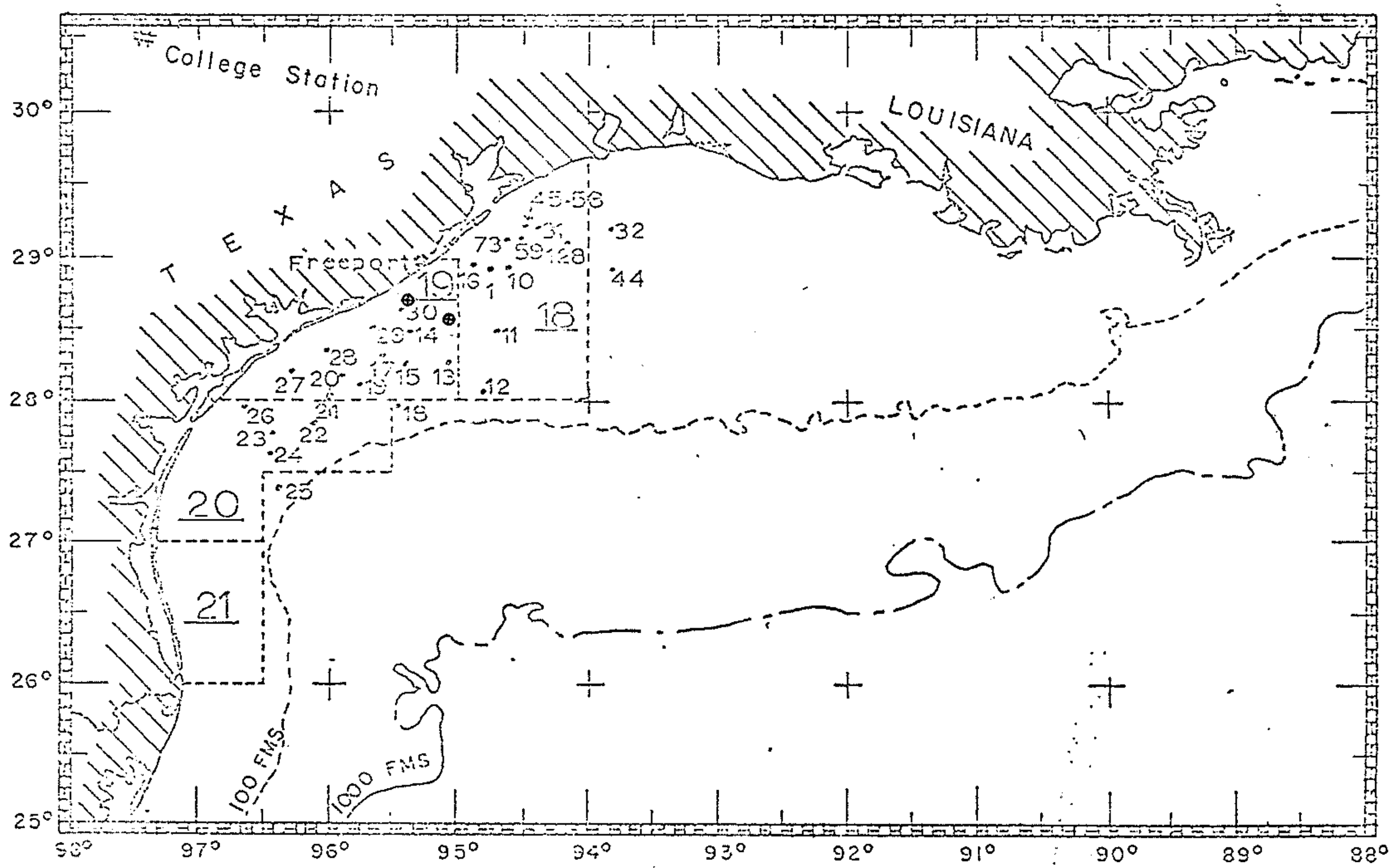

Figure II-17. Map of northern Gulf Coast showing: a) fishery statistics areas of the Texas shelf (18, 19, 20, 21), b) location of 1971 trawling stations of R. M. Darnell, and c) proposed location of supertanker ports offshore from Freeport, Texas (crossed circles).

antillensis, Penaeus aztecus, and Callinectes danae.

Recent Texas shelf collections by one of the authors of this report (R. M. Darnell) have been worked up and are presented in Table II-11. These data are in general agreement with those of Hildebrand, but they do suggest that the intermediate shelf is faunistically more diverse than the inner shelf. They also tend to suggest a greater abundance of organisms in the intermediate shelf zone.

Fishes - Important contributions to our knowledge of the fish fauna of the coastal lagoons and continental shelf of Texas have been made by Gunter (1945); Hildebrand (1954); Hoese (1958); Moore, Brusher, and Trent (1970); Parker (1972); and others. Parker (1972) lists about 450 species of coastal and marine fishes known from Texas, but this list would undoubtedly increase to 600-700 species if all the reef inhabitants and outer shelf fishes were included.

Darnell (1962) has pointed out that the euryhaline fish fauna of the northern Gulf of Mexico is a weakly-differentiated derivative of the rich coastal ichthyofauna of the West Indies and Central America. This northern fauna is representative of the Carolinean biotic province which extends from the Mexican coast below Tampico, north and east to Cape Hatteras, excluding the lower third of peninsular Florida. Few, if any, marine fish species are endemic to the Texas coast, although several species, such as the finescale menhaden (Brevoortia gunteri) reach their greatest abundance here. The Texas ichthyofauna is both abundant and diverse, but in both categories it is apparently eclipsed by the rich ichthyofauna of coastal Louisiana (Moore, Brusher, and Trent, 1970).

Species composition and life history relations of the Texas lagoonal ichthyofauna are fairly well known. A very few species, such as the bay anchovy (*Anchoa mitchilli*) appear to be year-around residents. However, most of the lagoonal fishes are seasonal transients derived from the fauna of the inner shelf. These fishes, by and large, invade the coastal lagoons as juveniles during the spring and summer, feed and grow as summer residents, and pass to the outside waters during the late summer and fall. Prominent among the seasonal transients are the menhadens, sea catfishes, mullets, and several members of the drum family (croakers, spots, seatrouts, and red drums).

In contrast to the lagoonal fauna, our knowledge of the shelf fishes is limited largely to check lists, identification keys, and distributional studies. Very little is known about the ecological relations of most fish species of the shelf, especially those which live beyond the inner shelf. From data presented by Hildebrand (1954) and Moore, Brusher, and Trent (1970) a comparison may be made between the fish faunas of the inner and intermediate shelf zones of the Texas coast. Catches on the inner shelf tend to be less abundant and less diverse than on the intermediate shelf. Hildebrand (1954) records only 80 fish species from the inner shelf, whereas 122 species are recorded for the intermediate zone. Catches of the inner shelf are seasonally quite variable and tend to be dominated by species which utilize the lagoonal habitat in part of their life histories. Among the inner shelf dominants are the sea catfish (*Arius felis*), Atlantic threadfin (*Polydactylus octonemus*), Atlantic croaker (*Micropogon undulatus*), sand seatrout (*Cynoscion arenarius*), silver seatrout

(Cynoscion nothus), spot (Leiostomus xanthurus), and southern kingfish (Menticirrhus americanus). Dominants of the intermediate shelf include only a few of the inshore species. The intermediate shelf dominants are listed as follows: inshore lizardfish (Synodus foetens), longspine porgy (Stenotomus caprinus), Atlantic croaker (Micropogon undulatus), sand seatrout (Cynoscion arenarius), silver seatrout (Cynoscion nothus), gulf butterfish (Peprilus burti), shoal flounder (Syacium gunteri), and rock bass (Centropristis philadelphica).

Recent Texas shelf collections by one of the authors of this report (R. M. Darnell) have been worked up and are presented in Table II-12. A synthesis of the data is given in Table II-13. These data suggest a greater species diversity for the inner shelf and greater abundance on the outer shelf with the intermediate shelf being also intermediate in fish diversity and abundance.

Life Histories of Important Migratory Species

Shrimp - Three species of commercial shrimp are taken in Texas coastal waters, the white shrimp (Penaeus setiferus), brown shrimp (Penaeus aztecus) and pink shrimp (Penaeus duorarum). The brown shrimp is by far the most important, and it is this species which essentially supports the shrimp fishery of the state. The brown shrimp fishery tends to be concentrated in the intermediate zone from Galveston to the Rio Grande. The white shrimp appear to be most abundant in the inner shelf zone along most of the Texas coast, and especially in the grounds east of Galveston. Pink shrimp constitute less than one percent of the Texas catch.

All three species spawn in the shelf waters, and the young, aided

Table II-12. Fish Collections From the Upper and Central Texas Continental Shelf, 1971.[a]

Species	Inner shelf	Intermediate shelf	Outer shelf
Rajidae			
Raja texana	–	.06	–
Muraenidae			
Gymnothorax nigromarginatus	.07	.41	.11
Muraenesocidae			
Hoplunnis schmidtii	–	.06	–
Congridae			
Congrina gracilior	–	.12	–
Ophichthidae			
Mystriophis mordax	.06	–	–
Ophichthus gomesi	.01	–	–
Clupeidae			
Etrumeus teres	.06	.06	–
Harengula pensacolae	.11	–	–
Engraulidae			
Anchoa hepsetus	2.04	–	–
Synodontidae			
Saurida brasiliensis	.11	6.76	29.20
Synodus foetens	.83	1.57	1.92
Ariidae			
Arius felis	.79	–	–
Batrachoididae			
Porichthys porosissimus	.47	1.22	.64
Antennariidae			
Antennarius radiosus	–	.70	.21
Histrio histrio	.02	–	–
Ogcocephalidae			
Halieutichthys aculeatus	.06	1.69	.43
Ogcocephalus nasutus	.30	.06	–
Ogcocephalus parvus	–	.93	1.81

Gadidae			
Urophycis cirratus	–	–	.11
Urophycis floridanus	.11	.23	–
Ophidiidae			
Brotula barbata	.46	–	–
Lepophidium brevibarbe	.74	1.98	–
Ophidion welshi	.12	–	–
Syngnathidae			
Hippocampus erectus	.25	–	–
Syngnathus lousianae	.01	.06	–
Serranidae			
Centropristis philadelphicus	4.24	2.10	1.81
Diplectrum bivittatum	.51	3.03	–
Serraniculus pumilio	.11	.12	–
Serranus atrobranchus	.11	14.30	6.61
Grammistidae			
Rypticus saponaceous	–	–	.11
Carangidae			
Chloroscombrus chrysurus	.34	–	–
Selene vomer	.11	–	–
Trachurus lathami	–	.87	–
Vomer setapinnis	.11	–	–
Coryphaenidae			
Coryphaena hippurus	.01	–	–
Lutjanidae			
Lutjanus apodus	.10	.06	–
Pristipomoides aquilonaris	–	1.22	–
Pomadasyidae			
Orthopristis chrysoptera	.06	–	–
Sparidae			
Stenotomus caprinus	3.04	1.46	.21
Sciaenidae			
Cynoscion arenarius	.01	–	–
Cynoscion nebulosus	16.60	–	–
Cynoscion nothus	.25	–	–
Larimus fasciatus	.22	–	–
Menticirrhus americanus	.29	.23	–
Micropogon undulatus	1.97	–	–
Stellifer lanceolatus	.11	–	–
Mullidae			
Mullus auratus	–	.06	–
Upeneus parvus	–	.06	–

Ephippidae			
Chaetodipterus faber	.06	-	-
Polynemidae			
Polydactylus octonemus	11.40	-	-
Uranoscopidae			
Kathetostoma albigutta	-	-	1.06
Gobiidae			
Bollmannia communis	-	2.21	.11
Trichiuridae			
Trichiurus lepturus	.46	-	-
Stromateidae			
Peprilus burti	1.35	-	-
Scorpaenidae			
Scorpaena calcarata	-	.06	-
Scorpaena dispar	.06	.35	-
Triglidae			
Prionotus ophryas	.01	-	-
Prionotus rubio	25.70	7.98	2.56
Prionotus salmonicolor	.06	.06	-
Prionotus stearnsi	-	2.04	46.06
BOTHIDAE			
Ancylopsetta dilecta	-	.06	.43
Ancylopsetta quadrocellata	.08	.18	.53
Citharichthys macrops	4.13	14.50	.53
Citharichthys spilopterus	1.02	.35	-
Cyclopsetta chittendeni	.06	.41	.64
Cyclopsetta fimbriata	.01	-	-
Engyophrys senta	.06	2.68	-
Etropus crossotus	3.45	1.63	-
Syacium gunteri	5.41	17.80	2.88
Syacium papillosum	.07	-	-
Trichopsetta ventralis	-	-	1.71
Soleidae			
Gymnachirus texae	.01	.18	-
Cynoglossidae			
Symphurus diomedianus	.01	1.57	-
Symphurus plagiusa	5.31	4.72	-
Balistidae			
Monacanthus hispidus	.29	.12	-
Ostraciidae			
Lactophrys quadricornis	.06	.06	-
Tetraodontidae			
Lagocephalus laevigatus	2.58	.12	-
Sphoeroides parvus	5.09	3.32	.32
Sphoeroides spengleri	-	.12	-

Total number of fishes	1781	1716	938
Number of fishes/15-min haul	161.9	245.1	312.7

[a] By R. M. Darnell (Id. by C. Cashman). All collections were standard 15-min. drags with a 20-ft. otter trawl. Station locations are shown in Figure II-17. Abundance of each species is given as percentage of all fishes taken in the particular zone of the shelf.

Table II-13. Comparison of Trawl Fish Catches in Relation to Shelf Zone for the Upper and Central Texas Continental Shelf.[a]

Shelf zone	Diversity (no. of spp.)	Abundance (no./haul)	Dominant groups	Dominant species
inner shelf	61	161.9	searobins (26%) flatfishes (21%) drums (20%)	blackfin searobin (*Prionotus rubio*) spotted seatrout (*Cynoscion nebulosus*) Atlantic threadfin (*Polydactylus octonemus*)
intermediate shelf	48	245.1	flatfishes (45%) seabasses (20%) searobins (10%)	shoal flounder (*Syacium gunteri*) spotted whiff (*Citharichthys macrops*) blackear seabass (*Serranus atrobranchus*)
outer shelf	23	312.7	searobins (49%) lizardfishes (31%)	shortwing searobin (*Prionotus stearnsi*) largescale lizardfish (*Sauridia brasiliensis*) blackear seabass (*Serranus atrobranchus*)

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[a] Data derived from Table II-12. Most of the collections were made during the period May - July, 1971.

by seasonal and tidal currents, make their way as planktonic larvae, into the estuaries during the spring and summer months. Feeding, growth, and maturation take place largely in the estuarine and lagoonal nursery areas, and in late summer and fall many of the new adults move back to the outside waters. Smaller numbers of young may over-winter in the estuaries and pass outside in a spring "run". Both sexes migrate to the spawning grounds where mating and egg-laying take place. An estuarine shrimp fishery does exist, but this produces mostly small and less valuable individuals. The most important shrimp fishery harvests the adults on the shelf. Figure II-18 shows the general shrimping areas of the Texas coast.

Blue crab - Although many species of crabs are found in Texas coastal waters only the blue crab (Callinectes sapidus) reaches a readily marketable size. The life history of the blue crab on the northern Gulf coast has been worked out primarily by Darnell (1959), Daugherty (1952), Gunter (1950), and Hildebrand (1954). Egg-bearing females tend to concentrate in the inner zone of the shelf, although a few stray out into the intermediate zone. Upon hatching, the planktonic young pass to the estuarine and lagoonal waters where they feed and grow to maturity. Copulation takes place in the inside waters, after which, the inseminated females move back to the Gulf. Adult males remain in the inside waters where they may copulate with additional maturing females. During exceptionally dry years many of the inseminated females may remain in the more saline estuaries and lagoons. Oviparous females are captured in Gulf waters in greatest abundance during the months of June and July. In contrast with the shrimp fishery, major blue crab fisheries are pursued in the inside

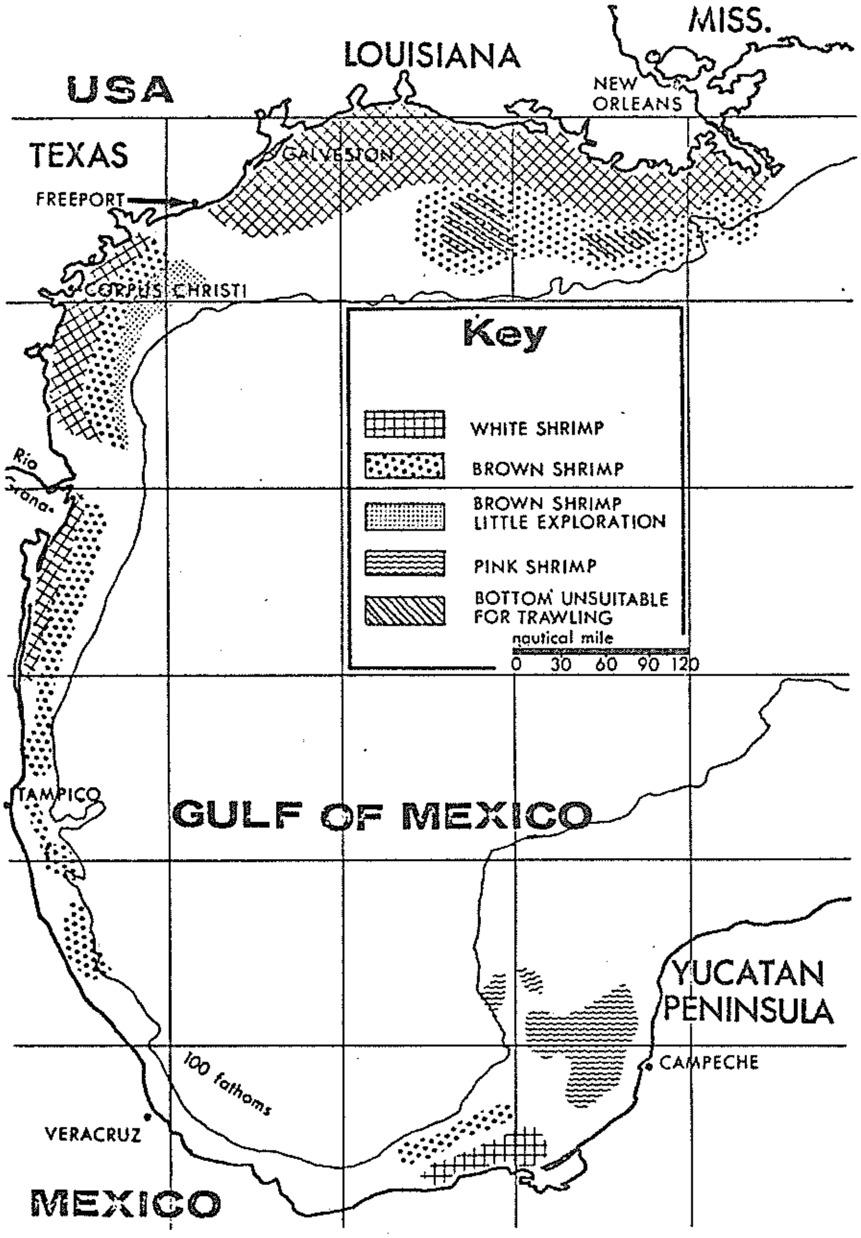

Figure II-18. Shrimping areas of the Western Gulf of Mexico (after Hildebrand).

as well as the inner shelf Gulf waters.

Shallow-water fishes - Fishes of the menhaden, shad, mullet, sea catfish, and drum families all spawn in shallow coastal waters (primarily on the inner shelf, but sometimes also on the intermediate shelf). As in the case of the shrimp and crabs, the young make their ways into the estuaries and lagoons, primarily in the spring months. Summer feeding and growth periods are followed by mass migrations to the outside waters where additional growth and reproduction take place. A few individuals may overwinter in the inside waters and move to the outside in the spring.

Most of the migratory coastal fishes, shrimp, and crabs apparently live only about 18-24 months. As a result, each year's crop depends greatly upon the success of the previous year-class. Thus, if the chain is broken, as for example, by a major oil spill, recovery could take years. Although no solid information is available on the subject, it seems likely that these coastal species are made up of semi-isolated genetic races, each race adapted to the prevailing local conditions (i.e., to the local estuarine feeding grounds, shelf breeding grounds, and seasonally available currents for larval migration). Extinction of a local race could leave a void which might take years to overcome by either natural or artificial means. Evidence is now available indicating that subtle chemical odors are utilized by juvenile fishes and shrimp as cues to migration (Kristensen, 1964; Odum, 1970). Masking of the necessary estuarine odors by petroleum fractions could seriously interfere with normal migratory patterns.

Oceanic fishes which visit the shelf - A number of species of oceanic fishes regularly visit the inner and intermediate shelf zones of Texas during the summer months. These include the mackerels (Spanish, king, chub, frigate, and cero), bonito, tunny, amberjack, several jackfish (horse-eye, bluntnose, crevalle, bar, and yellow), as well as the blue runner, dolphin, and a number of billfishes and other species of sport and commercial interest. These wide-ranging, fast-swimming predatory fishes are often caught within sight of shore, especially around the mouths of passes where they gorge themselves upon anchovies, silversides, squids, shrimp, and bottom fishes. Large schools of mackerels and bonitos have been observed over the inner shelf at Freeport, Texas (R. M. Darnell), which is a major center for sport-fishing activities on the Texas coast. Life histories of all such species are poorly known, but it is certain that they are only temporary visitors to the Texas coastal waters, the major part of their life histories being spent elsewhere.

Catches - Both projected offshore port sites lie within fishery statistics area 19 which annually provides around five thousand metric tons of brown shrimp or 43% of the total brown shrimp harvest of the Texas shelf (Linder and Bailey, 1969). At the current price of $1.10 per pound the brown shrimp harvest alone from the area is worth over twelve million dollars annually. The Matagorda Bay System (including Matagorda, East Matagorda, Lavaca, San Antonio, Mesquite, and Espiritu Santo Bays and Green Lake) produced over half a million pounds of oyster meats, 1.7 million pounds of crabs, and 1.6 million pounds of finfish.

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CHAPTER III

PRACTICAL CONSIDERATIONS OF AN OFFSHORE PORT

NEED FOR OFFSHORE PORT

Demand for Crude Oil

The United States is faced with a serious national problem related to the availability of adequate supplies of energy in the very near future. The impending energy crisis, which has been brought about by the shrinkage of proven domestic reserves of oil and gas relative to the growth in demand for energy, portends an insecure future for the nation. For the first time in history, we are increasing our use of electricity, natural gas, coal, and oil faster than the suppliers can boost the output. While some observers see the problem as temporary, the majority of those concerned believe we have reached a turning point at which the energy resources that we have taken for granted are now a limiting factor in national growth.

Alternate sources of energy other than oil and gas present serious handicaps. Nuclear fission can provide an almost inexhaustible supply of energy but its impact in resolving the national energy gap has to be discounted for the present because of public objection to the construction of nuclear plants. The only other alternative to liquid and nuclear fuels that is readily available is coal. Only coal is available domestically in sufficient quantity to satisfy the energy demands of future years. But the environmental impact of coal could be massive compared to that of other fuels.

Because the demand for oil and gas is outstripping proven domestic reserves of these commodities, increased imports are becoming a necessity in order to bridge the rapidly widening energy gap. Interior Secretary Rogers C. B. Morton has predicted in hearings before the House Interior Committee that the United States will probably need to import half of its crude oil needs by 1985 (Morton, 1972). Humble Oil and Refining Company has projected that in 1985, at least 62 percent of the petroleum consumed in the United States will be imported from offshore, with three-fourths of this originating in the Middle East (Humble Oil, 1971).

Present Harbor Facilities

The increased importation of oil and gas from offshore sources means increased dependence upon ocean transportation. Unfortunately, recent trends in the sizes of oil tankers create a serious problem in providing facilities in the United States to berth the new breed of supertankers. The drafts of vessels, 250,000 dead-weight tons (dwt) size and over, range from 60 to 90 feet. Even larger ships, with drafts of 100 feet or more, are predicted to be built in the near future.

The average maximum depth of most United States harbors and channels is 45 feet; only a few have depths greater than this, but none of these are located where large volumes of crude oil must be received. On the Texas Gulf Coast, where petroleum shipments are dominant, no port has a depth greater than 40 feet and no port is actively planning for more than 45 feet.

Dredging of existing channels to depths on the order of 60 to 90 feet is impractical, if not impossible, in most United States ports due to physical obstacles and the staggering costs of such projects. Instead, approaches using offshore terminals, located in naturally deep water and connected to onshore receiving facilities by undersea pipelines, appear to offer more advantages than other methods of accommodating ships that are too large to enter existing harbors.

Impact on National Issues and Needs

Without adequate berthing facilities in the United States, supertankers will be used on other trade routes in the world and imports of oil and gas into this country will continue to be transported in ships of less than 80,000 dwt capacity. Such a circumstance will have several unfavorable consequences:

1. Additional transportation costs of almost $700 million per year by 1980 will have to be borne by our economy.
2. The amount of vessel traffic in our harbors and channels by 1980 will result in chaotic congestion, and the risk of major water pollution through spills will rise to intolerable levels.
3. The probability that domestic refineries will relocate to locations abroad, with a consequent loss of thousands of jobs in this country, will become greater as producers begin facing higher costs of imported crude transported in the smaller ships.

4. The already-deteriorated condition of the U.S. Merchant Marine Fleet will be further affected by the continuing shift of cargos to larger vessels which cannot use U.S. ports.

Construction of a supership port in the Texas Gulf of Mexico, and at other key locations along the three major coastlines of the United States will:

1. Reduce potential oil spills in harbors and inland areas, where the greatest damage can be done, by moving tanker-handling facilities offshore;
2. Make the United States once again competitive in marine transportation;
3. Help alleviate the energy crisis;
4. Help establish a more favorable balance of payments.

Why are Deepwater Terminals Needed in Texas?

In the past three decades, the economic base of Texas has changed from one dominated by agriculture to one oriented toward minerals and manufacturing with a strong dependence upon water transportation. Petroleum refining and petrochemical-based industries have grown especially fast during this period due to Texas' plentiful supplies of essential raw materials.

However, prospects for continuation of present levels of oil-related business in Texas appear to be in jeopardy. Although Texas has traditionally been a net exporter of crude oil, natural gas, and refined products, today's economic incentives are not sufficient to encourage much petroleum exploration, and the state's reserves of oil and gas are rapidly being depleted. As a result, Texas' dependence upon imported crude oil will become more significant in the near future. In 1970, Texas exported to other oil-using regions of the United States an average of 325,000 barrels of crude oil per day. In 1980, it is estimated that Texas will be importing 2,100,000 barrels of crude oil each day, and this is expected to increase to more than 3,500,000 barrels per day by 1985.

A major portion of the oil imported into Texas after 1980 will come from the Persian Gulf, a distance of 12,000 miles from the Texas Gulf Coast. Such a long haul in tankers of 50,000 deadweight tons average size will make the transportation cost of a barrel of oil so high as to be totally unacceptable. Only supertankers, with the economies of scale they offer, can operate in this trade and deliver crude oil to Texas refineries at reasonable cost.

Existing channel depths of Texas ports are shown in Figure III-1. At the present time, no port in Texas has an authorized depth of greater than 40 feet, and no Texas port is actively planning for more than 45 feet. No ships larger than 80,000-90,000 dwt can enter Texas ports fully loaded. Yet, today's world tanker fleet includes more than 700 ships that exceed this size and therefore cannot dock in Texas. By 1983, it is predicted that one-third of the projected world tanker fleet of 4,300 ships will be unable to enter Texas ports.

The problem of ship size versus port depths assumes a more critical nature in the Texas Gulf Coast region than in other parts of the nation due to the state's heavy dependence on the hydrocarbon processing industry and the industry's need for adequate supplies of raw materials.

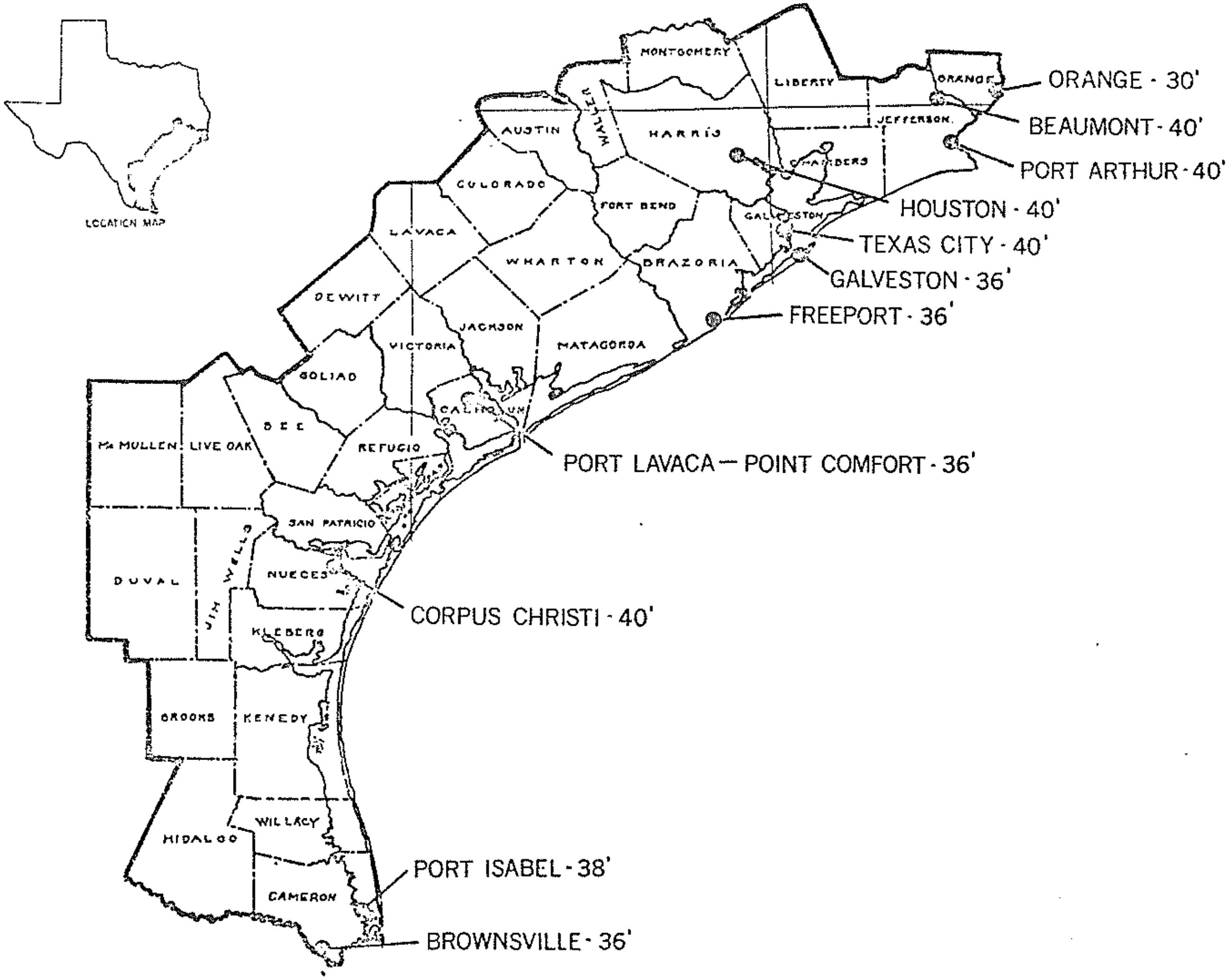

Figure III-1. Existing Channel Depths of Texas Ports.

More than 40 percent of the nation's petrochemicals are produced in the Texas Gulf Coast areas of Port Arthur, Beaumont, Galveston, Houston, and Corpus Christi. During the last decade about 118 new chemical and allied materials plants have located in this area, and 272 plants expanded. This concentration of industry comprises more than one-fourth of the nation's entire oil refining capabilities and more than 50 percent of the nation's petrochemical processing ability.

In 1970 over 185 million tons of cargo went through Texas' 12 deepwater ports in comparison to 192 million tons handled through the ports of New York. Of the 185 million tons moved in Texas, 140 million tons consisted of liquids, mainly petroleum and chemical products.

Economic Impact of a Deepwater Terminal in Texas

The potential economic implications of a deepwater terminal in Texas cannot be overestimated. But in order to give the proper perspective to a discussion of the economics of a terminal, it is necessary to study several sectors of Texas business activity.

The leading sectors of the Texas economy have, in recent years, made the following contributions to the State's business activity:

petroleum refining	-	$6.3 billion per year
petroleum mining	-	$4.4 billion per year
agriculture	-	$3.3 billion per year
facility construction	-	$2.2 billion per year
banking and credit	-	$1.9 billion per year.

A more detailed examination of one sector, petroleum refining, provides considerable insight into the type of stakes Texans are gambling with in considering whether or not to build a deepwater terminal.

During 1971, United States oil refining capacity rose to almost 13.1 million barrels per day (MMB/D) of crude oil. Of this capacity, Texas contributed 3.4 MMG/D, or 26.5 percent of the total. It is estimated that by 1985, the U.S. will need refining capacity of 27.5 MMB/D, an increase from 1971 of 14.4 MMB/D, or the equivalent of 96 new 150,000 barrels-per-day refineries.

Presently the Gulf Coast has 40 percent of the nation's refining capacity but only 12 percent of the demand for refined products. Conversely, the East Coast has only 12 percent of national refining capacity, but it consumes 40 percent of the nation's refinery output. Because of various factors such as environmental constraints, as well as a general lack of suitable refinery sites on the East Coast, these ratios of capacity and demand are expected to remain constant, provided the availability of refinery feedstocks maintains the same balance between areas as now exists.

ALTERNATIVES TO AN OFFSHORE PORT

The primary objective of this discussion is to make realistic comparisons of the several alternatives to an offshore port in Texas. Comparisons will be made of such alternatives as channel-deepening at existing ports, lightening of deep-draft vessels at sea to permit them to enter existing harbors, transhipment of petroleum from Very Large Crude Carriers (VLCC's) into shallow-draft vessels at deepwater ports in the Bahamas for subsequent movement to Texas ports, and carriage of petroleum in shallow-draft vessels from origins in the Middle East and South America to destinations at existing Texas ports.

Two alternatives that will not be considered in this discussion are the shallow-draft VLCC concept and the philosophy of reduced energy demand. In the former case, although naval architects have proven the structural integrity of special shallow-draft designs, their questionable economics means that much development work remains before such breakthrough concepts become widely accepted by vessel users. Consequently, this factor is not expected to have an impact on the need for deepwater ports in time to avoid a crisis.

In the second case, that of reduced energy demand, although a recent inter-agency study released by the Office of Emergency Preparedness holds out the prospects of a 7.3 million barrels per day reduction in oil demand by 1980 if vigorous energy-conservation measures are taken, the likelihood of this happening is remote. Even if it comes about, numerous studies have concluded that drastic reductions in the use of energy for maintenance of "the good life" -- television, air conditioning and home appliances, for example -- would result in minimal payoff in total energy savings, and the lowered standard of living which resulted from such conservation measures would rule against continued public acceptance of them.

Deepening of Existing Harbors

Traditionally, changes and improvements to existing harbors to accommodate larger classes of vessels have taken place in response to needs which were fairly slow in developing. Because of existing constraints, i.e., depth and width limits of the Panama and Suez canals, for example, upward revisions in the physical dimensions of ocean vessels came about very gradually during the years up to and including World War II. As a result, port authorities had no great difficulty in keeping up with such needs, usually through occasional 5-foot increases in depth or through nominal widening of channels. And, because ship developments moved more slowly then, the customarily long cycle times for port projects -- 7 to 15 years on the average -- seldom resulted in crisis situations.

Even though the historical approach to channel deepening frequently has resulted in projects which were obsolete upon completion, this has not proven to be a serious handicap in the past. However, with the dynamic growth in vessel capacities and draft requirements in recent years, particularly in the bulk trades, proposed harbor and channel improvement projects, using the time-honored methods of the past hundred or so years, are becoming obsolete by the time they are started.

If it is decided that channel-deepening is the solution to the problem of accommodating superships, then it is likely that an effort of great magnitude will be necessary to achieve the goal. Many ports, including nearly every major port in Texas, will have to be deepened. The cost of such a massive effort, on a national level, could well be beyond the nation's capabilities, especially in view of the resource requirements of other programs of equal social importance. Allen F. Clark, Jr., president of the Philadelphia Port Corporation, speaking before the 15th Annual API Task Conference in April, 1970, gave an example of the kind of costs involved in major channel improvement projects when he stated "... the Delaware channel, now carrying some 27 million tons of foreign crude and nine million tons of foreign residual oil a year -- will cost on the order of a billion dollars to deepen to only 50 feet. What it would cost for 80 feet has not even been estimated."

In addition to the first cost aspects of channel deepening, other considerations which, when taken _in toto_, appear to rule out this approach as an alternative to the offshore port, include such things as annual maintenance costs and environmental impacts other than those associated with disposal of dredge spoil.

Lightening at Sea to Enter Shallow Ports

Another possible alternative to the offshore terminal is the concept in which fully-loaded VLCC's rendezvous at sea with smaller vessels, at locations near a destination port, and off-load sufficient quantities of cargo to permit the VLCC to proceed into a port where it can dock in a normal fashion.

Most lightening operations to date have been performed in Northwestern Europe locations during about the last four or five years.

Some have also occurred in the United States, in Long Island Sound, New York Bay and lower Delaware Bay, but these have not involved ships of the VLCC size. One reason for this is that if a VLCC (250,000 dwt or larger) is lightened enough for it to enter and dock in an existing harbor on either the East or Gulf coasts, the lighter which took aboard part of the cargo would then be too large to enter an East or Gulf port itself. The solution to this, of course, would be to use two or more lighters which could enter port at full load. However, the use of more than one lighter in this type of operation can be economically self-defeating. Therefore, until at least some port deepening is done, it will not be economically feasible to ship oil to the United States in full-loaded VLCC's with the intention of lightening them for entry into existing ports.

From the environmental standpoint, lightening a VLCC by offloading part of its cargo into a lighter or shuttle vessel is as safe as, but no safer than, the use of single-point buoys for offloading cargo. This is because, in practice, the ship-to-ship cargo transfer operation is carried out with the two vessels lashed together, separated only by large, pneumatic fenders, with no relative motion between the vessels other than change in freeboard. Under this arrangement, spills are rare. Naturally the prevailing weather and sea conditions are important in this type of operation and it should be noted that northwest Europe has the advantage of a number of deepwater areas that are relatively sheltered by land.

However, in moving the cargo to on-shore storage facilities, strong differences exist in the potential environmental impact of shuttle vessels as compared to that of pipelines commonly employed to move cargo between a single-point buoy and the shore. If the volumes of crude oil projected to be imported in 1985 actually result, the movement of this much oil will require the equivalent of 2000 tankers of an average 70,000 deadweight tons size or 700 VLCC's of 200,000 deadweight tons. If no deepwater facilities are provided, and vessel lightening at sea for subsequent entry into existing harbors becomes widely practiced, the already-congested ports, harbors and channels of this country will have to absorb the added traffic created by 700 VLCC's and 700 - 1,000 smaller feeder vessels carrying crude oil, along with a new and additional fleet of product carriers. This consequence of our failure to build offshore facilities could result in massive pollution of harbors and shorelines from the inevitably greater risks of collisions and groundings.

For a number of reasons, it is not likely that the nation will be faced with a situation such as the one described above. Practical use of transhipment between vessels at sea cannot be extended to a large import program because successful implementation of the method requires use of the most highly-trained vessel crews available due to the hazardous nature of the operation. When used on a large scale, therefore, integrity of the lightening operation in regard to accidents and spills would quite likely deteriorate. This problem, along with the sometimes marginal economics of at-sea lightening, causes users to regard the practice as a temporary "fix" until proper port facilities become available.

Transshipment in the Bahamas

The lack of deepwater ports on the United States Atlantic and

Gulf coasts has encouraged the exploitation of natural deepwater found in the Eastern Canada and the Bahamas. In these areas, petroleum refining complexes and petroleum transhipment facilities have recently been built and are being actively promoted by the governments of the two regions.

Transhipment of crude oil from Very Large Crude Carriers (VLCC) to vessels that are small enough, with sufficient shallowness of draft, to permit normal entry into existing Texas ports, is attractive from several standpoints. Economically, this system would offer most of the advantages expected from using VLCC's for the entire voyage between the Middle East and the Texas Gulf. Because of the proximity of the Bahamas to Texas -- a little over 1,000 miles -- cargo transported to these Atlantic islands for transhipment and subsequent movement to Texas would travel over 90 percent of the voyage in a VLCC, and could conceivably reap almost 90 percent of the potential transportation savings.

Under the 1985 requirement for moving vast quantities of crude oil into the United States, transhipment in the Bahamas, as opposed to providing deep-draft offshore terminals along the Atlantic and Gulf coasts, will do nothing to reduce the impact of numerous and frequent ship callings at existing ports. If tankers with an average size of 70,000 deadweight tons are used, the U.S. ship traffic in 1985 will amount to almost 12,000 arrivals and 12,000 departures per year in addition to the traffic being handled today. And, this figure does not include the increase in the number of product carriers used in coastal service between Gulf and Atlantic ports. Under such circumstances, the probability of spills resulting from collisions and groundings rises to an alarming level.

Total Use of Smaller Vessels

If the United States decides to adopt a policy against offshore deepwater terminals and if, for various reasons, shippers cannot make use of lightening at sea or transhipment at nearby foreign ports, then one of the few remaining alternatives is the use of vessels which are small enough and which have sufficiently shallow draft to be used in existing U.S. ports. However, implementation of this practice could have undesirable consequences.

Based upon projected oil import levels, it has been estimated that the United States' economy will be forced to absorb an additional $700 million per year in transportation costs by 1980 if vessels of an average 47,000 deadweight tons size are used to carry the imports, instead of vessels exceeding 200,000 dwt. Such a penalty would increase American industry's cost of doing business and would make American products less competitive in world markets.

The higher probability of collisions, groundings, and strandings as a result of increased volumes of vessel traffic in the nation's harbors and waterways, along with the consequential environmental impact of such incidents, has been touched upon earlier. The use of a vast fleet of oil tankers, which are small enough to enter existing U.S. harbors, to transport all of the oil expected to be imported into the United States in the next thirty years, makes it almost a certainty that the rate of ship accidents will rise far above recent levels reported by the U.S. Coast Guard.

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CHAPTER IV

GENERAL CHARACTERISTICS OF OIL

This chapter includes a description of the general characteristics and properties of oil, a review of existing oil spills and a description of how the oil might affect the various environmental elements. The chapter provides the basis for predicting the fate of oil spilled on the sea surface and the potential impact of an oil spill off the Texas Coast.

While the general characteristics of oil can be determined by relatively simple field and laboratory experiments, very little work in this area has been reported in the literature. A comprehensive impact study will require that additional experiments be undertaken.

Crude petroleum is a complex mixture of hydrocarbons together with organic compounds of sulphur, nitrogen and oxygen. The three main hydrocarbon classes can be listed as

Alkanes (paraffins) - saturated chain compounds,

Cycloalkanes (naphthenes) - saturated cylic compounds, and

Aromatics, compounds with the benzene ring structure.

During refining crude oil is separated into products approximately as listed below.

Product	Approximate Molecular Size
Refinery gas	$C_3 - C_4$
Gasoline	$C_4 - C_{10}$
Naphtha	$C_{10} - C_{12}$
Kerosene	$C_{12} - C_{16}$
Gas oils	$C_{16} - C_{25}$
Residual oil	$> - C_{25}$

PHASES OF OIL

Oil that is spilled on the sea surface will form a relatively thin film on the surface. As shown in Figure IV-1, part of the oil evaporates into the atmosphere, and part dissolves into the water column. Oil can also be emulsified in the form of a suspension in the water column. The oil that is in solution or suspension can be expected to mix in the water column down to the thermocline. In addition some of the oil may precipitate from the water column and sink to the bottom. The oil on the surface, in the water column both in suspension and solution and on the sea floor is subject to biological degradation. Thus the five major mechanisms by which oil is removed from the surface of the sea are evaporation, solution, emulsification, precipitation and decay. The rate at which the oil changes phases is highly dependent on the type of oil; the weather conditions, in particular the wind and temperature; and the conditions of the sea. The characteristics of the oil slick on the sea surface will change with the age of the oil.

Evaporation

Evaporation of oil from a slick on the surface of the sea is most important in the early life of the slick. The rate at which the oil is evaporated from the slick is dependent on the temperature, the type of oil, and the exposed area. The higher the temperature, the higher is the evaporation rate. In a study using 100 medium grade crude oils evaporation rates were observed to double on the average when the temperature was increased from $15^{o}C$ to $25^{o}C$ (ZoBell, 1963). The type of oil will affect the evaporation rate. A lighter or lower gravity oil

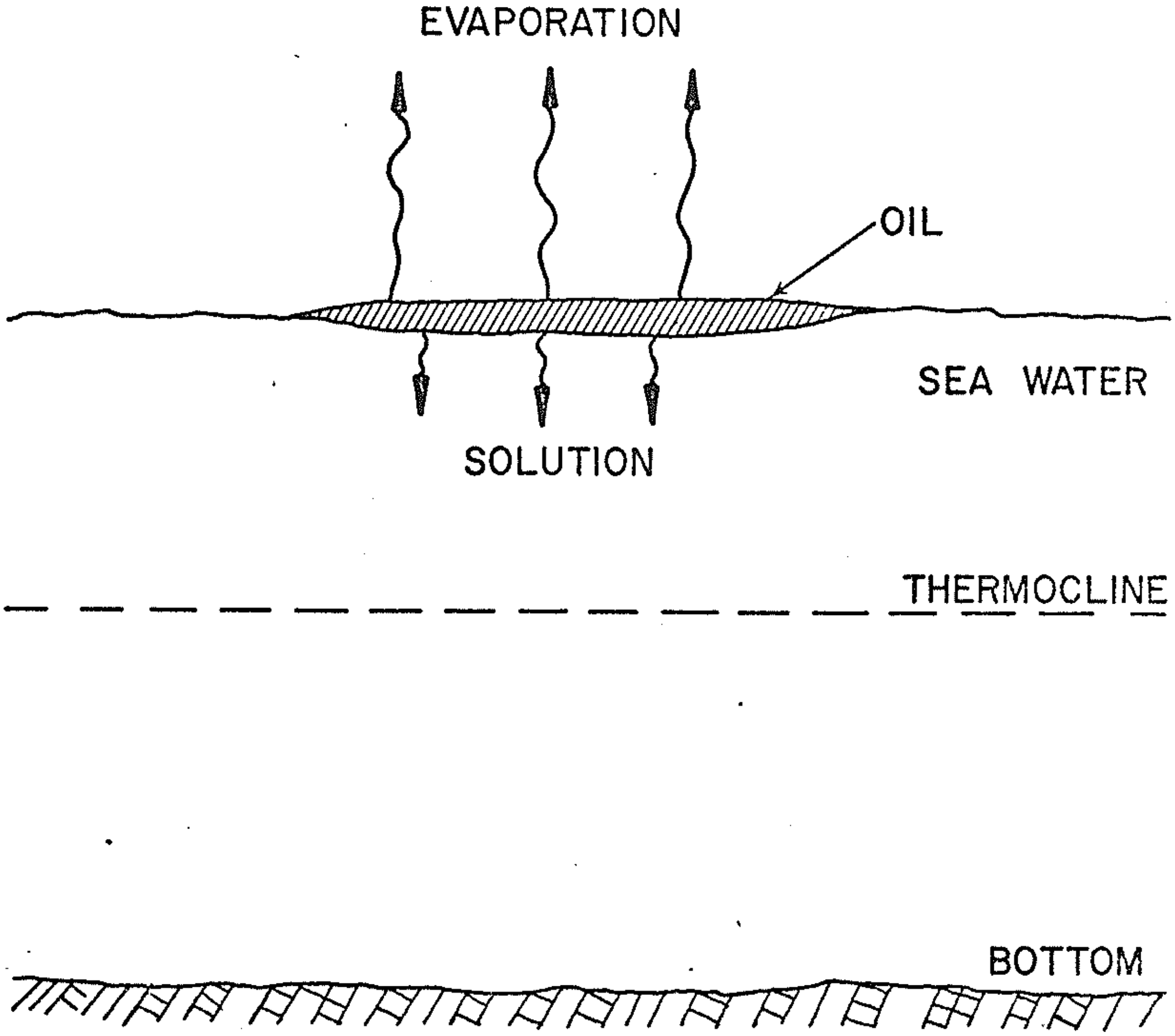

Figure IV-1. Fate of Oil on the Sea Surface.

having a large number of light ends will evaporate at a higher rate than the higher density more viscous oils. In general the fraction of the oil evaporated early in the life of a slick contains the most toxic fraction of the oil. The exposed area has a direct effect on the rate and volume of oil that is evaporated. In general the larger the exposed area the higher will be the evaporation rate. The important role of evaporation in removing oil from the sea was demonstrated in a study conducted during the "Torrey Canyon" spill. The study indicated that 25 percent of the oil, by volume, was lost in the first few days after spill (Smith, 1968).

Solution

The amount of oil that dissolves into the water column is important in assessing the potential impact of the offshore port for several reasons. First, the oil that is in solution is in direct contact with the marine organisms in the water column. Secondly, as will be shown later in this chapter, the low boiling aromatic fractions of oil such as benzene appear to be the most toxic. These fractions are the most soluble and the most volatile.

Emulsification

Sea conditions, the type of oil, and weather are the major factors in determining the amount of emulsification. A turbulent, choppy sea causes a much higher degree of emulsification than a calm or even a rolling sea (Murray, 1970). The formation of an emulsion can cause the movement of oil from an oil slick in a direction different from the motion of the slick itself. This was observed in the Chevron spill. The slick on the surface moved in the direction of the wind driven current and the emulsified oil below the surface moved as a submerged mass with the subsurface currents. In general the oils in most of the spills that have been reported tended to form emulsions. However, the type of emulsions and the fraction of the oil that was incorporated in the emulsions depended on the type of oil and in particular on the temperature and the conditions of the sea.

Precipitation

During the evaporation process the density of the oil is increased. As the density of oil approaches the density of water, the action of waves may cause more of the oil to move below the surface of the water where it may encounter sand grains or silt to which it becomes attached. Once the oil is attached to a sand grain it can be separated from the surface oil slick. The density of the sand grain and oil may be equal to the density of water, it may be greater than the density of water, or it may be less than the density of water. The motion of the oil will depend on the density of the combination of the sand grain and oil. A particle having essentially the same density as the water will travel a great distance before reaching the bottom of the ocean or the surface. A particle having a high density will drop fairly rapidly to the bottom of the sea. A particle having a density less than that of sea water will move to the surface.

In general, very little oil will be deposited on the bottom of the ocean unless the sea is rough and silt particles are present to cause sinking. For example, in the Chevron spill, samples of soil taken directly from below the platform from which the oil was being discharged into the sea contained concentrations that were never higher than a few parts per million (Mackin, 1972).

Decay

Biological degradation of oil does occur in nature but is a slow process aerobically and even slower anaerobically. Oil is poor in nutrients and the presence of adequate nutrients is essential for biological degradation. Large populations of bacteria acclimated to the oil are required to effectively degrade the material. These populations would not be available for the slug loadings of 500T or 30,000T; however, they could develop about the port facilities and might aid in degradation of the continuous spill.

Rates

The method and rate at which the various components of the oil slick are lost are important in estimating the impact of an oil spill on the environment. Very little information is known on the rates of transfer and additional studies will be required for a comprehensive environmental impact study. Moore (1972) presented a first order model to approximate the rates of evaporation, dissolution and biological degradation for six fractions. The basic data for the six oil fractions are listed in Table IV-1. The basic equation for each fraction of oil is given by

$$\frac{dC}{dt} = (K_e + K_d + K_b)C \qquad (1)$$

where C is the concentration and K_e, K_d and K_b are the evaporation, dissolution and biological decay coefficients respectively. Solution to this equation is

$$C = C_o e^{-(K_e + K_d + K_b)t} \qquad (2)$$

where C is the concentration of a particular fraction after some exposure period t in days and C_o is the initial concentration. A listing

Table IV-1. Basic Data for Oil Spill Weathering Model.

Fraction	Description[a]	% by wt.[a] in Crude Oil	Density[b] (gm/ml)	Boiling Point[b] (°C)	Molecular Weight[b]	Solubility ($gm/10^6 gm$ Distilled H_2O)
1	Paraffin C_6-C_{14}	0^+ -25	.66-.77	69-253	86-198	9.5-.003
2	Paraffin $C_{15}-C_{22}$	0^+ -10	.77-.78	270-368	212-290	.007-.003
3	Cyclo-Para. C_5-C_{11}	1 -25	.75-.9	49-200	70-152	156.-1.
4	Aromatic (Mono-Cyclic) C_6-C_{10}	0 -5	.88-.90	80-204	78-136	1780.-50.
5	Aromatic (Poly-Cyclic) $C_{10}-C_{18}$	0^+-5	1.1-1.2	$218-350^+$	128-234	12.5-0
6	Residual	30-70	1.-1.1	>350	200-900	0

Source: Moore, 1972.

of six fractions along with approximate values of the coefficients are given in Table IV-2.

The percent remaining in the surface oil slick for each of the six oil fractions after 12, 24 and 48 hours exposure is given in Table IV-3. The amount of each fraction remaining is listed for wind speeds of 5, 10 and 20 knots. For most practical purposes the oil fractions paraffin (C_6 - C_{14}), cycloparaffin (C_5 - C_{11}) and aromatic mono-cyclic fractions (C_6 - C_{10}) are essentially lost at the end of one day.

The following listing was made from the transfer rates listed in Table IV-2. The values listed below are for a 10 knot wind which would be typical of the offshore area.

Fraction	Evaporation Rate	Dissolution Rate	Ratios Evap/Diss
1	- 6	- 0.1	60
2	- 0.002	0.0	--
3	- 6	- 0.5	12
4	- 6	- 1.0	6
5	- 0.02	- 0.001	20
6	0.0	0.0	--

This listing indicates that about 1/60 of fraction 1, 1/12 of fraction 3, 1/6 of fraction 4, and about 1/20 of fraction 5 will go into solution. The remainder of these fractions will be lost to evaporation into the atmosphere.

Table IV-2. Approximate Transfer Rates for Six Oil Fractions.[1]

Fraction	Description	Evaporation Rate	Dissolution	Biological
		K_e[2]	K_d[2]	K_b[2]
1	Paraffin C_6-C_{14}	$-0.8e^{0.2w}$	-0.1	relatively small
2	Paraffin C_{15}-C_{22}	-0.002	0.0	-0.03 @ 12°C (-0.06 @ 22°C)[3]
3	Cyclo-Paraffin C_5-C_{11}	$-0.8e^{0.2w}$	-0.5	relatively small
4	Aromatic (Mono-cyclic) C_6-C_{10}	$-0.8e^{0.2w}$	-1.0	relatively small
5	Aromatic (Poly-cyclic) C_{10}-C_{18}	-0.02	-0.001	small
6	Residual	0.0	0.0	small

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[1] These values are only approximate and are probably all dependent upon temperature and oil film thickness.

[2] W is the wind speed in knots.

[3] Estimated for the Gulf Region.

Source: Moore, 1972.

Table IV-3. Approximate Percent Remaining of Six Oil Fractions.[1]

		Percent Remaining of Six Oil Fractions								
	Wind	5 kts			10 kts			20 kts		
Fraction	Exposure	12	24	48 hrs	12	24	48 hrs	12	24	48 hrs
1		30	10	1	5	1	< 1	< 1	< 1	< 1
2[2]		97	95	89	97	95	89	97	95	89
3		25	7	< 1	5	1	< 1	< 1	< 1	< 1
4		20	4	< 1	5	1	< 1	< 1	< 1	< 1
5[3]		99	98	96	99	98	96	99	98	96
6		100	100	100	100	100	100	100	100	100

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[1] Determined from coefficients listed in Table IV-2.

[2] Estimated time for 10% remaining is 40 days.

[3] Estimated time for 10% remaining is 110 days.

REVIEW OF OIL SPILLS

Oil Spills from Existing Shipping Procedures in Texas

Potential oil pollution from shipping operations are of two types. The first is from normal shipping operations and the second is from a catastrophe.

During normal shipping operations oil may be discharged into the water during refueling, loading and unloading, deck washing and ballast discharge. In the refueling, loading and unloading operations of tankers, oil is pumped through flexible hoses which are subject to damage through wear and ship movement. If the hose is too long, it may fall between the hull and the dock, becoming damaged and possibly torn. If the hose is too short, it may be ripped from its couplings by sudden movements caused by the close passage of another vessel. Failure to close off both ends of the hose as soon as it is disconnected could allow the fluid remaining in the hose to drain into the sea. Tank overflows and deck spills will reach the sea unless special precautions are taken.

On tankers the use of oil tanks for the storage of water ballast also may contribute to water pollution. As the tanker is loaded with oil the water ballast is discharged from the oil tanks. As shown in Table IV-4 in Galveston Bay, for example, where the monthly water discharge into the bay is 90.8 million gallons, ballast alone contributes 99.15 percent with ship cleanings contributing 0.62 percent and the remaining 0.23 percent from liquid domestic waste. An oil carryover of 5 parts per million in the water ballast could cause 449 gallons of oil per month to be discharged into Galveston Bay.

Table IV-4. Summary of Vessel Waste Distribution

Waste Type	Total Man-Days Per Month	Houston Ship Channel Turning Basin	 Turn. Basin to San Jac. River	 San Jac. River to Morgans Pt.	Texas City	Galveston Wharves	Total	Remarks
Ballast	-0-	880,000 Gal/Mo	44,025,000 Gal/Mo	43,145,000 Gal/Mo	1,950,000 Gal/Mo	-0-	90,000,000 Gal/Mo	Contains oil residue, discharged into water.
Ship Cleaning (Interior)	-0-	50,000 Gal/Mo	18,000 Gal/Mo	465,000 Gal/Mo	-0-	-0-	533,000 Gal/Mo	Treated in dockside facilities.
Ship Cleaning (Exterior)	-0-	18,000 Gal/Mo	7,000 Gal/Mo	-0-	-0-	5,000 Gal/Mo	30,000 Gal/Mo	Discharged into water, contains detergent.
Domestic (Volume)	35,088	98,820 Gal/Mo	52,940 Gal/Mo	21,180 Gal/Mo	4,950 Gal/Mo	32,650 Gal/Mo	210,540 Gal.Mo	Discharged into water with no treatment.
(5-Day B.O.D.)	35,088	2,800 Lbs/Mo	1,500 Lbs/Mo	600 Lbs/Mo	140 Lbs/Mo	925 Lbs/Mo	5,960 Lbs/Mo	

Oil pollution from a shipping catastrophe is a possibility but the probability is very low. Records of oil spills into the Gulf and bays in the Corpus Christi, Texas area were obtained from the U. S. Coast Guard. For a two year period from 7/13/70 to 6/6/72 there were 28 reported incidents of oil spillage. Twenty-seven of these were in the bays and only one was offshore. This one incident was due to pumping of bilge oil into the Gulf.

Oil Spills from Offshore Drilling and Production Operations.

In 1967, 47 percent of all mobile offshore rigs in the world and 57 percent of all fixed platform rigs were being operated in the Gulf of Mexico. Annual oil and condensate production from the Gulf is expected to reach from 750 to 1150 million barrels by 1975, and account for 20-30 percent of the estimated total domestic production.

At present there are 2408 platforms located in state and federal waters in the Gulf of Mexico, and an additonal 4105 production platforms in the bays of Texas and Louisiana. Most of the offshore drilling and production operations in the Gulf are located offshore Louisiana. A very small portion is located off Texas. As an example, in November 1972, there were 88 drilling rigs operating offshore Texas and Louisiana; 82 were offshore Louisiana and 6 were off Texas.

The oil pollution from offshore drilling and production operations in Texas offshore waters is very small. There are several factors which contribute to the low pollution levels. First of all there are few fields located off the Texas Coast; and secondly, most of these fields produce only natural gas.

The Effect of Weather on Supertankers

Ever since man has traveled upon the sea, the weather and the sea conditions created by this weather have been very important factors in determining the successfulness of the sea voyage.

Today, excellent weather reporting is made possible by modern weather tracking stations around the world which make use of such devices as weather balloons, radar, and even space satellites, all of which combined enable ships at sea to travel in the most advantageous sea conditions. Because of this weather forecasting, a ship is rarely lost due to adverse weather conditions. The standard procedure of all ships is to avoid storms at sea whenever possible. If they are unable to do so, the ships then follow the same type of preparations to sail through the storm. While actually in the storm, the ship will head into the seas or in the direction from which the waves are coming. This method offers the least resistance to the waves.

In the particular case of a supertanker, they have a special advantage during a hurricane in the fact that the ship itself is longer than the wave length of the largest wave, making the supertanker more stable during a storm than the smaller size tanker. This stability is further increased when the tanks are full causing the ship to ride lower in the water which reduces the amount of drop between the crests of the waves. In the event that the tanker is empty when the storm conditions develop, the tanker will take on as much sea water as possible to enable the ship to ride lower in the water.

The Bantry Class Tankers of Gulf Oil were found to be almost impervious to weather. Even in heavy weather rolling has been less than ten degrees. In fact, during the trial run of the UNIVERSE IRELAND a severe typhoon was encountered off the Japanese coast and it rolled only seventeen degrees in ballast condition. Speed losses encountered during heavy weather for these supertankers are just about the same as the speed losses encountered on other smaller vessels indicating that the size of the supertanker is more of an advantage than a disadvantage.

LONG AND SHORT TERM ENVIRONMENTAL EFFECTS OF OIL SPILLS

In March of 1967, the tanker "Torrey Canyon" ran upon the rocks off Cornwall, England traveling at a speed of 17 knots. During the following ten days, its cargo of 117,000 tons of crude oil leaked into the sea, causing oil pollution on an unprecedented scale (Smith, 1968). This disaster brought about a new awareness on the part of the public concerning the marine environment.

The short term environmental effects upon the marine environment are quite often disasterous. Pollution by the "Torrey Canyon" oil had little biological effect apart from the destruction of several thousand sea birds. The detergent used to treat the oil away from the coast was not noticeably injurious to marine life except in the extreme surface layers, where pilchard eggs and some phytoplankton were affected. The direct treatment of polluted shores, however, resulted in the death of a large number of shore organisms of many different kinds, and effects were also observed in the sublittoral zone. On shores left untreated, evidence has been obtained of removal of the oil by the fauna as well as by other natural agencies (Smith, 1968). In addition, tests conducted in the laboratory showed that detergent treatment was the major offender in this disaster.

In the Santa Barbara spill which occurred in January of 1969, seven to eight thousand birds were killed along the 80 miles of contaminated California shoreline (Stracke, 1970). Efforts to minimize the loss by establishing a wild fowl treatment center resulted in only a small number of those birds treated surviving (Straughan, 1971).

It has been suggested that the birds deliberately settle in polluted areas, in search of food or because the water is calm, but there appears to be little evidence for this. Observations made by Bourne (Straughan, 1971) led him to suggest that the birds do not notice the oil until they swim into it, at which time, they try to escape. Aerial species such as gulls fly away, but aquatic species such as the auks try to escape it like any other hazard by diving. Bourne stated that of the 7815 birds affected by the "Torrey Canyon" spill, 7746 of them were auks and this was probably caused by their efforts to escape by diving.

The total effect of the spill on the ecology in the Santa Barbara Channel will probably never be known, because, as Straughan points out, there was a complex interaction of forces operating in the area at the time of the spill, and also, there is a general lack of knowledge of the ecology of the area before the spill (Straughan, 1971). What is known is that "there is no evidence of gross effects of oil pollution on plankton in the Santa Barbara Channel", and, "the United States Bureau of Commercial Fisheries, on a cruise through the area on February 11, 1969, reported no effects on fish eggs and larvae; and while the phytoplankton count was lower than at a nearby station in the previous month, there is no way of knowing if this variation is a function of patchiness in phytoplankton distribution, a normal seasonal variation, or a direct or indirect effect of the oil spill" (Straughan, 1971).

"A study of benthic foraminifera detected no mortality attributable to oil. Evidence suggests that there was higher productivity in inshore waters. Studies of the sandy beach fauna did not reveal any direct effects of oil pollution." (Straughan, 1971).

Immediately after the Santa Barbara oil spill, Dr. Michael Neushul (1970) initiated a study in intertidal and kelp bed areas. While Neushul's work was to determine the immediate effects of the oil spill, the work by Nicholson and Cimberg (1971) was aimed at determining the longer term effects.

Neither Neushul nor Nicholson and Cimberg were able to demonstrate widespread effects of oil pollution from the January, 1969, oil spill on intertidal species. Both these studies, along with a study by the California Department of Fish and Game, reported smothering of Chthamalus fissus and morality in Phyllospadix torreyi. The California Department of Fish and Game reported that the latter species was growing again in damaged areas on the Channel Islands in August, 1969. At Punta Arena, Santa Cruz Island, Hesperophycus harveyanus was damaged by the oil, but "by August 6, near normal quantities of alga were observed" (California Department of Fish and Game, 1969:8). Nicholson and Cimberg reported that Pollicipes polymerus was loose and later lacking from the substrate at Carpinteria and East Cabrillo beaches. They attribute this to oil pollution. While P. polymerus is present in low numbers at oil seep areas such as Coal Oil Point (Straughan, Chapter 10), in these areas it is found growing with bases surrounded by oil. Hence this effect on P. polymerus may have been caused by other factors, particularly as it is unclear from the text if these particular animals were covered by oil.

The California Department of Fish and Game, after surveys at Anacapa and Santa Cruz Islands (1969:9), reported that "While the shells of such invertebrates as black abalone, Haliotis cracherodii, and goose-neck barnacles, Pollicipes polymerus, were covered with oil, the animals themselves appeared to be healthy and viable." They did not record any loss of Pollicipes polymerus (Straughan, 1971).

"There was a decrease in the number of algal species found at both Coal Oil point and Carpinteria between February-March (winter), 1969, and June-July (summer), 1969. The lowest number of algal species was recorded at Carpinteria (18) in July, 1969, and at Coal Oil Point (15) in August, 1969. Subsequent to this, there was an overall increase in the number of species recorded at both stations during the next twelve months. The pattern and extent of reduction and increase in species numbers was similar at both Coal Oil Point and Carpinteria, even though the former received a negligible amount of clean-up by Union Oil and the latter was subjected to large scale clean-up operations (Straughan, 1971).

Straughan examined several intertidal species for the sublethal effects on breeding population and/or inhibition of larval settlement, which determines the recovery of the intertidal areas. No effects on breeding were found on surviving oiled individuals of two species of barnacles, Balanus glandula and Chthamalus fissus in upper intertidal areas. The former species settled on oil less than seven weeks after the spill and the latter settled on oil ten months after the spill. There are no records of Pollicipes polymerus settling on oiled surfaces and this species did show the effect of reduced breeding in oil seep areas and oiled individuals in lower intertidal areas. But, according to Straughan, as this species ranges from Alaska to Mexico, a reduction in breeding in a small section of its range will not endanger the species as a whole.

Data presented on fish catch in the area, and surveys by the California Department of Fish & Game suggest that the oil did not deplete the fish population and that the fishing industry suffered economic losses more from indirect causes such as the closing of harbors and fouling of boats and equipment (Straughan, 1971).

Data on the marine mammal populations do not prove large scale mortality as a result of the oil spill and Brounell and Le Boeuf, 1971, indicate that DDT may be the major cause of the mortality in California sea lion pups.

In the long run, it was determined that recolonization commenced in the intertidal areas within seven weeks of the spill which occurred on January 28, 1969 and that as of November, 1970, most intertidal areas have a "normal" population on intertidal invertebrates.

In March of 1970 a blowout occurred off the coast of Louisiana which has become known as the "Chevron Spill". After the fire was extinguished, oil continued to be released for another month. The oil slicks were primarily influenced by the tidal currents as was evidenced by their flow in directions often times in opposition to the wind (Murray, Smith & Sonn, 1970).

There was no recorded bird kill and no evidence of any damage caused by the spill to the marine environment at the well site or at stations surrounding it (Mackin, 1972). Despite the fact that the government would not allow the use of detergents or the Shell coagulating substance, oil only reached the shore of one island, and this was due to a spill on March 16 & 17 onto fresh water which was easily transported to shore by the wind. The fact that oil only reached the shore in this one case is mainly due to the fact that the Mississippi River was flooding at the time of the spill and the interfaces of river and sea water acted as a barrier to the oil slick. Other factors that aided were the high waves and winds which caused stirring and mixing and hence continued the break up of the oil slicks (Murray, 1970).

An earlier spill occuring in the spring of 1957 was not as lucky. When the "Tampico" ran aground off the Mexican state of Baja California, it blocked the entrance to a small cove, into which it released its entire cargo of about 60,000 barrels of diesel oil, killing everything in the cove in the intertidal region. In the entire cove, the only creatures that survived and remained were the seaweeds in the sublittoral region, the *Littorina planaxis*, a tiny snail that lives above the high water mark and several large green anemones, *Anthopleura xanthogrammica*, found alive in the tide pools. Among the dead species were lobster, abalone, sea urchines, starfish, mussels, clams, and hosts of smaller forms (North, 1970).

By the summer the little cove was again fresh and clean. Mobile animals such as large fishes, sea lions, and lobster appeared first. Tiny organisms such as certain bryozoans began to colonize the barren places. Sixty-nine species of animals have recently been observed in the cove, compared to only two species immediately after the shipwreck. Plants now number fifty-seven compared to four, one month after the accident (North, 1967). Complete recovery of the cove took between three to six years (Mackin, 1972).

EFFECTS OF OIL ON ENVIRONMENTAL ELEMENTS

This section of the report describes how the oil will affect the various environmental elements if the oil does come into contact with the element. As discussed in a previous section of this chapter, the weathering and age of the oil affect the general characteristics of the oil and are important considerations in estimating the impact of oil on the environment.

The literature includes many conflicting statements on the effects of the oil on the environment. Many of these conflicting statements are due to the variation in equipment used for measurement and the general backgrounds of the authors. The following assessment of the effect of oil on each environmental element is believed to be fairly accurate; however, missing information was assumed where necessary. It should be noted, however, that not all members of the study team agree to all statements listed in this report.

Offshore

The water soluble factors of the oil are expected to mix with the surface water. The depth of mixing within the water column will be a function of the sea state. The mixing depth as indicated by the depth of the thermocline in summer is 10 to 30 meters. In the winter time, low surface salinity in the nearshore water causes a pycnocline to form at 10 to 20 meters. The shallower mixing depths are associated with calmer sea states while the deeper mixing depths are associated with the rougher sea states.

Very little oil is expected to sink in the offshore area and only under very heavy sea conditions will a significant amount of the oil particles from the slick be entrained in the water column.

The concentration of the water soluble fractions of the oil below the sea surface (C at a depth z) can be estimated from (California, 1965)

$$C = C_s \exp \left[\frac{-z^2}{2\sigma_z^2} \right]$$

Where C_s is the surface concentration. If $2\sigma_z$ is assumed to be the depth of the thermocline or about 33ft (10 m), z is the depth in meters and the equation becomes

$$C = C_s \exp \left(- \frac{z^2}{50} \right)$$

The highest concentrations of soluble fractions will normally be found near the surface.

Nearshore

Several observations from satellite photos have shown that the width of the turbid or discolored waters will commonly extend to 5-7 statute miles (8-11 km) offshore due to wave action along the coast. This would represent a water depth of about 30 ft (10 m). The thermocline would slope upward in the nearshore area, thereby decreasing the thickness of the surface mixing zone. Where the nearshore zone is turbid, the soluble oil in the water column would be expected to extend to the bottom. The suspended silts in the water column would indicate that the surface mixing due to wave action would reach the ocean floor. Some oil droplets in the turbid area are expected to combine with silt particles and may sink to the bottom, but because of the low level of turbulence in this zone, sinking of oil is expected to be relatively minor.

Surf Zone

As the oil approaches the beach, the surf action will mix some of the oil into the water. In the highly turbid nearshore zone along the coast, the suspended silt particles will combine with the entrained oil and cause some sinking. The rate at which this occurs is a function of the turbulance within the surf zone and the contact time with the silt particles. The presence of the oil slick will also cause some smoothing the surf zone. The following characteristics of the surf zone were estimated (Bascom, 1964).

Wave Height ft	Percent of Time	Wave Period Sec	Breaker Depth Ft	Surf Zone(1 Width Ft
0-2	40	3	2	100
2-5	40	5	5	300
> 5	20	7	8	400

(1 Beach slope of 2%

The effect of the soluble oil fractions in the surf zone will be minor. In this zone the sinking of the oil to the bottom might occur because both silt particles and turbulent mixing are present. In order to prevent damage to the bottom sorbent floating material should be added to the oil slick before it reaches the surf zone. This material will aid in the oil removal operations expected to be in progress along the beach.

EFFECTS OF OIL ON THE BEACH

The most effective method of handling the oil and minimizing the impact on the environment is to physically remove the oil from the water. The beach forms the barrier which concentrates the oil and causes it to become thicker. Barriers normal to the beach could be established to stop the longshore transport and sorbent materials used to increase the removal efficiency. Less damage to the environment is anticipated if the oil is not allowed to drift uncontrolled but is quickly removed.

Oil from a large spill that piles up near the beach will move parallel to the beach with the longshore drift. The breaking waves in the surf zone will tend to provide contact between the suspended sands and silt within the water column and the floating oil slick. Some of the oil will sink to the bottom in the nearshore area.

The oil rises on the beach with each tide and the waves bring the oil higher on the dry sand areas. As the tide drops an irregular coating of oil covers the intertidal zone. The oil will adhere weakly to wet surfaces, and with successive tides, the oil coating floats off wet surfaces and much of the material is redeposited on the upper parts of the beach that are exposed long enough to be dry between tides (Foster, Charters and Neushul, 1971).

The slope of the beach was estimated from Texas Coast Inlet Studies--Beach Profiles, Jetty Condition Surveys and Mid-Point Survey, 1971, by the Galveston District, Corps of Engineers. For most areas beach profiles were available from 1966 to 1971 with observations taken during several seasons of the year. While the shoreline slope generally changes seasonally, an average was selected that was representative of the slope between +2 and -2 ft. elevation. The beach slope ranges from about 1 percent to 3 percent. An average value of 2% was selected as being representative of most of the coast.

With a tidal range of one ft (0.3 meters) the tide would expose a 35 ft (10 meters) strip of beach to oil. Assuming an oil thickness of 1/4 inch (7 mm) the beach could trap and hold the oil at a rate of about 3/4 cu ft per lineal ft (0.07 m^3 of oil per lineal meter of beach) or about 100 tons per mile of beach. If 50 percent of the oil is lost to evaporation before reaching the beach and the sinking of oil is neglected, the 500 ton (570 m^3) annual spill could affect about 3 miles (5 km) of beach while the 30,000 (34,000 m^3) ton spill could affect as much as 150 miles (240 km) of beach. Hence, it is essential that oil control and removal procedures be initiated along the beach for the large spills.

ESTUARIES

The Texas coast consists of a series of bar-estuaries which will generally prevent oil from entering the estuaries under normal conditions. However, if the oil spills enter across a bar, as might happen during heavy seas, then they will stay much longer than in any other types of estuaries because of the poor flushing rates of bar-estuaries. The flushing of Texas estuaries is limited by the small tides in the Gulf, hence it is likely that if the oil enters the estuary it will be trapped by marsh.

By the time the oil reaches the estuary nearly all of the toxic compounds in the oil will have been lost. The major damage that occurs will be along the inland beaches and marsh areas.

PARKS AND RECREATION AREAS

Oil pollution can have a negative effect on park and recreation areas, namely, to make the areas less attractive. During the past few years, the increasing number of incidents of oil pollution in public parks and on recreation beaches has caused public attention to be focused on the problem.

The Gulf of Mexico has a long history of oil pollution from natural and human sources. Oil slicks were reported along the Texas Gulf Coast in the late 1500's, and natural seepage is known to occur in several places. Although the oil pollution problem of the Texas coast has received little publicity (Hawkes, 1961), public attention was greatly increased by such incidents as the Torrey Canyon, Santa Barbara, and Louisiana (Platform Charlie) oil spills. When the Torrey Canyon grounded off England (in 1967), oil fouled miles of beaches on both sides of the English Channel and presented an enormous cleanup problem. The Santa Barbara oil spill (in 1969) left over 45 miles of beach coated with oil. Since then, there have been several spills in English waters, along the eastern, western, and Gulf coasts of the United States, and around the globe (Environment, 1971).

Beaches which are oil-fouled are vacated except for sightseers and workers cleaning the beach. The loss of attendance at public and private beaches which have been fouled by oil represents an economic loss to the community and region (Hawkes, 1961; Smith, 1972).

MARSH

Cowell (1971) conducted several tests on the effects of oil on salt marshes. In the tests, oil adhered to the plants and little washed off during successive tides. Under the oil films, leaves may remain green initially, but eventually yellow and die. Plants, however, recover by producing new shoots a few of which are observed within three weeks of pollution unless large quantities of oil have soaked into the plant base and soil. Seedlings and annuals rarely recover directly. Chronic pollution may completely eliminate vegetation.

The effects of oil on plants depend upon several factors (Baker, 1970) including:

1. Species and age of the plants.
2. Time of year and whether the plant is in an active-growth stage or dormant.
3. Amount and type of oil involved.
4. Degree of weathering of the oil.

In general, toxicity to plants increases along the series: Paraffins - nephthenes - aromatics. Within each series of hydrocarbons the smaller molecules tend to be more toxic than the larger molecules. Large molecules cannot penetrate plant tissues and volatile oils may evaporate before they affect the plant. As a result, naphtha and kerosene fractions may be the most toxic to plants (Baker, 1970).

Weathered crude is less toxic to salt marsh vegetation than fresh oil (Cowell, 1969). A badly oiled marsh at Bentless on Pembroke River which was severely damaged after the Chrysse P. Goulandis tanker accident in 1967 was virtually completely recovered two years later. (Cowell and Baker, 1969).

In studies conducted by Carr (1919) it was found that 0.75% crude oil in soil improved growth and root-nodule development of soybeans. Mackin (1950) reported that crude oil rapidly caused the death of saltgrass and saltwort but later the plants completely repopulated the area and resulted in lush growth. Kuwait residual was observed by Baker (1969) to stimulate the growth of saltmarsh grasses and presented the possible reason for growth stimulation as release of nutrients from the oil and oil-killed vegetation.

Stebbings (1968) studied salt marshes in Brittany that were damaged by oil in April, 1967. A second study was conducted 16 months later to review the recovery of the salt marsh. These marshes were able to withstand heavy contamination (2-10 cm of oil) with only slight and probably short term floral composition changes. The oil had been at sea for 14-18 days and essentially all toxic fractions had been lost. The oil behaved primarily as an impervious layer and prevented gas exchange from below the blanket. There was extremely vigorous growth of certain plant species and it seemed that these plants were deriving some nutritional benefit from the breakdown products of oil. The concluding statement of Stebbings (1970) was "salt marshes can be very important sites for trapping and holding oil off coastal waters while biodegradation and other breakdown processes occur."

From the review of literature the following conclusions were made in regard to marshes.

1. Heavy concentrations of oil on the marsh and salt grass will temporarily destroy the vegetation.
2. Oil does not appear to cause any significant long term damage to the marsh area.

The rate of recovery for the marsh area will depend upon local conditions, amount and type of oil, and type of grass. From the literature it appears that it will require about two years for the marsh to recover in northern climates and probably less in the warmer Gulf areas. In the marsh areas, the presence of organic material and nutrients will provide favorable conditions for degradation whereas on the sandy beaches the time required for degradation will be considerably longer. As a general rule in biological treatment processes, the rate of biological activity will double for each $10^{o}C$ rise in temperature within the range of 5^{o} to $35^{o}C$.

Physical weathering and photochemical decay are also factors involved in the degradation of the oil. The relative importance of these factors is not known.

The amount of oil trapped by the marsh can vary but an average thickness of 1/2-inch (12 mm) does not seem unreasonable for rough estimates. For the 30,000 ton (34,000 m^3) spill, a maximum of approximately 50% could under certain conditions reach marsh areas. This amount of oil could be trapped by 300 acres ($1.3(km)^2$) of marsh or approximately 0.1% of the marsh along the Texas Coast.

LIVESTOCK

Much of the Texas coast is used for grazing of livestock. Salt grass is often burned in the winter to remove the dead vegetation and promote the growth of new grass in the spring.

McKee and Wolf in 1963 conducted an exhaustive search of literature to determine the toxic concentrations of components of refinery waste to humans. It was concluded that the threshold odor concentration was low enough that the waters became esthetically objectionable at concentrations far below the chronic toxicity level. Crude oil was detectable by taste at a concentration of 0.5 ppm. The odor of gasoline was more easily detected than that of crude oil but crude oil was tasted more quickly. Aging caused petroleum odors to become musty.

In 1935 Ferguson and his committee stated that some cattle, sheep, and hogs develop a liking for crude oil and suffer adverse physiological effects from ingestion of oil-polluted waters. The adverse effects may have been due to laxative properties or possibly to toxicity. Whatever the cause, the animals failed to thrive and have been reported to die as a result. Thus the toxic effects of a continuous spill might be harmful to livestock in a fresh water area.

If the oil does affect the fresh water in the upper reaches of the estuary, the strong odor and disagreeable taste of water heavily polluted with hydrocarbons will make it unlikely that animals will drink such water (McKee and Wolf, 1963). Animals will probably postpone drinking until the water clears up or another source is available.

WILDLIFE

Due primarily to a high degree of mobility, most forms of land animals may escape the effects of oil spills and leakages. These animals, including most mammals and reptiles, can escape all but sudden spills on land, and can avoid waterborne oil easily. On the other hand, the mammals, reptiles and amphibians living in aquatic, swampy, or marshy habitats are not so fortunate, as their natural habitat can be destroyed by the oil, so that they have no place to return to. Those animals which do not flee from the oil may be killed by the ingestion of contaminated foods or suffer "skin burns" from being covered with oil. If they flee from their homes, these animals face stress and possible death from overcrowding, starvation, predation, or disease.

The terrestrial mammals which would most likely be affected by an oil spill and are of some aesthetic or economic value to man are: the river otter (Lutra canadensis), the beaver (Castor canadensis), and the muskrat (Ordatra zibethicus). The nutria, an exotic nuisance introduced from South America, occurs in the same aquatic habitats.

EFFECTS OF OIL ON BIRDS

Bird casualties from oil pollution number many thousands each year. Moreover, several authors, who have summarized the nature and extent of pollution-caused bird kills, have also pointed out the upward trend in both the number of oil spills and the numbers of avian casualties resulting from them (McCaull, 1969).

Because of their behavior and habitat, aquatic bird species (the swimming and diving birds) have been found to be most affected by oil spills. While aerial and coastal species avoid the oil and are not greatly affected, aquatic species cannot readily escape (Straughan, 1971)(Aldrich, 1970)(Zeldin, 1971). Those orders of birds which would be most affected are: the Gaviformes (Loons), the Podicipediformes (Grebes), the Procellariformes (Tubenoses), the Pelicaniformes (Pelicans and their Allies), the Ciconiiformes (Herons and their Allies), the Anseriformes (Waterfowl-ducks and geese), the Cruiformes (Cranes and their Allies), the Charadriiformes (Shorebirds, Bulls and Alcids), and the Coraciiformes (Kingfishers).

Two factors that appear to be involved in the death of aquatic species, the external oiling and the ingestion of the oil, have received some attention during the past few years (Hartung and Hunt, 1966; Zeldin, 1971). While the chemical differences between commerical crude oils and between various refined products present problems in determining the exact effects of the petroleum on the birds, Hartung and Hunt (1966) have reported that lipid pneumonia, gastrointestinal irritation, fatty livers, adrenal cortex hyperplasm, acinar atropy of the pancreas, and toxic nephrosis have been found in several kinds of ducks when they were fed industrial oils, cutting oil, or diesel oil. This suggests that the preening of oil-fouled feathers, which results in the ingestion of large amounts of oil, causes the death of many birds.

Furthermore, the external oiling of aquatic birds has numerous direct negative results. The oil coats the bird's body, mats its feathers, displaces air between the feathers and the skin, and breaks down the natural insulating oils and waxes. Damage to the plumage, the weight of the fouling oil and water, and the loss of natural buoyancy prevent the bird from flying and necessitate constant swimming. Exhausted and emaciated by constant swimming, an increased metabolic rate, and improper feeding, the oiled bird also spends a disproportionate amount of time preening (instead of feeding) and its condition worsens. Efforts to preen the oil from the feathers result in the ingestion of the oil, which is usually toxic to the waterfowl. Thus, the waterfowl, weakened by the combination of a number of factors, usually succumbs to the adverse effects resulting from its contact with oil (Hawkes, 1961)(Aldrich, 1970)(Zeldin, 1971).

Efforts to rescue oil polluted birds have achieved negligible results, with rarely more than 10 percent of the treated birds surviving. For example, of the 7,849 birds rescued after the _Torrey Canyon_ spill, less than 400 (5%) survived (Conder, 1967). Those birds surviving the initial treatment for ingested and external oil pose additional problems of housing feeding, and handling. Also, crowding, behavioral stresses, and diseases can create numerous difficulties. Because of these factors, it is estimated that "it can cost $1,000 to _try_ to save a single bird. With a success ratio of only 10 percent, only 100 of every 1,000 oiled birds treated are likely to survive. Thus the cost could run to $10,000 per surviving bird" (Zeldin, 1971).

Because the costs of saving waterfowl are so high, it is necessary to find ways to keep the birds out of the oil when a spill occurs. This is complicated by the fact that "Some researchers think birds are unable to distinguish oil-polluted waters from unpolluted waters. Others think seabirds are attracted by dead and dying marine life on oil slicks and oil-covered beaches" (Zeldin, 1971). It has been suggested that the birds' own alarm call or other sounding devices be used to scare birds away from oil slicks. However, these devices, which have been used to scare gulls and rooks, may not be applicable to all species of aquatic birds.

Effect of Oil on Marine and Estuarine Organisms

General considerations: Blumer (1969) and Goldberg (1970) have estimated that about 10^6 metric tons of oil are annually injected into the world oceans primarily through leakage and spillage, and most of the loss occurs in the coastal waters.

Crude oil is a complex mixture of organic compounds with a wide range of molecular weights and structures. Although different crude oils differ markedly in their physical properties, chemically they all contain essentially the same homologous series of closely related hydrocarbons and non-hydrocarbon elements, but in different proportions. The oil fractions principally responsible for immediate toxicity to living organisms include the low boiling saturated hydrocarbons (which tend to be soluble in seawater and highly toxic to marine life) and the low boiling aromatic hydrocarbons (including benzene, xylene, naphthalene, and phenanthrene). The aromatics are highly soluble and more toxic than the saturated hydrocarbons.

Laboratory studies indicate that marine algae are less severely affected by oil than are marine animals (North, et al., 1964), but phytoplankton death occurs after four or five days exposure to levels as low as one part per million if aromatic hydrocarbons are present. (Lacaze, 1967; Mironov and Lanskaya, 1967).

Laboratory studies suggest that among marine animals the eggs, larvae, and juvenile stages are generally more susceptible to the effects of oil than are the adults (Hufford, 1971). Oil products emulsified in seawater cause greater damage than oil films on the surface (Mironov, 1970). Damage may result from physically clogging the gills, precipitation of certain metals on the gill epithelium, direct action of hydrocarbons on sensitive gill cells, blockage of taste receptors, and mimicking or masking of natural chemical messengers important in the biology of sea life (Blumer, 1969; Mironov, 1970). Five to sixty minute exposures to 1000 ppm diesel oil proved lethal to zooplankton and planktonic stages of benthic marine animals (Mironov, 1970). Benthic invertebrates (especially mollusks) vary in their sensitivity to oil, some forms succumbing quickly at exposures of 10 ppm, while others remain active at concentrations of 1000 ppm (Mironov, 1967; 1969).

A number of studies indicate that the high boiling aromatics may be carcinogenic. Carruthers, et al., (1967), demonstrated that certain fractions of Kuwait crude oil are carcinogenic. Hueper (1963) reported tumor growths in soft clams associated with crude oil pollution, and Wilbur (1969) suggested that all crude oils and all oil products containing hydrocarbons with boiling points between 300 and 500°C should be viewed as potential cancer producers. This, of course, implies danger to the marine life, but also to humans and domestic animals which might consume marine organisms exposed to sublethal concentrations of petroleum and its derivatives.

Hampson and Sanders (1969) found that fuel oil spilled near West Falmouth, Massachusetts killed life in all phyla represented in that habitat (from surface to the bottom - 10 m). Holmes (1969) showed that in the Santa Barbara oil spill toxicity is almost immediate, leading to death within a few minutes or hours. Also, the most immediately toxic fractions can be spread vertically and horizontally for considerable distances, especially if turbulence and water currents are pronounced.

Johannes (1970) pointed out that coral reef communities normally exposed at low tide are especially vulnerable to the effects of oil pollution, but he indicated that little is known about the effect of oil on submerged reefs. Since some of the toxic fractions are soluble, however, and since lighter oils fractions quickly adsorb to suspended sediment particles and then sink (Hawkes, 1961), it would be expected that reefs in only a few fathoms of water would be damaged to a certain extent.

All of these problems become accentuated when oil pollution occurs within confined or semi-confined basins. Kasymov (1970), writing about oil pollution in the Caspian Sea, pointed out a sharp reduction in phytoplankton photosynthesis associated with petroleum pollution. Shallow polluted areas always gave productivity values six to ten times less than values obtained at stations in non-polluted areas, even though the basic mineral nutrients were within the normal range. Zooplankton values were only one third of the normal. Benthic fauna was reduced from 507.27 g/m^2 to 28.09 g/m^2. Fishery catches during the past 35 years have been reduced from 300 million kg (excluding herrings) to 110 million kg (including herrings). Although many factors were implicated in the recent dramatic reduction in the productivity of the Caspian Sea, Kasymov was emphatic in his indictment of petroleum pollution as being the major factor.

The Torrey Canyon spill off Cornwall, England, pointed not only to the adverse effects of petroleum on marine life, but also to the greater dangers associated with the addition of detergents (Smith, 1968).

From the above information it may be concluded that the effects of an oil spill will vary with the composition of the oil, extent of the spill, sensitivity of the target species, life history stages involved, general environmental conditions, and presence of other (potentially synergistic) agents. Furthermore, little is actually known about the toxicity levels of the particular petroleum products, acting singly or in concert with other agents, especially in relation to plant and animal species native to the northern Gulf coast. For these and other reasons it is not possible to generalize with a high degree of certainty concerning ecological effects of oil spills in the area.

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CHAPTER V

SPREAD AND TRANSPORT OF THE OIL

The prediction of spread and transport of oil is essential for a realistic evaluation of environmental impact. In this chapter models and the methodology are presented to predict the fate of oil at sea. The accuracy of the predictions cannot be better than the data on which they are based. As pointed out in Chapter II, the wind and water current data off the Texas coast are poor. A final environmental impact analysis will require more complete wind and sea data. Ichiye (1972) developed a model for predicting the gravity spread of the oil from a spill. A copy of this paper is given in Appendix C. Ichiye demonstrated that initial bore from an instantaneous spill will be dissipated within minutes after the spill. The effects of viscosity will become important in limiting the spreading and in several hours after the spill the average oil thickness will be about 1 mm. Horizontal turbulent diffusion is assumed to become the dominant driving force in the spread of the oil.

The volume and area for the 500-ton spill and the 30,000-ton spill are listed in the following table for an average thickness of 1.0 mm. The area of the slick at the end of the gravity spread is probably overestimated in that the oil will remain thicker in the center than at the edges for some time after the spill. Diffusion will tend to break the slick into patches and also reduce the thickness of the oil.

Table V-1. Initial Area of Oil Spills.

Spill Tons	Volume m^3	Diameter km	Surface Area of Oil [1] $(km)^2$	$(nm)^2$ [2]
500	550	0.85	0.55	0.16
30,000	33,000	6.5	33.	9.6

[1] Surface area if the average oil thickness is 1.0 mm.

[2] Square nautical miles.

MODEL

The diffusion (transport) equation for oil is given by

$$\frac{\partial d_o}{\partial t} + \vec{U}\,\nabla d_o + d_o\,\nabla\,\vec{u} = \nabla(\vec{D}\nabla d_o) \qquad (1)$$

where d_o is the oil thickness, $\vec{U}$ is the mean flow (like tidal currents, wind drift, slope or density currents) and $\nabla\vec{u}$ is perturbation. $\vec{D}$ is (pseudo) vector of its eddy diffusivity. $\vec{u}$ is mainly due to gravity effects and expressed by

$$\frac{\partial}{\partial t}\,\vec{u} + \vec{U}\nabla\vec{u} = -g\frac{\rho_o}{\rho}\nabla d_o \qquad (2)$$

where ρ_o and ρ are density of oil and water respectively when operator $d/dt = \partial/\partial t + \vec{U}\cdot\nabla$ is applied to (1) and $d\vec{u}/dt$ is substituted from (2), we have

$$\left(\frac{d}{dt}\right)^2 d_o = g' d_o \nabla^2 d_o + \frac{d}{dt}\nabla(\vec{D}\cdot\nabla d_o) \qquad (3)$$

where $g' = g\rho_o/\rho$.

The order of magnitude of the gravity term (the first term of the r.h.s. of equation (3)) and the diffusion term can be expressed by

$$|g'd_o\nabla^2 d_o| \text{ and } \left|\frac{1}{\grave{p}}D\nabla^2 d_o\right| \qquad (4)$$

where $\grave{p}$ is the time scale of spreading of the oil pool. The ratio of two terms is given by

$$\grave{p}g'd_o/D = K \qquad (5)$$

On the other hand $D\ \dot{\alpha}\ \grave{p}^{n+1}$ and n is usually positive. If Kolmogroff's hypothesis is valid, n = 1. Experimental data (dye patches) show n is between 1 and 2. Therefore

$$K\ \alpha\ g'd_o\grave{p}^{n} \qquad (6)$$

Thus when $\grave{p}$ is small $K < 1$ and the gravity effect cannot be neglected.

Forrester (1971) reported that the oil spill from the tanker Arrow in February 1970 off Nova Scotia produced cohesive oil lumps to 1 to 2 mm^3 after about 8 days of the spill. After 10 to 20 days, suspended particles of oil of 100μ to 1 mm diameter were found at 5m depth up to 120km from the source, and their concentrations were more than 2 ppb. Since the particles were collected by the Clark-Bumpus plankton sampler which is not designed to collect oil particles, many particles might have escaped from the sampler and thus actual concentration might have been higher than these values. Also the oil particles may float at the surface and make surface concentration much higher. It should be noted that the oil spill was dispersed as suspended particles and not as a cohesive layer or film. The concentration of the suspended particles can be treated by the diffusion equation which thus will be valid several days after the start of the spill.

The rate at which oil is spread by horizontal diffusion depends upon both the sea state and the size of the oil slick. A modified form of the Fickian diffusion equation is presented here to account for the transport, spreading and decay of the oil slick.

$$\frac{\partial d_o}{dt} = - \frac{U \partial d_o}{\partial X} + \frac{D_x \partial^2 d_o}{\partial X^2} + \frac{D_y \partial^2 d_o}{\partial Y^2} - Kd_o \qquad (7)$$

Where d_o is the oil thickness, U is the unidirectional velocity of the slick in the X direction and is the vector summation of the wind and current components, D_x is the longitudinal spreading coefficient, D_y is the transverse spreading coefficient, and K is the decay coefficient. K includes losses due to the water by solution and to the air by evaporation. This equation is valid only when the gradient of thickness ($\partial d_o/\partial X$ and $\partial d_o/\partial Y$) is small and thus the gravity effect is small compared with the diffusion effects. However, this equation is valid when the oil pool is broken up in small patches. Then d_o represents the average concentration of oil. The spreading coefficient (D) is assumed to include both the gravity spreading after the initial stages and eddy diffusivity. The effects of biological degradation are considered to be very small in relationship to the solution and evaporation terms. The oil slicks described by this equation are shown in Figure V-1.

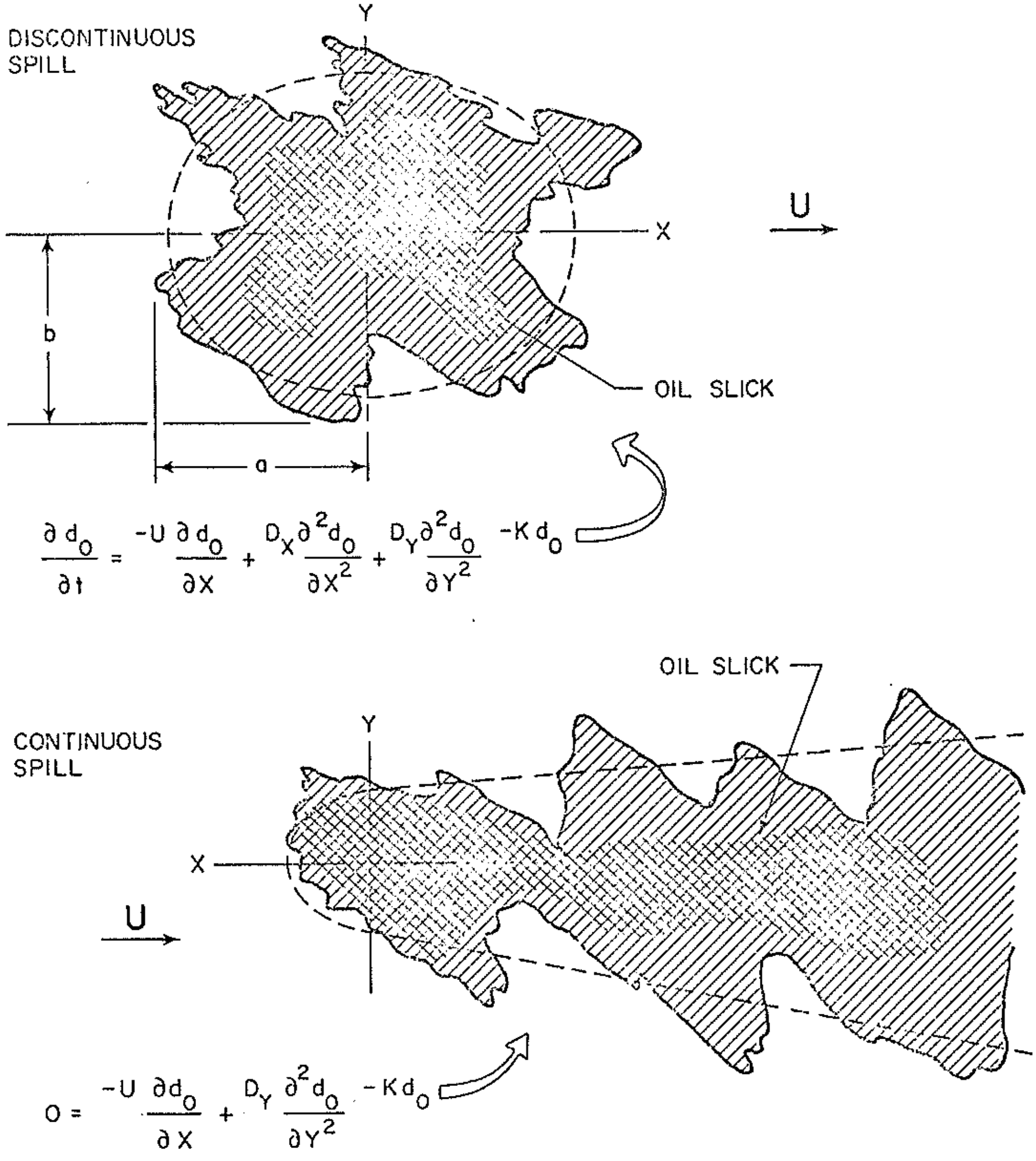


Figure V-1. Models for Predicting Oil Movement.

For a slug loading or discontinuous discharge a solution to the above equation is

$$d_o = \frac{M\ e^{-Kt}}{\pi\sqrt{2\pi}[\sigma_x{}^2\sigma_y{}^2]^{1/2}}\ \exp{}^{-[\frac{x^2}{2\sigma_y{}^2} + \frac{Y^2}{2\sigma_y{}^2}]} \qquad (8)$$

Where the coordinate axis moves with the center of the waste field, ($x = X - Ut$), M is the initial volume of the oil spill, and $\sigma_x{}^2$ and $\sigma_y{}^2$ are the variances in the longitudinal and transverse direction respectively. The term

$$\frac{M\ e^{-Kt}}{\pi\sqrt{2\pi}[\sigma_x{}^2\sigma_y{}^2]^{1/2}} \qquad (9)$$

is equal to the maximum thickness at the center of the slick (d_m). The relationship between the change in variance and the spreading coefficient is given by

$$D_x = \frac{1}{2}\frac{d\sigma_x{}^2}{dt} \qquad (10)$$

$$D_y = \frac{1}{2}\frac{d\sigma_y{}^2}{dt} \qquad (11)$$

The equation of contours of equal thickness (concentration) is obtained by dividing equation (8) by the maximum thickness at the centroid, taking the log of each side and multiplying by two, the equation. It represents a family of ellipses with a center at $X = Ut$ as given by

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1 \qquad (12)$$

$$a^2 = 2\sigma_x{}^2\ \ln[\frac{d_m}{d_o}] \qquad (13)$$

$$b^2 = 2\sigma_y^{\ 2} \ln[\frac{d_m}{d_o}] \tag{14}$$

where a and b are the major and minor semi axis of an ellipse. After the slick is broken into patches the edge of the slick is assumed to form an irregular boundary. The average oil thickness for an ellipse fitted to the outer edge of this slick (see Figure V-1) was taken as half the average thickness (dm/2). With these assumptions the values of the semi major and semi minor axis become:

$$\sigma_x^{\ 2} = 0.7a^2 \tag{15}$$

$$\sigma_y^{\ 2} = 0.7b^2 \tag{16}$$

The 4/3 law of eddy diffusion is the same as the variance increasing with the cube of the time and the diffusion coefficient varies to the square of the time. For a continuous source, the width of the oil slick would increase at an increasing rate if the 4/3 law were applicable as shown in Figure V-2.

The resulting shape of the Louisiana slick is shown in Figure V-3, indicating a constant spreading coefficient. This seems to be due to neglecting the gravity effect in the initial stages of the spreading. For the purpose of this study the spreading coefficient will be assumed to be constant for a given sea state and spill volume. High diffusion rates will be estimated for the model and these values will be assumed to include the effect of gravity spreading during the early stages.

Blacklaw, et al., (1970), showed that the energy available for

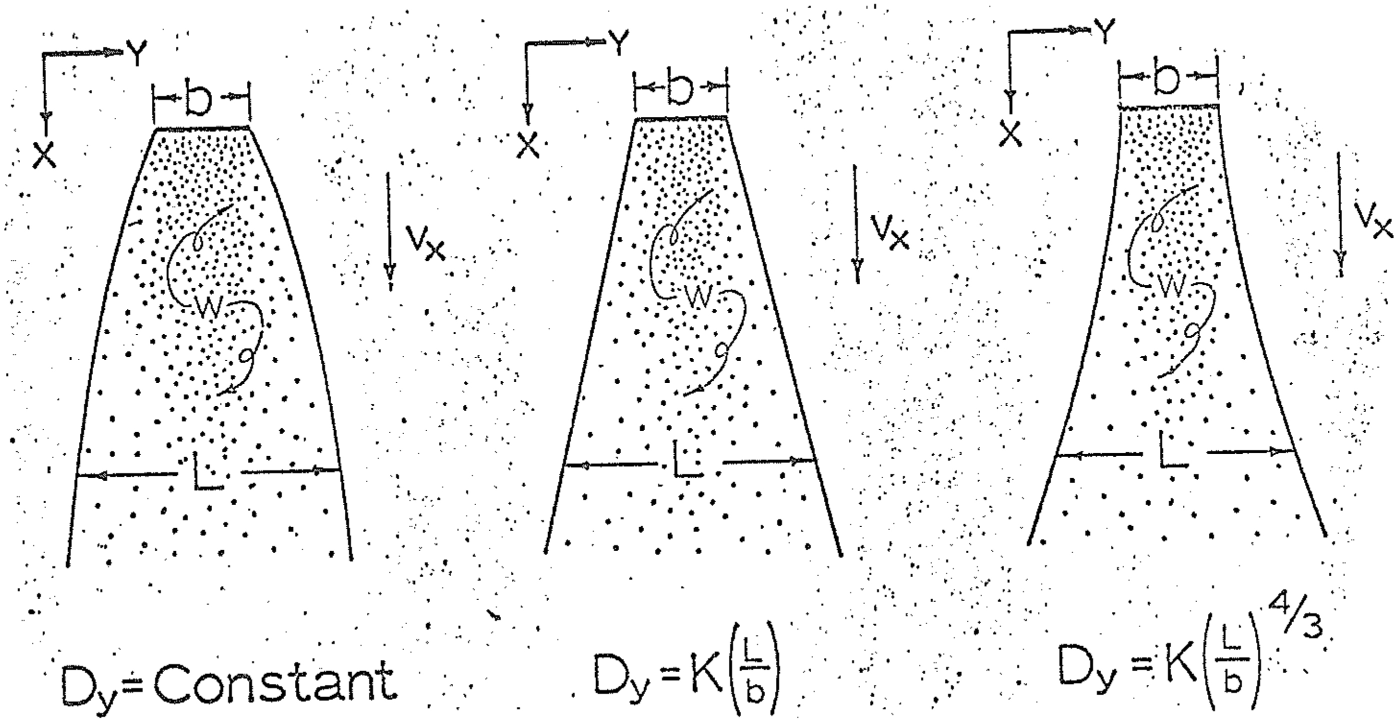
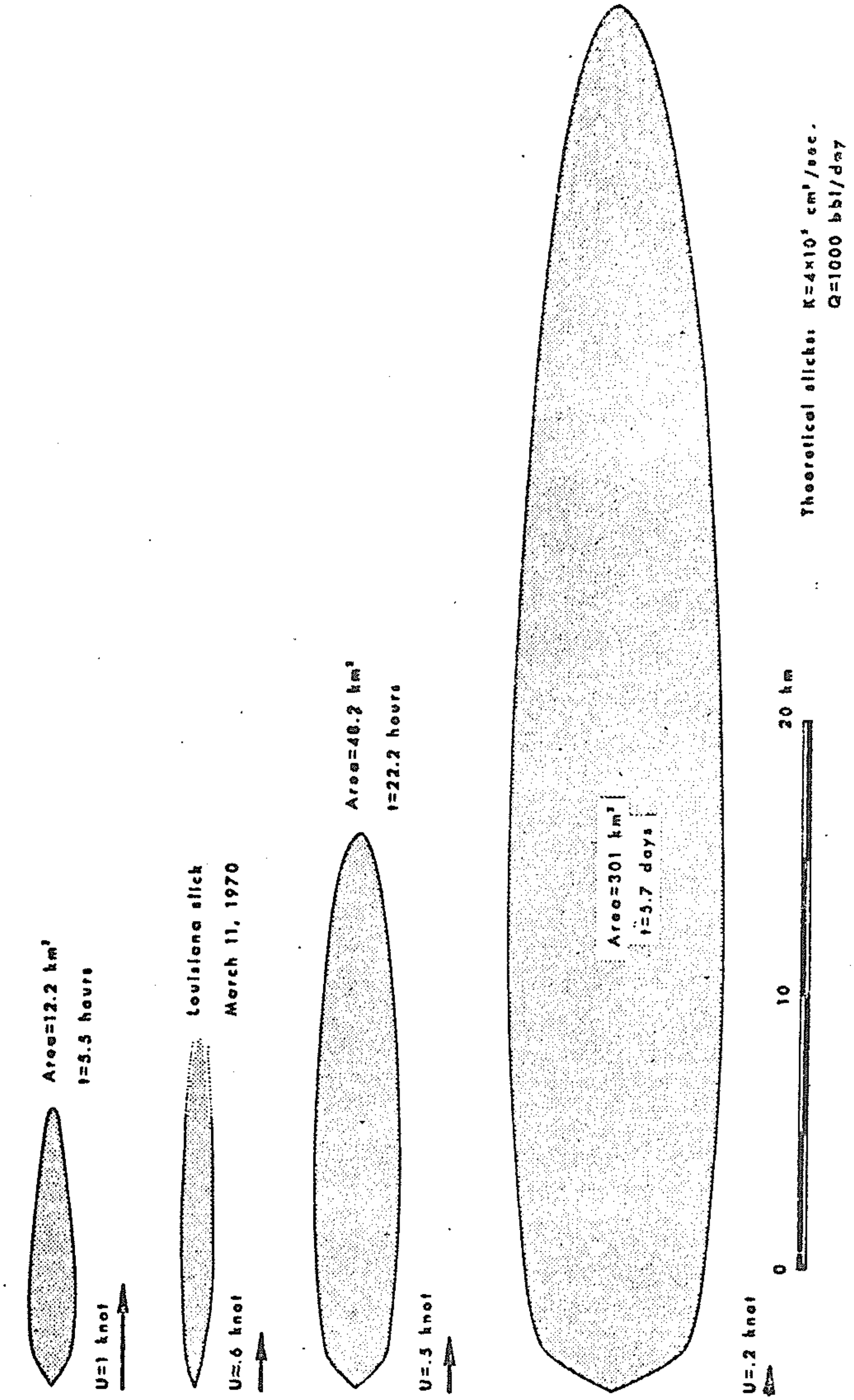


Figure V-2. Plume Patterns for Various Spreading Coefficients.



Source: Kennedy and Wermund, 1971.

Figure V-3. Comparison of Observed Slicks with Theoretical Slicks.

mixing increased with approximately the cube of the wind velocity as listed below:

Table V-2. Energy Available for Mixing.

Wind Velocity		Mixing Energy	
kts	m/s	ft-lbs/ft^2	cm-gm/cm^2
2	1.4	0.03	0.5
5	3.4	0.4	6.0
10	6.8	4.0	60.0
20	13.6	30.0	450.0
30	20.5	100.0	1500.0
40	27.3	260.0	3900.0

Thus as the sea state increases both the spreading coefficients and decay term should increase. Table V-3 gives the relationship between sea state and wind velocity for the open sea, not limited by fetch or duration.

Kennedy and Wermund (1971) were able to reproduce the Louisiana slick of March 11, 1970, using a spreading coefficient of 400,000 cm^2/sec. This value appears high when compared to values normally encountered in water quality studies where the waste is mixed throughout the water column. An oil slick is on the water surface and the air turbulence and wind gusts are more effective in spreading the surface slick than spreading particles within the water column.

If the oil slick is transported by the mean flow, the spread

Table V-3. Wind Scales and Sea Descriptions (after Bascom 1964).

Beaufort Scales	Wind Velocity Knots	m/s	Description	Wave Heights Feet	Meters	State of Sea Code
1	1-3	0.6	Light air; ripples - no foam crests.	0	0	0
2	5	1.5	Light breeze; small wavelets, crests have glassy appearance and do not break.	0-1	0 -0.3	1
3	10	3.1	Gentle breeze; large wavelets, crests begin to break. Scattered whitecaps.	1-2	0.3-0.6	2
4	15	4.6	Moderate breeze; small waves becoming longer. Frequent whitecaps.	2-4	0.6-1.2	3
5	20	6.1	Fresh breeze; moderate waves taking a more pronounced long form; mainly whitecaps, some spray.	4-8	1.2-2.4	4
6	25	7.7	Strong breeze; large waves begin to form extensive whitecaps everywhere, some spray.	8-13	2.4-4.0	5
7	30	9	Moderate gale; sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind.	13-16	4 -5	5 1/2
8	40	12	Fresh gale; edges of crests break into spindrift. The foam is blown in well-marked streaks along the direction of the wind.	16-20	5 -6	6
10	50	15	Whole gale. The surface of the sea takes on a white appearance. The rolling of the sea becomes heavy.	20-30	6 -9	7

of the oil patch decreases. An increase in wind speed increases the surface drift and thus produces an elongation of the patch. On the other hand, the increase in the wind speed increases the turbulence in the upper layer of the ocean and thus the spreading coefficient will be considered to increase with the wind speed. Therefore, an increase of the wind speed may spread the oil patch and elongate it. The longitudinal spreading coefficient (D_x) is not considered effective in reducing the average oil thickness for a continuous spill with a mean flow because of the low gradients. However, for a slug or discontinuous spill the longitudinal spreading coefficient is effective in spreading the oil.

Spreading coefficients assumed for this study are listed in Table V-4. As discussed above, the spreading coefficients will increase with the wind speed. Since the dimension of the three spills each differed by a factor of 10, the spreading coefficient was also considered to increase with the size of the spill. This increase is to account for the shift in describing the spill movement from the convection term to the spreading term in the model as the size increases.

Table V-4. Spreading Coefficients for Three Oil Spills.

WIND	SPEED	SPREADING COEFFICIENTS x 10^{-5} cm^2/sec					
		Continuous Spill		500-ton Spill		30,000-ton Spill	
kts	m/s	D_x	D_y	D_x	D_y	D_x	D_y
5-10	2.5- 5	0.7	0.5	1.5	1.0	3.0	2.0
10-20	5 -10	1.5	1.0	3.0	2.0	6.0	4.0
20-40	10 -20	3.0	2.0	6.0	4.0	12.0	8.0

The transport of oil on the sea surface is illustrated in Figure V-4. The resulting movement of the oil is estimated as the vector sum of the water current plus 3.1% of the wind. In this study, no correction was applied for the coriolis force.

CONTINUOUS SPILL

The American Petroleum Institute investigated the spreading of oil on water surfaces and presented the thicknesses and descriptions listed in Table V-5.

Table V-5. Appearance of Thin Oil Films.

OIL ON SURFACE			
Gallons Per Sq Mi	Liters per sq. km.	Approximate Film Thickness, mm	Appearance
25	36	0.00004	Barely visible under most favorable light conditions.
50	73	0.00008	Visible as a silvery sheen on surface of water.
100	150	0.00015	First trace of color may be observed.
200	290	0.00030	Bright bands of color are visible.
666	970	0.0010	Colors begin to turn dull.
1332	1950	0.0020	Colors are much darker.

Films up to 0.00008 mm did not persist for more than five hours on agitated water surfaces. A slug of oil at sea required 40 to 100 hours to thin out to 0.001 mm but thereafter disappeared

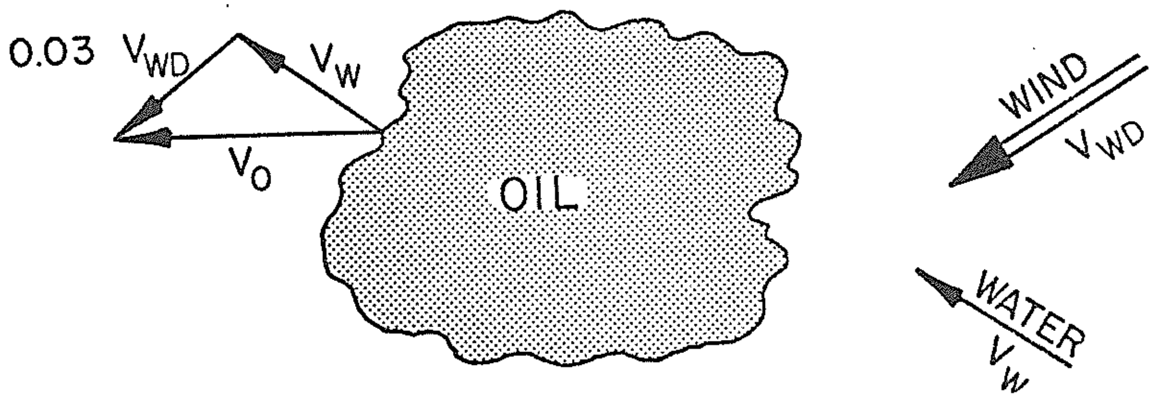


Figure V-4. Oil Transport on the Sea Surface.

entirely in less than 24 hours. The API reports that oil may be discharged uniformly at a rate of 10 gallons per hour per square mile without becoming visible, but a rate of 28 gallons per hour per square mile would result in a continuous irridescent film.

The flow rates for a continuous spill were 1.2, 2.3, 4.2 and 8.5 barrels per day (7.9, 15.2, 28 and 56 liters per hour). Assuming an average wind speed of 10 kts (5.1 m/s) and a ratio of oil slick to wind speed of 0.031, the oil from the continuous source would be transported away from the port facility at a rate of approximately 0.3 kts (0.15 m/s).

Since the oil volume is small for the continuous spill, surface tension spreading is assumed to be effective in reducing the oil thickness. Several hours after spilling the oil slick is assumed to appear as bright color bands. According to Table V-5 the thickness would be approximately 0.0003 mm. The initial width of the plume required to achieve this thickness would be as listed in Column 2 of Table V-6. The third column of the table lists the plume width required so that the average oil concentration is less than 10 gal per sq mile at which time the oil film should no longer be visible to the eye. For a section across the plume as it travels away from the source, the time required for the oil to disperse was estimated from

$$D_y = \frac{1}{2} \frac{\Delta\sigma_y^2}{\Delta t} \qquad (17)$$

where the width of the plume was assumed to be equal to three times σ_y. Based on a normal distribution, nearly all the oil

Table V-6. Area of Visible Influence of a Continuous Spill.

Barrels Per Day	Initial				Time Required in hrs [2]			Length	Area
	ft.	m	ft.	m	D_y=50	D_y=100	D_y=200	km	$(km)^2$
1.2	200	60	2,000	600	1	0.5	0.2	0.5	0.2
2.3	400	120	4,000	1,200	4	2	1	2.2	1.4
4.2	600	180	6,000	1,800	9	4	2	5.0	5.0
8.5	1,300	400	13,000	4,000	44	21	11	24.	53.

[1] Width of the plume required to have an average concentration of 10 gal per sq mile.

[2] Spreading coefficient (D_y) in ft^2/sec.

would be within this width. Since both the oil slick velocity and diffusion coefficient increased with the wind speed, the area of visible influence of the continuous spill is nearly independent of the wind speed. Figure V-5 shows the estimated relative size of the visible area of influence of the continuous spill for the year 2000 at the offshore site (site 1).

If the oil at a concentration of 10 gal per sq mile (14.61 liters per sq. km.) is assumed to be dissolved and suspended in the upper two meters of water, the resulting concentration would be 50 parts per billion. The wind will carry the oil away from the site, at an average rate of about 0.1 kts (0.15 m/s) while the water currents in the area are about 0.1 kts (0.05 m/s) parallel to the coast. Hence the oil that does enter the water column generally is expected to travel parallel to shore rather than towards the beach.

ACCIDENTAL SPILLS

Wind data at Houston can be used roughly to predict oil spill movement by using a wind factor of 0.031; i.e., the oil slick speed is estimated at 3.1% of the wind speed. By use of mean wind speed and distances of site 1 (offshore) and site 2 (nearshore) of the proposed port, hours to reach the beach for each direction of wind and percentages of such occurrence were computed and shown in Table V-7. The results indicate that in most months the spill will reach beach within two days at Site 2 and 4 days at Site 1. The percentage of time that beaching is likely to occur is listed in Table V-8. The data indicate that the oil will travel towards

Table V-7. Beaching Time [1] in Hours for Oil Spill.

WIND DIRECTION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
						(month)						
					Offshore Site 1							
SSW	134	132	126	123	136	156	181	190	175	163	142	141
S	89	88	84	82	91	104	121	127	117	108	95	94
SSE	71	70	66	65	72	83	96	100	93	86	75	75
SE	67	66	63	61	68	78	90	95	87	81	71	70
ESE	82	80	76	75	83	95	110	115	107	99	86	86
E	131	129	123	120	133	153	177	185	171	159	139	138
ENE	337	331	316	308	343	393	456	477	441	409	358	355
					Nearshore Site 2							
SSW	58	57	54	53	59	67	78	82	76	70	61	61
S	40	40	38	37	41	47	54	57	53	49	43	42
SSE	35	34	33	32	35	40	47	49	45	42	37	36
SE	36	35	33	33	36	42	48	51	47	43	38	37
ESE	43	43	41	40	44	51	59	62	57	53	46	46
E	72	71	68	66	74	85	98	103	95	88	77	76
ENE	220	216	206	201	223	256	297	311	287	267	233	231

[1] Oil slick movement based on 3.1% of wind.

Table V-8. Percentage of Winds From Beaching Direction.

Wind Direction	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg.
	(month)												
SSW	6	5	6	4	5	8	10	10	3	3	4	6	5.8
S	9	9	10	8	9	15	16	12	6	5	7	6	9.3
SSE	11	11	13	20	23	21	18	14	9	9	9	8	13.8
SE	6	6	10	17	17	15	11	9	10	10	6	7	10.3
ESE	7	8	9	10	8	8	6	7	11	11	9	8	8.5
E	6	6	5	5	4	4	3	6	8	7	6	6	5.5
ENE	8	8	7	5	4	5	4	6	12	10	9	8	7.2
ALL	53	53	60	69	70	76	68	64	59	55	50	49	60.5

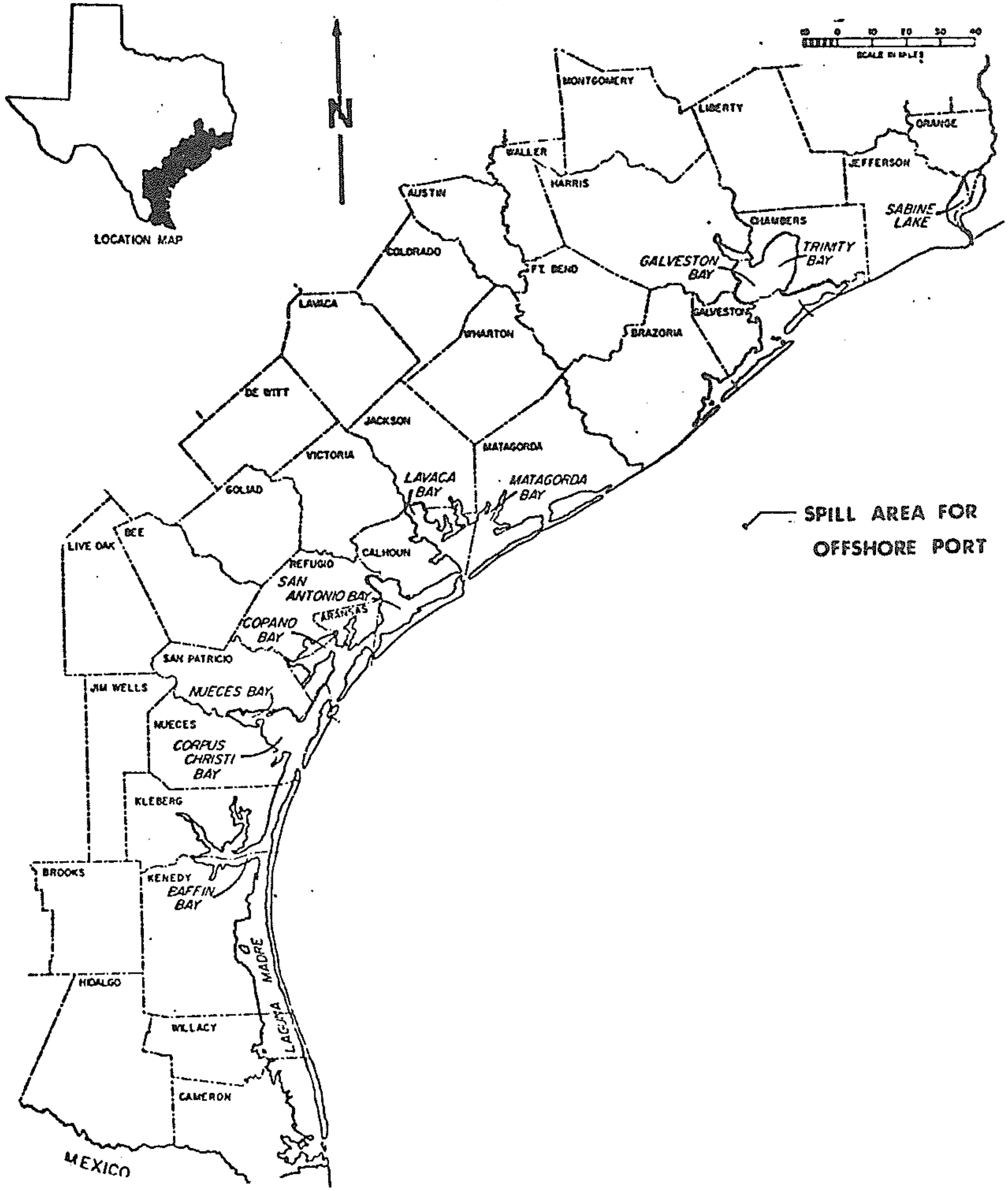


Figure V-5. Approximate Area of Direct Impact for a Continuous Spill of 2.3 Barrels Per Day.

the beach more than half the time. The percentage of time that the spill would reach the beach within a given time period is listed in Table V-9.

500-TON SPILL

The transport model given by equation 8 of this section was used to predict the size of the oil spill at several times after release and for three different wind conditions. Tables V-10, 11 and 12 show the approximate size of the 500-ton (570 m^3) spill for times up to 61 hours after the spill.

As described in the section on the general characteristics of oil, part of the oil dissolves into the water column. The aromatic mono-cyclic fraction appears to be the most critical in their effect on life in the water column. From Table IV-2 a rough estimate of the amount of this fraction which would enter the water column is taken as the ratio of dissolution to evaporation rates, i.e., for each part that enters the water column approximately six parts should evaporate. The amount of aromatic mono-cyclic fraction in the oil is estimated at 2.5% (see Table IV-1) or 12.5 tons in the 500-ton spill. The aromatic mono-cyclic fraction is assumed to be dissolved into the water column uniformly to a depth of 10 m. If the horizontal extent of the dissolved oil is assumed equal to the horizontal extent of the oil slick at the end of 7 hours from Table V-11, the average concentration of aromatic mono-cyclic fraction would be 0.03 ppm. As shown in Figure V-6, the oil that goes into the water column does not necessarily move with the oil slick but will move with the water current. The oil that goes into solution originates

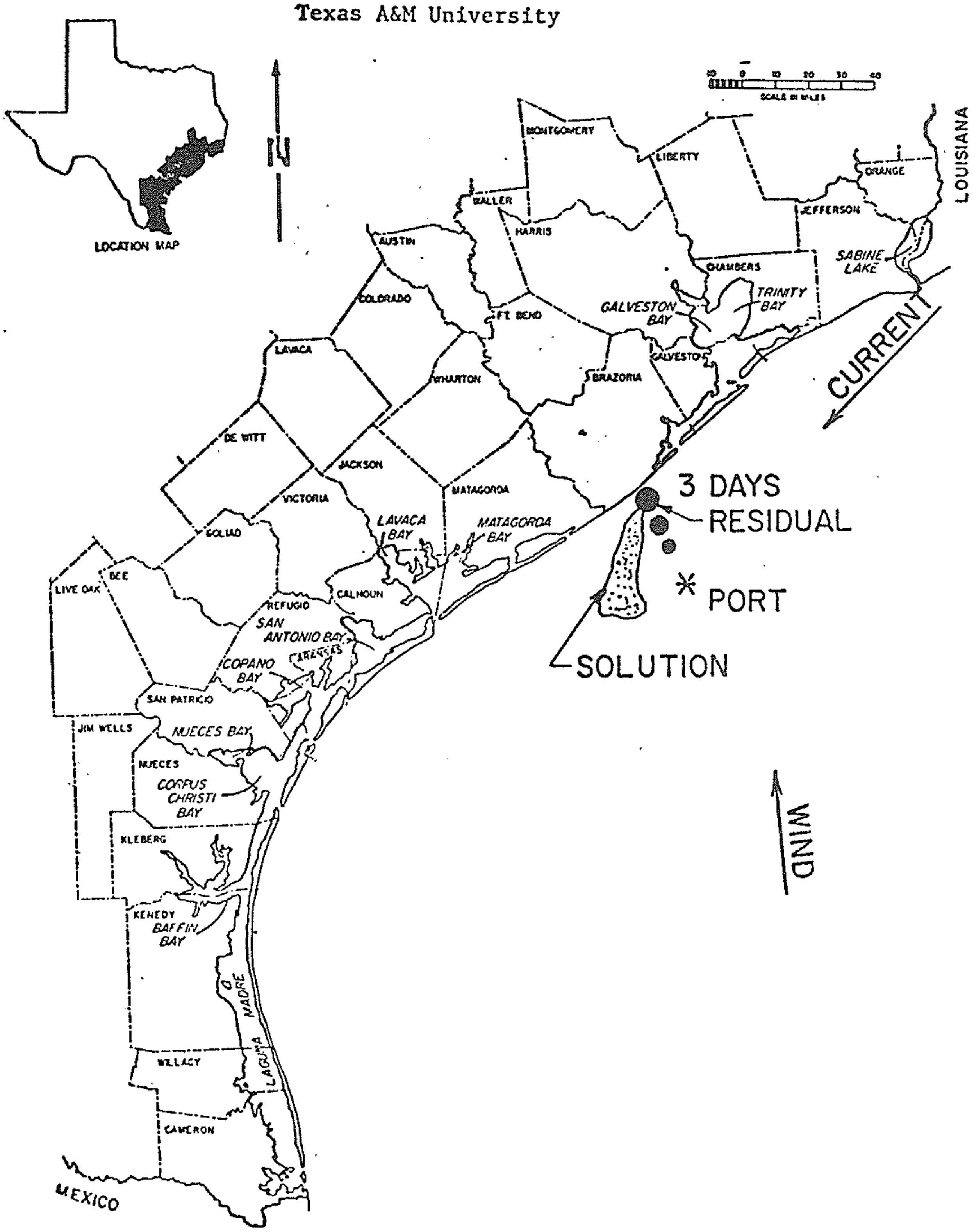


Figure V-6. Transport of Oil Fraction in Solution.

Table V-9. Percentage of Time that Beaching

Will Occur Within a Given Time.

						(month)							
TIME DAYS	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg.
					Offshore Site 1								
3	17	17	23	37	40	--	--	--	--	--	6	7	12.3
4	33	34	42	55	57	44	29	11	10	19	31	29	32.8
5	33	34	42	60	57	59	35	30	36	36	31	29	40.2
					Nearshore Site 2								
2	33	34	42	55	57	51	29	--	19	19	31	29	33.3
3	45	45	53	64	62	67	51	42	36	38	35	35	47.8

Table V-10. Oil Slick Size, 500-Ton (570 m^3) Spill, Wind 5 - 10 kts. [1]

Time Hrs.	Major Axis km	Minor Axis km	Area $(km)^2$	Average Thickness mm No Loss	Average Thickness mm With Loss
1	.85	.85	.567	1.000	1.00
7	2.12	1.79	3.09	.1836	0.138
13	2.88	2.39	5.41	.1049	0.065
19	3.48	2.87	7.84	.0724	0.043
25	3.99	3.27	10.25	.0554	0.029
31	4.44	3.64	12.69	.0447	0.023
37	4.85	3.96	15.08	.0376	0.019
43	5.23	4.26	17.50	.0324	0.016
49	5.58	4.55	19.94	.0284	0.014
55	5.91	4.81	22.33	.0254	0.013
61	6.22	5.07	24.77	.0229	0.011

[1] Diffusion Coefficients from Table V-4.

Table V-11. Oil Slick Size, 500-Ton (570 m^3) Spill, Wind 10 - 20 kts. [1]

Time Hrs.	Major Axis km	Minor Axis km	Area $(km)^2$	Average Thickness mm No Loss	Average Thickness mm With Loss
1	.85	.85	.567	1.00	1.00
7	2.88	2.41	5.45	.1041	0.073
13	3.99	3.30	10.34	.0548	0.030
19	4.85	4.00	15.24	.0372	0.020
25	5.58	4.59	20.11	.0282	0.015
31	6.22	5.12	25.01	.0227	0.012
37	6.80	5.60	29.91	.0189	0.009
43	7.34	6.03	34.76	.0163	0.008
49	7.84	6.44	39.65	.0143	0.007
55	8.31	6.83	44.58	.0127	0.006
61	8.75	7.19	49.41	.0115	0.005

[1] Diffusion Coefficients from Table V-4.

Table V-12. Oil Slick Size, 500-Ton (570 m^3) Spill, Wind 20 - 40 kt. [1]

Time	Major Axis	Minor Axis	Area	Average Thickness	
Hrs.	km	km	$(km)^2$	No Loss	With Loss
				mm	
1	.85	.85	.567	1.000	1.000
7	3.99	3.29	10.31	.0550	0.033
13	5.58	4.57	20.03	.0238	0.014
19	6.81	5.57	29.79	.0190	0.010
25	7.84	6.41	39.47	.0144	0.007
31	8.76	7.16	49.26	.0115	0.006
37	9.59	7.83	58.97	.0096	0.005
43	10.35	8.45	68.69	.0083	0.004
49	11.06	9.03	78.43	.0072	0.004
55	11.73	9.57	88.16	.0064	0.003
61	12.36	10.08	97.85	.0058	0.003

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[1] Diffusion Coefficients from Table V-4.

from a moving source and the horizontal area and the actual dilution are expected to be greater than that determined above. A more accurate assessment could be made of the concentration distribution by assuming a decaying source at a fixed location with the apparent motion replacing the uniform transport velocity in the diffusion model.

Upon reaching the beach nearly all the volatile fractions of the oil will have evaporated. Assuming that 50% of the oil is lost to the atmosphere and to the water column, approximately 250 tons of oil would reach the shore. It is expected that for this size spill the oil would not drift along the coast but would impact a section of the coast equal to the width of the oil slick.

30,000-TON SPILL

Tables V-13, 14 and 15 list the approximate size and thickness for the 30,000-ton spill for 5 - 10, 10 - 20 and 20 - 40 kt winds respectively. It is assumed that the oil will contain approximately 2.5% aromatic mono-cyclic fraction (750 tons) and based on the ratio of evaporation rate to dissolution rate, approximately 1/7 of this fraction will go in solution in the water column. From Table V-14, the 30,000-ton spill at the end of 8 hours will cover an area of about 43 $(km)^2$. The oil fractions in solution will cover a much larger horizontal area than the surface area of the slick (see Figure V-6). Using the surface slick area for the purpose of estimating a maximum concentration expected and a vertical mixing depth of 10 meters, the resulting maximum concentration of the aromatic mono-cyclic fraction in the water column would be 0.2 ppm.

Table V-13. Oil Slick Size, 30,000-Ton (34,000 m^3) Spill, Wind 5 - 10 kt. [1]

Time Hrs.	Major Axis km	Minor Axis km	Area $(km)^2$	Average Thickness (mm) No Loss	 With Loss
2	6.5	6.5	33.0	1.000	1.00
9	7.06	6.88	38.15	0.865	0.65
14	7.58	7.24	43.10	0.766	0.47
20	8.06	7.59	48.05	0.687	0.38
26	8.52	7.91	52.93	0.623	0.33
32	8.96	8.23	57.91	0.570	0.30
38	9.38	8.53	62.84	0.525	0.27
44	9.77	8.83	67.75	0.487	0.25
50	10.15	9.11	72.62	0.454	0.23
56	10.51	9.39	77.51	0.426	0.21
62	10.87	9.66	82.47	0.400	0.20

---

[1] Spreading Coefficients from Table V-4.

Table V-14. Oil Slick Size, 30,000-Ton

(34,000 m^3) Spill, 10 - 20 kt Wind.*

Time Hrs.	Major Axis km	Minor Axis km	Area $(km)^2$	Average Thickness No Loss mm	Average Thickness With Loss mm
2	6.5	6.5	33	1.00	1.00
8	7.6	7.2	43	0.77	0.49
14	8.5	7.9	52	0.63	0.33
20	9.4	8.5	62	0.53	0.26
26	10.1	9.1	72	0.46	0.23
32	10.9	9.6	82	0.40	0.20
38	11.5	10.1	91	0.36	0.18
44	12.2	10.6	101	0.33	0.16
50	12.8	11.1	111	0.30	0.15
56	13.4	11.5	121	0.27	0.14
62	13.9	12.0	131	0.25	0.13

* Spreading Coefficients from Table V-4.

Table V-15. Oil Slick Size, 30,000-Ton

(34,000 m^3) Spill, 20 - 40 kt Wind. [1]

Time Hrs.	Major Axis km	Minor Axis km	Area $(km)^2$	Average Thickness (mm) No Loss	 With Loss
2	6.5	6.5	33	1.00	1.00
8	8.52	7.90	52.86	0.628	0.46
14	10.15	9.09	72.46	0.458	0.23
20	11.55	10.14	91.98	0.361	0.18
26	12.80	11.09	111.49	0.298	0.15
32	13.93	11.96	130.85	0.253	0.12
38	14.99	12.78	150.46	0.220	0.11
44	15.97	13.55	169.95	0.195	0.10
50	16.90	14.28	189.51	0.175	0.09
56	17.77	14.97	208.93	0.159	0.08
62	18.61	15.63	228.45	0.145	0.07

[1] Spreading Coefficients from Table V-4.

By the time the oil reaches the coast approximately half of the oil will have evaporated leaving about 15,000 tons (17,000 m^3) in the oil slick. The beach is expected to act as a barrier and cause the oil to become thicker near the beach. Assuming an average thickness along the beach of one cm, the area of the slick would be 1,700,000 sq meters. If the width of the oil slick perpendicular to the beach is 100 meters, the oil slick will extend along the coast for about 17,000 meters initially and longer as the slick moves along the coast. With a 0.2 kt longshore current the oil slick will require several tidal cycles to pass a given point.

The beach will also absorb and retain a part of the oil at a rate estimated at 100 tons per mile. Absorption of oil is a complicated process including formation of suspended particles, attachment to bottom, biodegradation, etc., but it may mean longer duration than floating on the surface. Without other considerations it would take about 150 miles of beach to absorb the oil naturally. With a longshore current velocity of 0.2 kts, the oil would require about 30 days to traverse this distance.

The nearshore area along the Texas Coast is very turbid. It would be expected that after a few days of mixing in the surf zone, that some of the oil would sink. This process is not clearly understood and it may not be beneficial but rather damaging since the oil, in addition to causing damage to the bottom organism, will be a pollution source for an extended time period. This makes it desirable that floating sorbent material be added to the oil slick as it approaches the coast and mechanical methods along the beach be utilized to remove the oil from the sea.

Assume that the rate of sinking is proportional to the amount of oil remaining in the slick, the contact area between the oil slick and the turbid waters and the mixing time that the oil has been exposed to the suspended sediment in the nearshore water. The amount of oil remaining in the slick will decrease with time and the exposure area is expected to increase slightly. While studies are required, a simplified model is suggested for this report.

$$\frac{dV}{dt} = K_1 - K_2Vt$$

where V is the volume of the oil remaining on the sea surface, t is time in days, K_1 is the rate at which oil is absorbed on the beach, and K_2Vt is the rate at which the oil is sunk. A plot of this equation appears as shown in Figure V-7.

In addition to the loss of oil to the beach and to sinking, oil is also removed from the coastal slick by estuaries. As the estuaries are the most productive part of the marine environment, emergency plans for establishing barriers about the inlets should be formulated before constructing the port. The division of oil flow along the coast and into the estuary will depend upon the geometry of the inlet, wind direction, oil set up along the beach and the currents at the entrance. High altitude NASA aerial photography was used to identify and locate points along the coast where oil might enter the estuaries. Most of the shore impacted would be high energy beaches with a small amount of marsh areas affected.

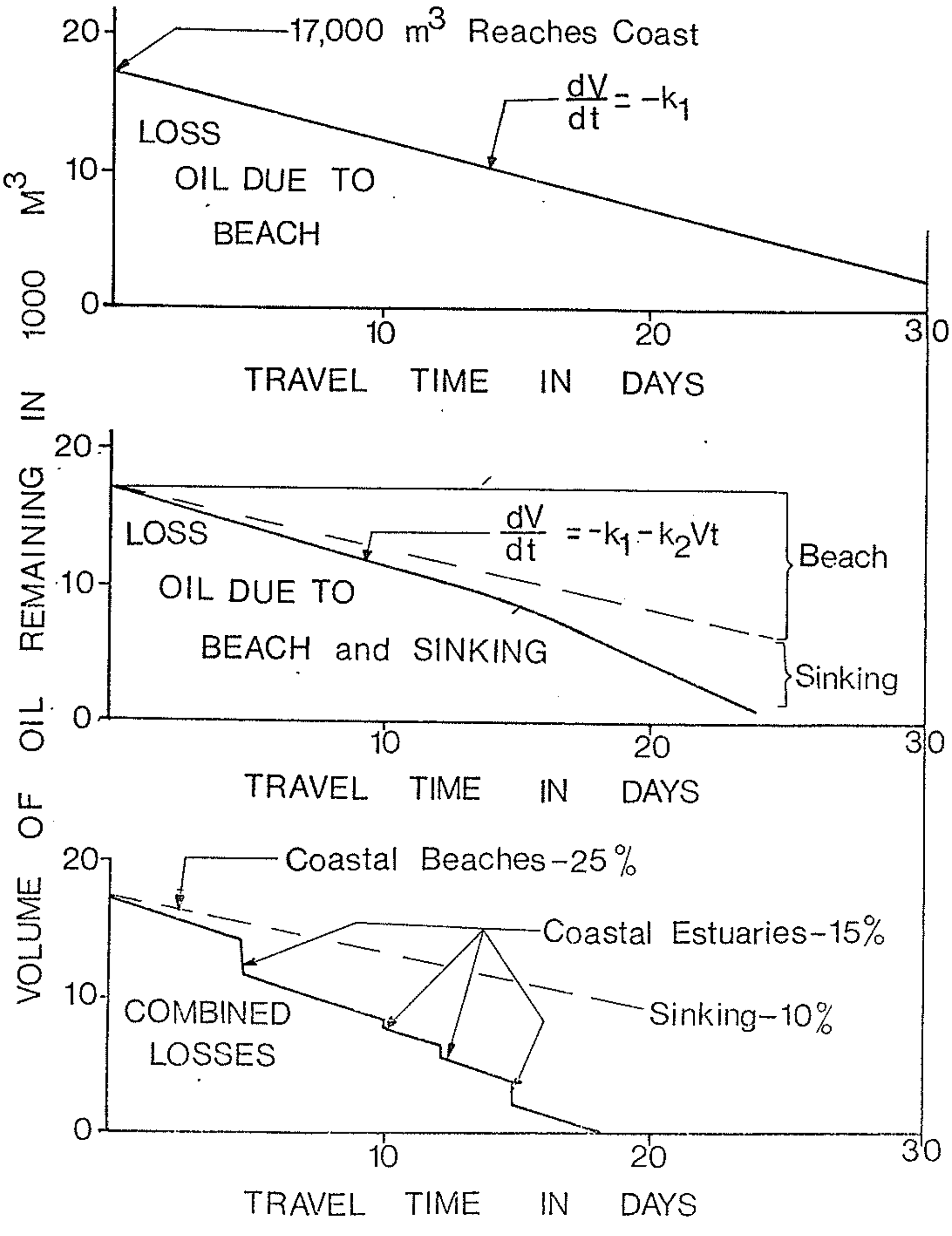

Figure V-7. Fate of Oil Along the Coast.

Most of the marsh along the outer coast is protected by a beach ridge.

The last plot in Figure V-7 gives an estimated division of oil for a 30,000-ton (34,000 m^3) spill without any form of oil spill control. It is estimated that 50% of the original oil volume would be lost to evaporation and dissolution before reaching the coast. After reaching the coast, approximately 25% of the remainder would be absorbed by the coastal beach, 15% would enter the estuaries and 10% would be sunk along the coast. As shown in Figure V-8, approximately 80 miles of coastal beaches might be affected along with another 70 miles of estuarine beaches. These are only rough estimates of the fate of the oil. Considerable research is required both in laboratory testing and field studies in order to predict accurately the fate of the oil from an offshore spill. It would be expected, however, that in the case of an actual spill, control procedures to block estuarine entrances would be initiated and the actual impact would be limited to coast beaches.

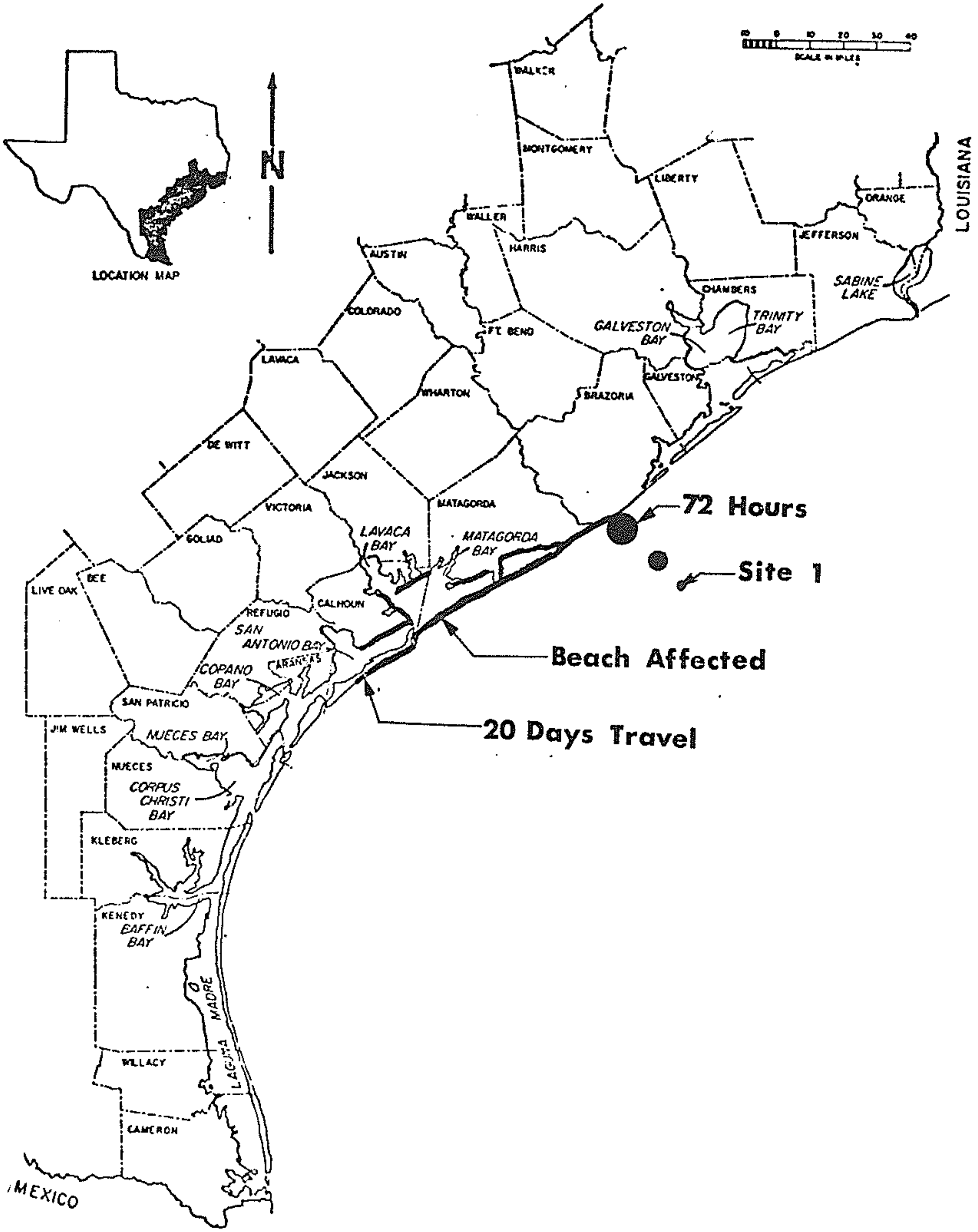

Figure V-8. Estimated Impact of a 30,000-Ton Spill Without Control.

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CHAPTER VI

CONTROL AND CLEANUP OF OIL

Control and cleanup procedures are an essential part of all environmental impact studies. Any realistic assessment of the impact of an oil spill must include those control measures which can reasonably be expected to be in operation. This chapter describes the existing state of the art for control and cleanup procedures. By the time the offshore port is constructed, additional advances are expected.

The control of accidental oil spills is broken down into three subgroups depending upon where the spill occurs: at the terminal, at sea; or near shore so that containment is concentrated at the coastal inlets.

CONTAINMENT AT TERMINAL

During the loading and unloading processes for both supertankers and transshipment vessels, some small quality of oil is inevitably spilled directly into the water or washed from the docks. In addition, a certain number of small accidental spills are likely to occur. The CEQ specification provides for the following quantities of periodic, operational oil spills at the terminal berths.

Alternative	Year	Amount	Frequency Supertanker	 Transshipment
A	1980	840 bbls	30 gals/oper. (588 total)	4.8 gal/oper. (3673 total)
A	2000	3094 bbls	30 gals/oper. (2165 total)	6.0 gal/oper. (10,827 total)
B	1980	420 bbls	30 gals/oper. (588 total)	-none-
B	2000	1546 bbls	30 gals/oper. (2165 total)	-none-

Because of the small quantity and periodic nature of these spills, it is anticipated that containment equipment will be in place surrounding the normal loading or unloading operation so that immediate containment and removal can take place should a spill occur. The protected environmental conditions afforded by Location #2 with the 6,000 foot breakwater would allow existing containment and pick-up systems to be employed with a fair chance for 100% removal. As will be demonstrated later, Location #1 is more susceptible to severe environmental stress, hence effective control and removal is less reliable with today's technology. Other floating wastes from bilge and sewage systems are not considered in this discussion as these wastes can be adequately controlled by a port operated holding and treatment facility.

Oil spill control at the terminal can be greatly influenced by terminal design. Consideration must be given this factor in site selection and ultimate design. For example, the island concept, if properly planned, (see Figure VI-1) could trap spilled oil from

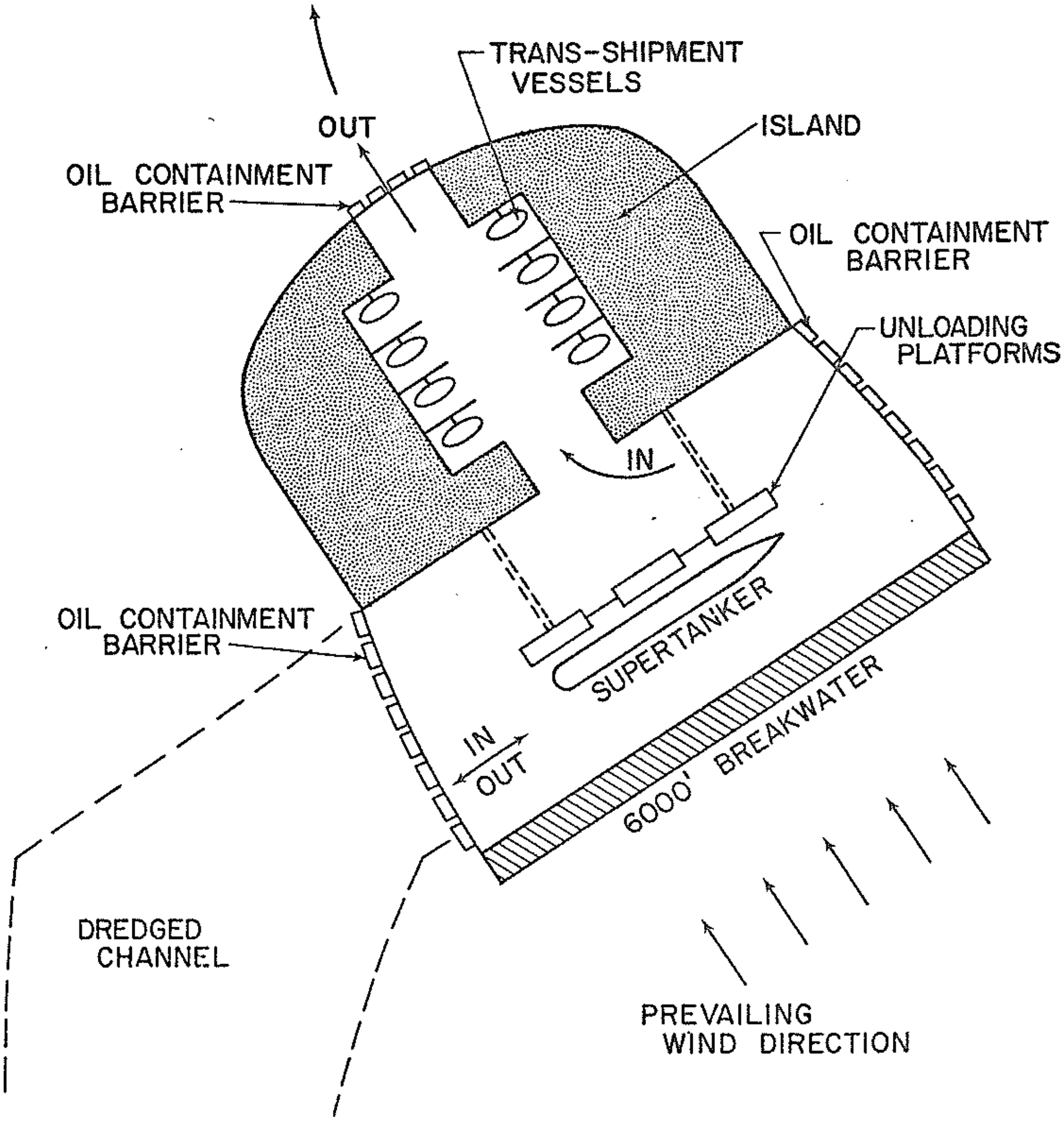

Fig. VI-1 Schematic Representation of Environmental Controls (Barriers) Employed During Unloading & Loading Operations.

supertankers or could allow slips to be sealed off during transfer. Breakwaters would make floating containment barriers surrounding ships function more effectively in reduced wave conditions. Strong currents could also be reduced by proper design and perhaps with the aid of a hydraulic model test. The limitations of existing and potential control equipment must therefore be considered.

There exists a vast number of floating oil spill containment devices (booms). Almost all have severe limitations regarding the wave heights and currents in which they can retain 100% of a spilled oil volume. Unfortunately, most manufacturers claim effective performance under conditions more severe than actual field test data warrant. Short, choppy waves usually are most troublesome because the barrier is too sluggish to "follow" these waves and oil sneaks out underneath or sloshes over the top. Excessive currents also entrain oil droplets near the front of the contained slick which pass undisturbed beneath the barrier. These limitations become crucial for open sea containment systems and will be discussed further in that section. This type of containment system however, does allow the removal system to become an integral part of the overall design which is a definite advantage over other concepts. It would be placed around the ship after docking and removed before sailing. Storage, maintenance and placement personal would be required.

A totally different concept in oil retention barriers has also found acceptance - primarily in European harbors and ports. The device is called the pneumatic barrier in which a continuous upward flow of air bubbles from a submerged pipe manifold drags water along creating an upward current. At the surface the air bubbles dissipate. The upward water momentum is deflected and causes a surface current which can be used to oppose the potential spreading energy of oil at a given depth of oil. When equilibrium is established the oil is essentially contained by the bubble generated current. Breaking waves and strong natural currents require large amounts of power to generate the water currents at the surface to contain oil. Under these conditions some oil continuously drains over the top as small droplets or is swept through. The limitations of this device will also be discussed in more detail in a later section on open sea containment. The primary advantage of the pneumatic system is its permanent installation below the water where ships can pass over or through it so that handling is not necessary for each vessel. However, separate pickup and removal equipment must be available to move into and extract the contained oil. A list of over 35 installations is known including the Antwerp Harbor (Belgium) where three pneumatic barriers (each 575 feet long) are installed across the docks of an oil refinery to prevent oil spillage during transfer operations from spreading into the harbor. Also, a pneumatic oil containment system is installed in the La Plata Harbor (Argentina) to stop floating petroleum from reaching commercial and public beaches in the area.

There are other methods of controlling and collecting spilled oil. Skimming devices scrape oil off the water surface or force it along rotating elements (plates, disks, belts, etc.) from which it can be recovered. Vortex generating devices act to separate oil and water and have been developed. Magnetic liquids can be added to the oil and recovery by magnetic pick-up devices is then possible. The most promising of all these collection devices for use in offshore terminal harbors appears to be the moving inclined plane oil skimmer developed by the JBF Scientific Company for the Environmental Protection Agency (See sketch, Figure VI - 2). As the collection boat moves through the water, oil is forced along the moving plane until it reaches the collection well from which it is pumped to an auxiliary collection tank. The Navy has purchased a 25 foot unit and a 35 foot unit has been designed. The details of this device can be found in the article by Bianchi, Farrell, and Johanson (1972).

A wide variety of treating agents have also evolved and have been used in the field. These include:

1. Sorbents - materials that absorb oil to form a floating mass for later collection and removal.
2. Sinking agents - materials (sand, etc.) which create a high density compound or agglomerate which sinks.
3. Burning agents - chemicals, materials, etc. which assist ignition and enhance combustion of spilled oil.
4. Dispersants - chemicals creating formation of oil-in-water suspensions.
5. Biodegradants - substances that oxidize oil by bacterial action.
6. Gelling agents - chemicals that form semisolid oil agglomerates for ease in removal.

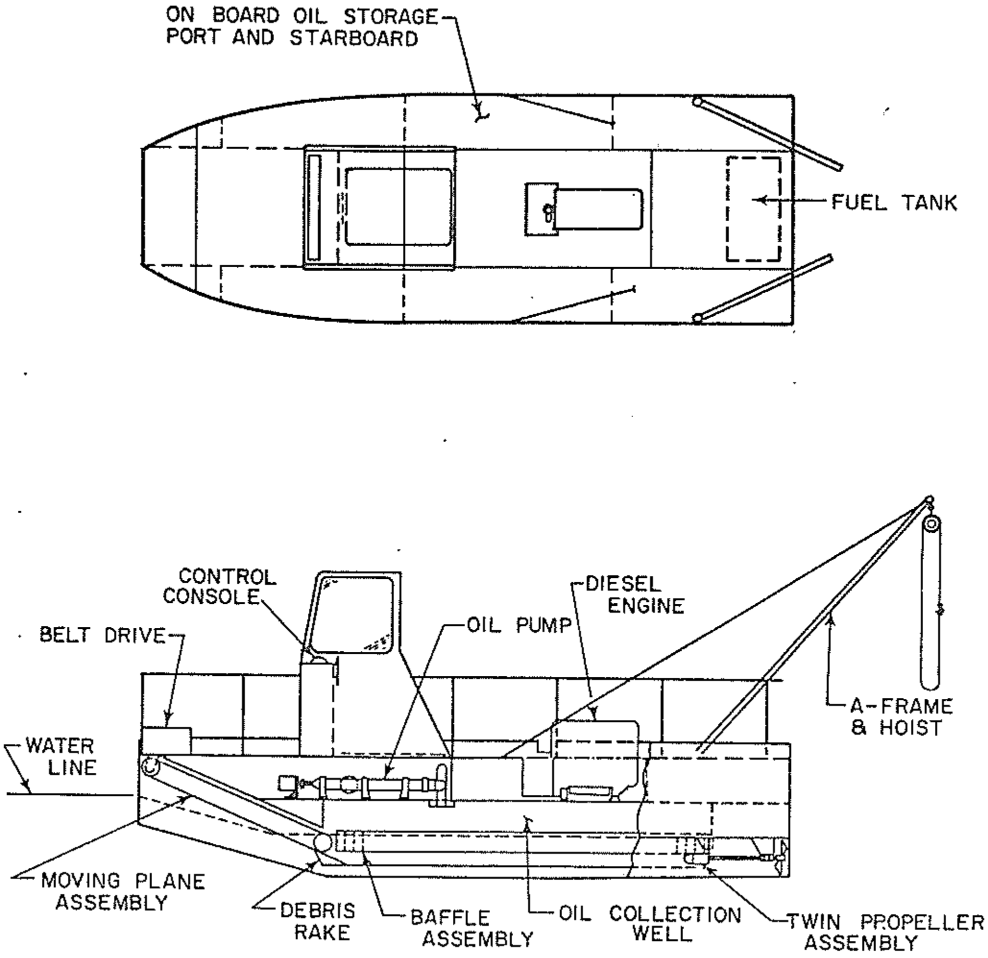

Figure VI-2. Moving Inclined Plane Oil Skimmer.
(Courtesy, JBF Scientific Company)

7. Herdering agents - chemicals that concentrate the volume of spilled oil in a small area.

An excellent review of these treating agents was presented by Blacklaw, Strand & Walkup (1971), and their use in treating large oil spills at sea will be reviewed extensively in a later section. Because of the relatively small quantities involved in periodic spills during normal terminal operation, the environmental effects stemming from the use of these treating agents is relatively small. Consequently, the toxicity and environmental impact of each type of agent along with its effectiveness will be discussed later for massive treatment operations. They are only mentioned here for completeness in rounding out the list of types of containment equipment, control and removal devices, and treating agents that have been developed and are discussed in the current literature.

All of the above mentioned control and containment methods are limited in performance and operation by environmental variables such as wave height, wind conditions, and currents. In some cases they have been designed to control spilled oil in certain sea states, but have never been actually tested under severe conditions. Other designs are primarily for use in protected harbor environments. Almost all actual field tests in which performance has been relatively successful have occurred under fairly ideal environmental conditions: wave heights less than 2-3 feet, light winds, and small currents of 0.5 knots or less. It therefore appears that control of oil spills at the terminal can be effective and is a relatively minor problem if terminal site selection and design can incorporate environmental considerations for the proper functioning and performance of existing oil spill containment and removal devices.

Since Location #2 provides a sheltered harbor area by the use of a breakwater, and since the platform or island of Location #2 can be designed to permit positive spill control in oil transfer, from the above arguments it would appear that this site would be preferable for oil spill control at the terminal. Location #1 is subjected to open-gulf environmental conditions at the unloading buoys and consequently, imposes severe limitations on "effective" performance of the control equipment presently available.

In addition, the volume of oil spilled should be relatively small and any that escapes collection will be readily diluted and naturally degraded. Use of toxic treating agents can be limited to small quantities as required to meet water quality standards.

It is therefore concluded that periodic, operational oil spills of the magnitude estimated can be effectively controlled with todays methods so that the impact on the water quality and environment in the terminal area is very small. This will be true provided the terminal is designed to create environmental conditions which will permit the control equipment to function properly. The reasons for this conclusion are essentially:

1. The relatively small volume of oil involved.
2. The proven effectiveness of the control technology when operating in a protected environment (small waves, currents, etc.).

3. The large dilution capability available with an offshore site.

CONTAINMENT AT SEA

For a wide variety of possible reasons, accidents could occur in the natural gulf sea environment which could cause oil spills that would be considered of major proportions. The CEQ specifications consider two types: a yearly 500 ton (125,000 gals) spill and a major 30,000 ton (7,500,000 gals) spill which occurs once in 20 years. The fate of these spills if not contained is discussed in another section of this report. This section will review the current state of the art of oil spill control and removal technology, in particular, the program of the U.S. Coast Guard, which began in 1968, for containment at sea under severe sea state conditions. In addition the environmental impact of numerous types of treating agents will be reviewed. It should become evident in the following discussion that although technically feasible, effective control of large massive spills in severe weather has yet to be positively demonstrated in the field. In addition, the national plans for control of at sea spills have yet to be implemented. Therefore, massive spills cannot now be controlled or stopped from reaching the shorelines of Texas if a spill should occur in the Gulf of Mexico.

In June, 1970, a plan of action for federal, state and local authorities was developed by the Council on Environmental Quality and was entitled the "National Oil and Hazardous Materials Pollution

Contingency Plan". In it a mechanism was established for coordinating the response to a spill of oil (or other hazardous material) among interested government agencies. For offshore waters the following three classes of spill volumes was established.

1. Minor - less than 1,000 gallons
2. Moderate - 1,000 to 100,000 gallons
3. Major - more than 100,000 gallons

By these definitions, the size of spills considered here are both of the "major" type. In the plan, because of its expertise in the fields of navigation, port safety, etc., the U.S. Coast Guard was given responsibility for developing regional plans and for furnishing On-Scene Commander who is the sole responsible agent to coordinate and direct the spill control activities. The Coast Guard has also assumed responsibility for controlling oil spills in other ways.

In 1968, plans were begun by the USCG to develop a prototype oil containment system for use on the high seas. It was considered that a prime requisite for effective cleanup of massive spills at sea is the ability to quickly confine the spilled oil to an area as small as possible. It was also felt that equipment and techniques which can control the spread of relatively thick films should allow the subsequent development of efficient cleanup devices and materials. The Coast Guard therefore undertook the development of two high-seas oil spill containment systems.

One was designated a "lightweight" system which was to be air dropped and easily deployed by locally available boats within four hours of a reported accident. Strategic positioning of the final system was assumed in order to cover the U.S. coastline. The other system was called the "heavy duty" system and was also to be designated for air transport to the near vicinity with final transportation and emplacement by CG buoytender type vessels. Emphasis for this system was on long term emplacement at sea with minimum deployment response time a desirable goal. Environmental criteria for the "effective" performance of the heavy duty system was as follows:

Wind: Hourly average of 40 mph at a standard reference height of 10 meters. Corresponding wind speed at any height below 10 m determined from table.

Height above MWL (meters)	Percentage of Wind Speed at 10 m
0.5	65
1.0	72
2.0	79
3.0	84
5.0	90

Waves:

Parameter	Deep Water	Shallow Water
Significant* height, ft.	10	10
Significant period, sec.	7.5	6
Average height, ft.	6.4	6.4
Average period, sec.	6.3	---
Average length, ft.	134	100
Range of periods, sec.	3.4 - 12	---
Period of energy max, sec.	8.9	---
Highest 1/10 wave ht, ft.	13	---

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[*] Significant height is the average height of the one-third highest waves of a given wave group (> 100 waves).

Current: Uniform over depth at 2 knots (3.38 ft/sec)

Similar criteria were established for the lightweight system; however, significant wave height was only 5 feet and the hourly average wind speed at reference elevation was 20 mph. A 20,000 ton overall spill capacity was desired for the barriers which were to be in 1,000 ft modular sections.

For the creation of these systems a development competition was instituted. Of over 40 proposals received, three were chosen by the Coast Guard for each system, to develop the design concept within a six month period (1969-1970). Texas A&M University participated in this competition, studying a pneumatic barrier for heavy duty and a "low tension" mechanical barrier for the lightweight concept. A brief review of these designs will be presented in a later section in which the limitations of all types of containment barriers will be discussed.

The design concept submitted by Johns-Manville and a group of consultants for the lightweight system was selected for prototype construction and field tests. The development of the heavy duty prototype was deferred until results of the lightweight system are known since environmental criteria were less severe for the latter.

Pollak (1972) discussed the development of this lightweight prototype offshore oil containment system in a paper presented at the recent Offshore Technology Conference (May, 1972). Besides the previously mentioned constraints, the geographical area within which the system is to be used was defined as up to thirty miles offshore along the entire U.S. coastline. The geographical, environmental, transport and delivery time constraints dictated the use of the C-130 transport aircraft to deliver a 1,000 ft barrier section to the site. Pollak briefly discussed the barrier design concepts, the air transport and drop container equipment and the mooring system, each of which was equally important for effective performance. The problem of determining the quantity of oil that any 1,000 ft barrier section could contain was also addressed. The exact maximum amount was found to be a complex determination dependent upon the barrier characteristics, type of oil and state of the environment. Pollak stated that,

> "There is no single number that gives the capacity of a specific size and length of barrier. However, even at best, the quantity that can be held within the barrier can only be measured in hundreds of tons as compared to the desired 20,000 ton overall capacity desired. ...The basic dilemma, ... is the low capacity of barriers as compared to the 20,000 - ton goal, even if multiple sections of 1,000 ft length each are used."

It was therefore concluded that the solution lies in not considering the containment process by itself but as part of a larger system. This would consist of the barrier; a removal system within the barrier which removes oil as it accumulates within the barrier; a separation device; and the storage and disposal of the collected oil. Finally, Pollak concluded that,

> "As of today, we are not yet capable of handling the results of a casualty to a very large tanker in the offshore area, even though substantial progress has been made to handling smaller spills under those conditions".

A field test of the prototype was conducted on the West Coast in March of 1972. Soy bean oil was used and various newspaper accounts (Houston Post, March 12, 1972) reported the test as successful. No official report of the environmental conditions, quantities of oil contained, etc. is available. In order to determine the latest developments on the project, Cmdr. Abrahams, Oil Spill Control Branch, Headquarters Office, U.S. Coast Guard, was contacted (Abrahams, 1972). He indicated that a report was in preparation for release in November or December (1972) which will include the field test results. However, he also permitted the use of his verbal comments about the barrier containment project for this report. The question of the exact meaning of the term "effective" barrier performance was brought up. To some it may mean 100% control. To others it could mean 5-10% loss over a given time interval and still allow significant quantities to be controlled. On the other hand, a 5% loss for a 20,000 ton spill would still be about 1,000 tons (250,000 gal) and considered a major spill. Cmdr. Abrahams indicated that the requirement to contain oil under 2 knot currents (3.38 ft/sec) was the critical issue. To date, all barrier tests have experienced catastrophic failure when subjected to 2 knot currents. At 1 knot some leakage occurs. When a current of 1/2 knot or less is present very little, if any loss occurs. The reasons for this phenomena are the subject of a current research project at Texas A&M University sponsored by the Coast Guard which will be briefly discussed in a later section of this report.

The Coast Guard has also been involved with the development of an air deliverable transfer pumping and storage system (ADAPTS) for the emergency unloading of damaged tankers to reduce the quantity of oil released. The system will be prepositioned at selected Coast Guard Stations and dropped at the scene of tankship casualties which threaten an uncontrolled release of oil. Ketchel and Smith (1971) described the system development. The unique feature of ADAPTS is the use of collapsible, inflatable, rubbercoated bladders, each capable of transporting 140,000 gallons of oil from a distressed tanker. In a collapsed state the bladders are about the size of small automobiles. When inflated and filled with oil, they expand to 135 feet in length and resemble large floating air mattresses. The complete system has the capability of unloading 20,000 tons of cargo oil within 24 hours of a reported incident and operating in winds up to 45 mph and 8 to 12 foot seas. The Coast Guard views the ADAPTS system as only one part of their overall program to control major oil pollution. Besides the open sea oil containment systems described above and the ADAPTS concept, they also have sponsored a number of research projects on oil removal devices, a brief summary of which is included below.

Oxenhan (1971) described efforts to use a continuous, moving oleophilic (adsorbent material) belt "oil scrubber" as a removal device. A free vortex system which migrated oil toward the vortex center was investigated by Nebeker, Rodrigues & Mikolaj (1971). Mensing & Stoeffler (1971) also describe a continuous-flow vortex separator in which tangential injection of the oil-water mixture produced the vortex. Bruch and Maxwell (1971) described a recovery device which picks up oil on both sides of a number of closely packed vertical discs, which are nominally half submerged in the sea and rotate continuously. The EPA sponsored development of fixed and moving inclined plane oil skimmers as discussed by Bianchi, Farrel, & Johanson (1972) can be found in an earlier section of this report. The optimum device for use in the Coast Guard's Open Sea Control Program has yet to be determined. Possibly it will be an entirely new concept which is integrally incorporated with the containment barrier as suggested by Pollak.

A state-of-the-art review of oil containment barriers has recently appeared in the literature. Mark, Geiss, & Hirshman (1971) discussed their work on the theoretical (computer/math model) and experimental (laboratory/physical model) evaluation of oil spill control devices for the American Petroleum Institute. A large number of completely different boom and barrier devices were tested although no trade names were revealed. Significantly, the math model results revealed a large number with heel angles greater than 30°, poor wave following characteristics, and structural deficiencies. The laboratory tank tests included both system response to waves and oil containment efficiency tests. The oil tests with waves revealed that all booms tested failed for a variety of reasons. For example, a boom that was successful in a relatively high seastate most of the time, failed upon interaction with an exceptionally large wave. Finally, the importance of the oil properties was demonstrated because in one case a boom which effectively contained No. 2 fuel oil and industrial lube oils, failed completely with No. 4 oil. In summary the author concluded that a wide variety of different types of barriers may be necessary for all conditions, and that barriers should be considered in combination with removal devices for maximum effectiveness.

As previously mentioned, the pneumatic barrier system concept for open sea containment was investigated at Texas A&M University. Complete details of the system dynamics under a wide variety of environmental laboratory conditions have been presented by Basco (1971). The bubble generated current was found to provide an effective means of containing oil on water under certain conditions. However, under strong natural sea currents or breaking wave conditions large quantities of air were required to create the necessary surface countercurrents to control oil effectively. The air pipe manifold horsepower verses maximum surface current varied as approximately to the third power and resulted in the pneunatic system being uneconomical for the sea state requirements required by the Coast Guard for the heavy duty containment system. Use of the pneumatic barrier system was recommended for protected areas where no breaking waves existed and natural currents were less than about 1 knot.

A mechanical, low-tension, oil containment barrier was also investigated at Texas A&M University. Fowler and Bailey (1972) presented the design details of the A&M concept. During these studies, the mechanics of oil contained by a barrier because of a uniform current was studied in some detail. It was observed that for currents beyond about 1.6 ft/sec (mean flow velocity of around 1 knot) a number of oil drops were entrained at the front or head wave region of the oil slick and were swept downstream and beneath the barrier. A continuous loss of oil occurred and eventually all the contained oil would be gone. This phenomenon appeared to be independent of the type of oil present. Numerous other investigators Milz (1970), Cross & Hoult (1970), Pollak (1972), Benjamin (1968), Wicks (1969), and Wilkerson (1972) have observed the loss of oil droplets and a general value of 1 knot has come to be accepted for their initiation. However, the phenomenon is not physically understood and other factors such as oil density and viscosity, interfacial surface tension, and wave characteristics are ignored. All of these factors including the water velocity are currently being studied at Texas A&M University in a research project for the U.S. Coast Guard. Hopefully, the results will give fresh insight into how containment barriers can be designed to eliminate the entrainment problem at higher velocities.

Besides containment and control equipment, a number of other "treating agents" have evolved for use in major spills. Their effectiveness, toxicity and general effects on water quality will be briefly reviewed below.

Sorbents

Any material that absorbs oil and floats for later pickup and disposal (or oil removal and reuse) can be considered as a sorbent. General studies were conducted by Schatzberg & Nagy (1971) and Dorrler (1972). Using laboratory procedures Schatzberg & Nagy studied twenty different types. Polyurethane foams showed the highest oil sorption capacity, while inorganic sorbants were worst. Detergents and other surface contaminants interfered with their effectiveness. Six basic unit operations required to achieve oil removal by sorbents were discussed by Dorrler. These are:

1. Sorbent broadcasting
2. Oil-sorbent harvesting

3. Oil-sorbent separation
4. Vessel or platform design
5. Oil storage or disposal
6. Sorbent reuse or disposal

The main advantage of this method is that it is not affected by sea conditions. Actually, better results are achieved with some mixing energy present. The biggest drawback is the nonexistance of a mechanical retrival system and manual labor must be used. The author also indicated that the use of sorbents did not contribute to solid waste or air pollution problems.

In cleaning up an arctic spill Glaeser & Vance (1972) stated that straw was superior to peat moss. Mclean (1972) in disucssing the use of sorbents for a Nova Scotia spill indicated that peat moss was more effective than straw. Obviously, a quantitative definition of "effectiveness" is lacking.

Finally, Milz & Frazer (1971) describe the combined use of a surface active chemical "herder" to prevent spreading and use of a polyurethane foam as a sorbent under both laboratory and field (4-6 ft. wave) conditions. They concluded that the system is "... a feasible technique for controlling and recovering oil spills on the ocean over a broad spectrum of weather conditions." Also, that "... the chemicals utilized are harmless to the ecology."

Sinking Agents

These are dense materials (sand, etc.) which create a high density compound of oil-solid agglomerate and sink to the bottom. Of concern obviously is what happens to the benthic organisms when covered by the sunken oil-sand conglomerate. European investigators Pordes & Jongbloed (1971) determined that, in general, sand-water slurries which contain a cationic wetting agent to render the solid surface oil wettable in the presence of water, can effect sinking provided the wetting agent concentration is large enough to produce oleophilic sand surfaces. To prevent the formation of solid continuous carpets of the sunken oil-sand conglomerate on the bottom, a dispersant chemical was first sprayed on the floating oil film before the sand-wetting agent was applied. Unfortunately, the authors failed to indicate the success or failure of this technique.

The CEQ "National Contingency Plan" (1970) provides some guidelines for the use of sinking agents. Primarily, the guidelines suggest that they be used only in offshore marine waters exceeding 330 feet deep where currents will not bring sediments on-shore, and only if all other methods are judged by the Water Quality Branch of EPA to be inadequate or not feasible.

Burning Agents

Materials or chemicals which aid burning of oil on water are considered burning agents. Note that they may also initially be sorbents. The results of laboratory and field investigations of burning agents including some case histories have been published by Freiberger & Byers (1971). Heavier crude and fuel oils require the use of burning agents to assist in ignition and continue combustion. The authors felt there was little toxicity to the surface waters since the burning agents employed were either inert or non-toxic. In addition, no evidence is available which indicates burning was harmful to marine life beneath the burn. Improved combustion would also reduce the smoke plumes by consuming more of the polluting exhausts. Field investigation did uncover problems with wind and wave action which separated the slick in smaller pools which did not ignite and burn. Barrier containment to provide continuous burning was offered as a possible solution.

The CEQ's "National Contingency Plan" (1970) does not mention burning agents as requiring environmental control.

Dispersants

These are chemical agents or compounds which emulsify, disperse, or solubilize oil into the water column or act to further the surface spreading of oil slicks in order to facilitate dispersal of oil into the water column. The toxicity of these dispersal agents to marine life and their secondary effects in the food chain have been the objects of considerable research in recent years.

Using a circulating aquarium system, Engel & Neat (1971) studied the toxicity of two types of non-ionic, oil-dispersing agents on a number of common marine species: an edible mussel, winter flounder, soft shell clam, mummichog, Atlantic silversides, and fourth stage lobster larvae. The very short term life period (24 hours) suggested that the high toxicity was due to the relatively volatile solvent fraction of the oil dispersant. The toxicity of both dispersants toward marine plankton was also investigated at a concentration of 30 ppm (dispersant). Before adding the dispersants, all organisms were alive and vigorous. Twenty-four hours later, 90% were dead or moribund. There was some discussion of the advantages of a circulating aquarium system for the test since no standard procedure was available. Along these lines, Strand (1971) recommended bioassay procedures that can be routinely applied to evaluate the relative toxicity of oil, chemical dispersants, and mixtures to both naturally occurring phytoplankton and representative marine cultures.

Dewling, Dorrler, & Pence (1971) suggest that other information besides toxicity and emulsion efficiency should be used to evaluate various chemical dispersants. They studied the biodegradability and ultimate oxygen demand of a number of dispersants in the laboratory. The five-day BOD (Biochemical Oxygen Demand) ran as high as 880,000 mg/l. They cited an example where if a 75,000 barrel (≃ 1200 tons) spill should occur in the Delaware River (mouth of the Schuylkill River) and chemical dispersants applied, then the one day oxygen deficit would be about 1.5 mg/l near the spill. In two days it would be approximately 3.4 mg/l. If the river were near saturation at 20°C, conditions would be satisfactory. However, if oxygen available were around 50% (4.6 mg/l or lower) then it would be only a few days before the dissolved oxygen in the river would be depleted.

In contrast to the above arguments which point out the harmful effects of oil dispersants, Robichaux & Nugent (1971) describe a series of laboratory tests in which they believe the use of chemical dispersants enhances the biodegradation of oil pollution. Since biological growth processes are surface-area related, they argued that the use of a dispersing agent increases the availability of the organic substance and the surface area. Their results showed that hydrocarbon pollutants can be destroyed biologically at increased rates by the use of a suitable chemical agent. In addition, the rate of biological destruction can be increased by seeding the emulsion with microorganisms which utilize the oil as a food source.

Canevari (1971) reviewed the past history of dispersants in order to derive the pros and cons regarding their use. Opinions varied from the extreme of no use whatsoever to the idea that it was the only practical technique under rough sea conditions. He concluded that those who say that all chemical dispersants are in themselves inherently toxic are incorrect. It could not be conclusively demonstrated that new dispersants developed since the Torrey Canyon incident were more effective and less toxic. The reason was that a single reproducible and representative laboratory test procedure was still not universally accepted.

Because of the above indicated controversy of the use of dispersants in controlling oil spills, a rigorous set of restrictions and guidelines was established by the CEQ in their National Contingency Plan (1970). The following is the list of restrictions that were established. Dispersants were not to be used:

1. on any distillate fuel oil
2. on any spill of less than 200 barrels in quantity
3. on any shoreline
4. in waters less than 100 feet deep

5. in any waters containing commercial populations, or breeding, or passage areas for fish or marine life which by exposure to dispersant or dispersed oil would render them less marketable;
6. in waters where winds or currents would carry the dispersed oil to shore within 24 hours (in judgement of EPA); or
7. in waters where the surface water supply would be affected.

However, dispersants may be used in any place and at any time if in the judgement of the Coast Guard's On-Scene Commander, their use will:

1. prevent or substantially reduce the hazard to human life or substantial hazard of fire to property;
2. in the judgement of EPA, prevent or reduce substantial hazard to vulnerable waterfowl; and
3. in the judgement of EPA, result in the least overall environmental damage.

The affected states would be consulted in all cases and the states dispersant laws, regulations, or written policies would supersede the above, if in effect.

An attempt to evaluate all types of treating agents (dispersants, sinking agents, combustion promoters, sorbents, etc.) was undertaken by Blacklaw, Strand, and Walkup (1971). The chemical reactions and mechanisms for controlling the field application were first defined. This permitted the identification of those parameters critical for the evaluation of both effectiveness and toxicity. The study again found that no existing standardized tests exist and recommended a series of procedures, equipment, etc. for this purpose.

Bernard and Jakobson (1972) reviewed the effectiveness of all types of oil spill control devices (barriers, removal units, and treating agents) that were employed in actual spill situations, i.e., the Chevron spill (≈ 2,600,000 gals) and the Shell spill (≈ 6,000,000 gals), both in the Gulf of Mexico. It was pointed out that since these massive spills did not occur very often, practical experience was lacking along with the needed off-the-shelf equipment to combat them. Also, since time was short, and no ideal approach was known, every avenue of promise was implemented. None of the equipment or materials used had any previous history of being totally effective, so no single approach could be relied upon.

It became apparent to these authors that wind and sea were main deterrents to any type of control in open seas. Equipment an order-of-magnitude larger than that used seemed necessary. Effective control appeared to depend on the ability to prevent or limit spreading on the surface. The boom-skimmer work-boat combinations employed for this purpose were found to be inadequate, however. The swaths cut by the skimmers were too small. Towing the booms through the water to collect thin oil films at relative speeds greater than 1 knot produced the entrainment failure phenomenon previously discussed. Darkness ceased all operation and permitted only a 12 hour work day. Consequently, all these factors permitted only a very small quantity of oil to be removed. To speed up the containment process or enable the booms to operate in higher than 1 knot currents, an oleophobi/hydrophilic oil retention boom was proposed which permitted water to pass through but retained the oil. Mention was also made of the possible improvements in removal capacity afforded by an open sea moving, inclined plane skimming boat which was only in the development stages at the time of the Chevron and Shell spills.

In addition, the use of sorbent materials in these field situations was discussed. It was concluded that for large spills the need for recovering the oil soaked sorbent, oil removal, and reuse of the sorbent was an economic necessity.

A cost effectiveness analysis was performed by Henager, _et al._, (1971) for equipment, materials and techniques applicable to the removal or dispersal of oil on open waters. Parameters included oil types spill locations (3 and 12 miles from shore) and spill sizes (2,700; 270,000; and 6,750,000 gals). Evaluation criteria included: completeness of oil removal; removal rate; hazard and pollution; use in small areas; environmental sensitivity; temperature extremes; toxicity to marine life; and system availability. The results indicated the most cost effective systems to be

1. burning,
2. dispersing, and
3. mechanical skimming.

The most practical universal system for massive spills with a favorable cost effectiveness ratio was found to be dispersing. Next best was containment barriers and dispersing. For spills up to 270,000 gallons, it was concluded that there would be no significant toxic or other deleterious effect on offshore fishing. However, for the massive 6,750,000 spill, large amounts of dispersants would be required and the chances of exceeding a 5 ppm limit on dispersant concentrate would be great. Finally, burning agents were judged to be the third best system based on favorable costs but limited applicability to oil types and allowable environmental conditions.

Summary - Containment at Sea

From all of the above discussion it can essentially be concluded for today's technology that:

1. containment barriers (booms) are ineffective in currents greater than 1 knot and waves about 6-8 feet or greater;
2. large removal devices have yet to be systematically developed and evaluated for optimum efficient designs; and
3. dispersants, although economic and effective in heavy seas are still toxic and their use must be restricted.

It is also apparent that technological breakthroughs are imminent in a number of methods and that work should continue on all types because each has a place in the total spectrum of control techniques. Barriers should be designed with the removal devices as an integral part of the total system and/or with skirts that let water through and not oil. Both types will enable barriers to be used in swifter currents or allow them to be swept at faster speeds for more economical containment. Mechanical methods must be developed for air deployment of barriers in heavy seas to remove the human element working on the surface. Completely non-toxic and possibly low BOD dispersing agents must be found which can be substantiated by the U.S. Standards Office. Burning agents must be perfected. Sorption systems must be built for sowing, removal, oil extract, reuse, and treatment of the reclaimed oil. And finally, all equipment, materials and methods must be field tested; experienced personal made available; contingency plans perfected; and systems made available and standing by.

Because such a capability is not available today, one must conclude that a truly massive spill of 30,000 tons could not be contained effectively in the open seas of the Gulf of Mexico off the Texas Coast. In the event of a spill we could only do as in the past - scrape together all types of available equipment and methods and hope for the best with little chance for effective, economic, cleanup and control. Consequently, for an offshore oil terminal under these circumstances distance from shore becomes the greatest asset. Increased distance from shore means more:

1. time to react,
2. time to deploy containment barriers,
3. time to pick up and remove,
4. time to dilute, disperse,
5. time for evaporation and biodegreadation to naturally occur,
6. time for natural wind and tide changes to move spill away from coastline.

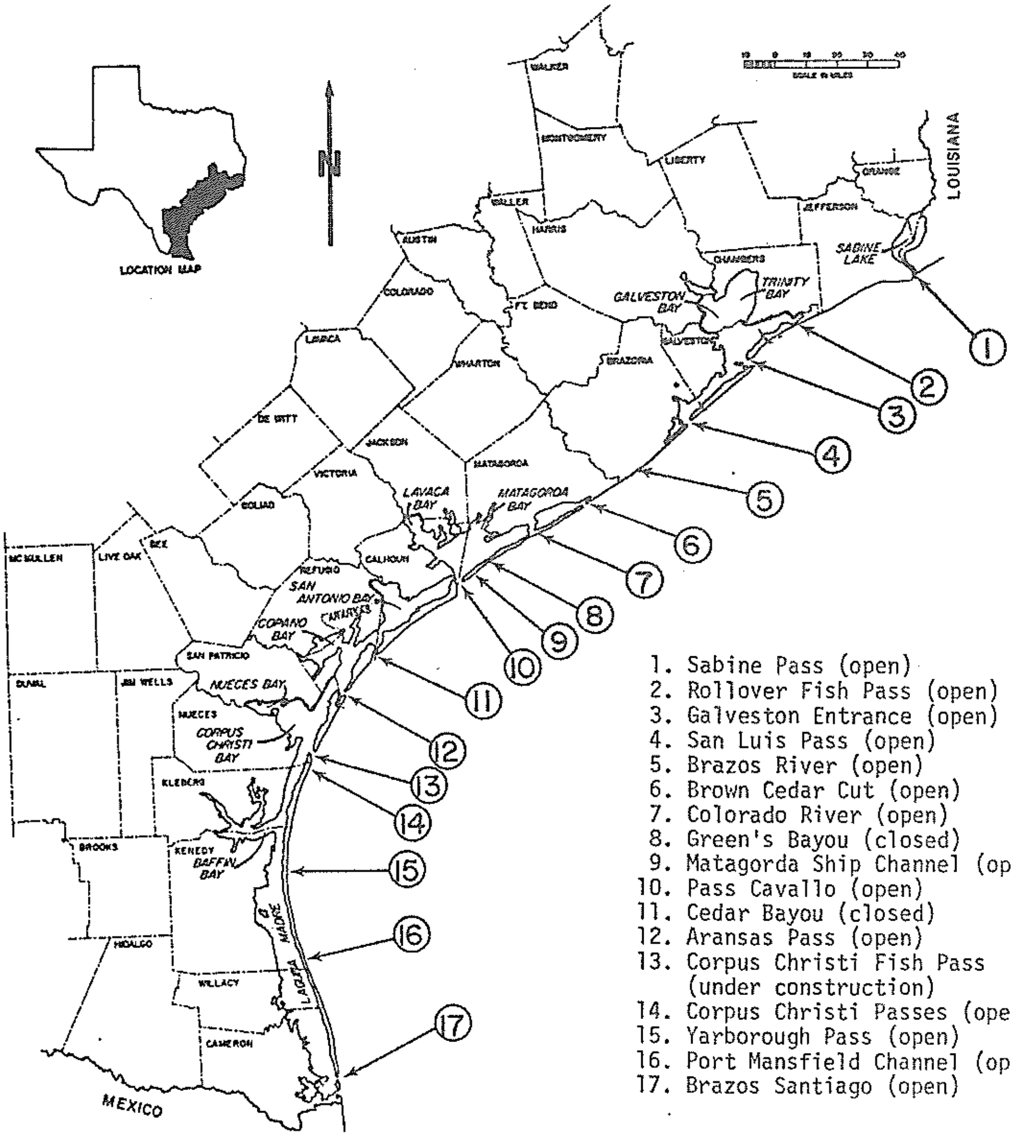
CONTAINMENT AT COASTAL INLETS

The bays, lagoons, and inland estuarine waters along the Texas Coast, which serve as the natural breeding grounds for marine and wildlife are naturally protected by a series of barrier beaches.

Openings in this barrier system exist in different forms. Six major tidal passes or inlets exist naturally and have remained open for over one hundred years (Schmeltz, 1972). Four of these need jetties to remain stable. In addition, a number of rivers open into the Gulf. Other passes (approximately 8) open and close intermittently for a variety of reasons. Three artificial, man-made inlets also exist to connect the inland waters to the Gulf of Mexico. Locations of the coastal inlets are shown in Figure VI-3.

In the event that oil from a major spill reaches the coast, it would be desirable to seal off the inlet(s) involved. Thus oil would be kept out of the most ecologically important areas with the minimum amount of effort. Even if oil should reach a barrier beach area far from an existing inlet opening, natural longshore sand transport processes would tend to eventually move the contamination along the shore until an inlet is reached. This part of the report attempts to briefly explore the possibilities for creation and effectiveness of a coastal inlet barrier containment system.

There are three possible locations for an oil containment barrier at the inlet. These are schematically illustrated in Figure VI-4. Location No. 1 outside the inlet would be in a lower tidal current zone. However, waves would be breaking on the barrier in the surf zone in this region and would tend to push the barrier into the inlet. The most economic location (shortest barrier) would be across the inlet (No. 2) however, this would be in the high velocity region and during some parts of the tide cycle currents might possibly exceed



1. Sabine Pass (open)
2. Rollover Fish Pass (open)
3. Galveston Entrance (open)
4. San Luis Pass (open)
5. Brazos River (open)
6. Brown Cedar Cut (open)
7. Colorado River (open)
8. Green's Bayou (closed)
9. Matagorda Ship Channel (open)
10. Pass Cavallo (open)
11. Cedar Bayou (closed)
12. Aransas Pass (open)
13. Corpus Christi Fish Pass (under construction)
14. Corpus Christi Passes (open)
15. Yarborough Pass (open)
16. Port Mansfield Channel (open)
17. Brazos Santiago (open)

Figure VI-3. Geographic Location of Texas Coastal Passes. (Courtesy Schmeltz, 1972)

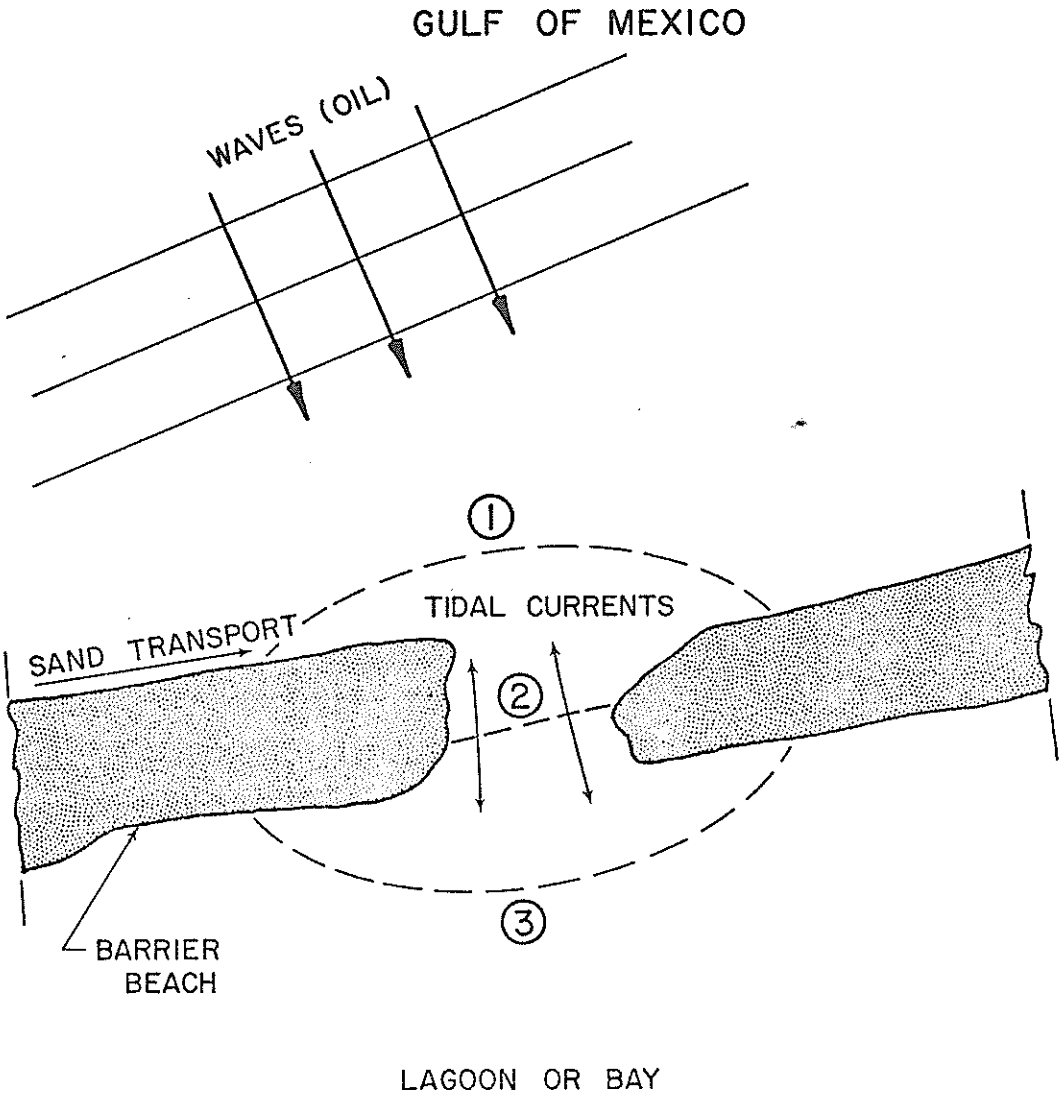


Figure VI-4. Schematic of Possible Barrier Locations at Typical Barrier Beach Inlet.

the 1 knot limit. Therefore the best location (No. 3) would be in the protected lagoon region where normal maximum velocities are found to be within the design limits of the barrier. The barrier configuration would also be optimum for Location No. 3. Mooring lines could be deployed to keep the barrier in the proper configuration throughout the tidal cycle if a floating type was employed.

The barrier could be either the floating, mechanical type or the pneumatic barrier. The limitations of current designs have been discussed previously. Each would have certain advantages over the other type. For example, the mechanical type floating barrier could be more readily installed at any of the possible inlets. Therefore, its portability and relative flexibility in length make it more versatile for possible use at any of the inlets from a central storage point. Certainly, if the offshore site is 25-30 miles from shore, time will be available to chart the spill movement course and prepare the shoreline defense in an analogous way as currently done for hurricanes. On the other hand, pneumatic barriers may be permanently installed across the major navigation inlets where their primary advantage lies in permitting an uninterrupted ship movement to continue until the oil endangers the coastline.

Currently, the State of Texas (Teller, 1970) has no legislation or equipment to control oil spills of a threat to the shoreland areas. Recently, the city of Corpus Christi, through a community action program, has developed a plan to combat spills that threaten the resort beaches of that area (Franklin, 1970). A report by a local committee made up of federal, state, and local governments, refiners, oil and gas producers, etc. was prepared which included a contingency plan. The plan spelled out the manager, superintendent, and other leaders for a spill along with coordination with the Coast Guard. It also recommended authorizing over $200,000 to purchase equipment and $50,000 for operation. The actual status of the planned emergency program is not known at this time.

It appears that a system to close the Texas inlets to keep oil out of the estuarine systems is a plausible idea and that its economic feasibility should be investigated. To date, to the writer's knowledge, no such system exists or has been considered. As a secondary line-of-defense when all else fails (containment at terminal, or open sea) it may prove the most practical approach.

BEACH CLEANUP

When oil comes into contact with the shore, detrimental economic and ecological consequences can result. In many cases of offshore spills, complete removal or dispersal of the oil will be impossible and, therefore, methods and procedures for beach restoration must be available. When a spill occurs and oil washes ashore, it accumulates along the shoreline and may contaminate vessels and shore installations. On beaches, the main impact is aesthetic and the immediate remedy is physical removal of the contaminating substance.

Sartor and Foget (1972) state that oil contamination of beaches usually results in one or both of the following situations:

1. Beach material becomes uniformly contaminated with a thin layer of oil up to the high-tide mark and/or deposits of oil dispersed randomly over the beach surface. Oil-deposit penetration is limited to approximately one inch.
2. Agglomerated pellets of oil-sand mixture or oil-soaked material, such as straw and beach debris, distributed randomly over the surface and/or mixed into the sand.

Beaches can be cleaned by a number of techniques. The use of straw on the beach after oil reaches shore is generally not very effective. However, if the straw is spread before the oil has a chance to reach the shoreline, then it is more effective in absorbing oil and minimizing the amount which penetrates into the sand.

At Santa Barbara, although several techniques were tried in rocky areas, including steam cleaning, sand blasting and the use of high-pressure water streams, only sand blasting was found to be totally effective. However, this method is slow and costly, requiring extensive use of hand labor to remove accumulated debris.

Other cleanup techniques used at Santa Barbara included:

1. vacuum tank trucks, of the type used in cleaning out septic tanks, which were used to recover accumulated oil from Santa Barbara Harbor.
2. straw mulchers or spreaders which were used to distribute the sorbent materials.
3. road graders, with tines welded below the blade, which were used for raking debris.

4. bulldozers, front-end loaders and dump trucks used for picking up and hauling away accumulated debris.

The restoration of beaches involves:

1. physical pickup and removal for disposal of oil deposits, oil-soaked sand, straw and other debris,
2. cleaning of the sand on the beach through removal by screen separation of contaminated materials, and,
3. disposal of contaminated materials at an approved site.

The choice of a restoration method to be used will depend upon the economic and recreational value of the area and the urgency of returning the area to normal conditions. A highly-developed resort complex, where a large proportion of the area economic activity depends upon retaining the attractiveness of the beach, will require implementation of cleaning methods chosen more for their quickness than for their cost. In other instances, where the shoreline is mainly regarded for its view, the presence of contaminants on the beach will not be so critical and restorative techniques of a slower, less costly nature will be found adequate.

In either of the above situations, the amount of equipment and manpower called into play will be a function of economic urgency. However, the choice of equipment to be used and the operating procedures to be followed will be dictated by the surface conditions and topography of the area to be cleaned. Surface conditions can vary from a smooth, hard, sandy surface to rocky, irregular surfaces. The topography can range from long, flat beaches to those that are short, steep and undulating.

Two examples of actual cleanup operations undertaken as a result of offshore oil spills give an indication of the costs involved in such operations (Sartor & Foget, 1972).

Santa Barbara, California. A work force of 50 men aided by four front-end loaders, two bulldozers and ten dump trucks, cleaned one mile of beach per eight-hour day. This was calculated to be a cost of \$325 per acre for one mile of beach 75 feet wide, or \$500 per acre for one mile of beach 50 feet wide. Cost of trucks to haul recovered materials to a disposal site is not included.

Grand Isle, Louisiana. At Grand Isle, the restoration procedure involved the use of motorized graders operating in conjunction with front-end loaders. A work force of one motorized grader, three rubber-tired front-end loaders and twenty men cleaned fifteen miles of beach in four days. The cleanup cost, calculated on the same basis as for Santa Barbara, yielded a cost of \$140 per acre for one mile 20 feet wide, and \$170 per acre for one mile 15 feet wide. No costs for trucking debris to disposal areas are included.

Summary of Treatment and Disposal Methodology

In conclusion, it appears that the most effective beach-cleaning methods available under the current state-of-the-art are as follows:

1. for rocky areas: sandblasting and/or steam cleaning
2. for sandy beaches: removal of the top oily layer of sand entirely or screen-separation where the contaminant occurs in lumps or nodules

3. disposal of debris in approved areas.

Other methods of cleaning contaminated sand that have been tried include:

1. froth flotation cleaning, at an estimated cost in pilot operations of 50-70 cents per ton of sand cleaned
2. hot water fluidization, a method that has not been successful.

The following table gives the cost results of tests run by Sartor and Foget.

Table VI-1. Cost of Restoration of Sandy Beaches.

RESTORATION PROCEDURE (a)	REMOVAL COST (b)			TRANSPORT COST (c) ($/ACRE) TO DISPOSAL AREA AT INDICATED DISTANCE			
				MILES			
	$/ cu. yd.	$/ gal.	$/ acre	1	5	10	20
Combination of motorized grader and 9 cu. yd. motorized elevating scraper with 24-in. belt conveyor system.	0.37	0.05	118	30	90	150	300
9 cu. yd. motorized elevating scraper with 24-in. belt conveyor system.	0.32	0.045	108	32	93	161	321
Combination of motor grader and 3 cu. yd. tracked front-end loader.	0.75	0.07	176	25	77	124	220
Combination of motorized grader and 2 cu. yd. tracked front-end loader.	2.50	0.19	450	20	60	96	173
Tracked front-end loader.	1.92	0.64	1,540	88	261	420	757

(a) Based on initial oil loading of 0.5 gallons per square yard.

(b) Based on 60-minute working hour.

(c) Based on 15 cubic yard capacity trucks.

SOURCE: Sartor, James D. and Carl R. Foget, "Evaluation of Selected Earthmoving Equipment for the Restoration of Oil-Contaminated Beaches," Proceedings of Joint Conference on Prevention and Control of Oil Spills, June 15-17, Washington, D.C., pp. 505-522.

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CHAPTER VII

ENVIRONMENTAL IMPACT

This chapter addresses the problem of the impact of construction and operation of the supertanker port on the total environment. Constraints of the project limited the study to existing data which were lacking in many areas. As a result, values were assumed when missing. Therefore, this study can only be considered a preliminary assessment of the probable impact on the area.

Both the non oil spill impact and oil spill impact of the port were considered. Vague and general statements which are often associated with impact reports were avoided whenever possible. Attempts were made to develop the methodology for quantitative evaluation of these impacts. It was felt that a more accurate assessment can be made using numbers to show the magnitude of the impact and probabilities to show the likelihood of an impact occurring. The relative importance of the impacts were included by relating to the overall coastal area or population.

EFFECTS OF CONSTRUCTION ON THE ENVIRONMENT

This section of the report will present a brief review of the literature regarding previously documented cases of construction in a marine environment and the resultant effects. Emphasis will be on dredging and its effects during and after channel digging and island construction, although all construction components will be addressed. In addition, equipment and methods to control pollution during construction will be discussed. An attempt will be made to put the construction related environmental changes in some perspective by relating them to the size and magnitude of the physical surroundings and to those changes that occur naturally.

There is no question that during and after construction of an offshore terminal, the local and surrounding environment (water column, bottom and subbottom depths, and possibly the atmosphere) will be affected in the following ways:

1. the bottom area will be disturbed or covered,
2. the water will have more or less turbidity, dissolved oxygen, current strength and direction, etc.
3. the air will be more polluted or noisy.

The third effect (atmospheric) is not considered in this report.

Of importance in considering these changes in the environment on the ecology present in the time factor involved. For purposes of discussion in this report the following time factors changes are defined.

1. "Temporary change" - a change in the water quality or bottom lasting only hours to a few days. After this time the factor involved has returned to normal. The ecological damage is usually insignificant.
2. "Eventual recovery" - a change that lasts months to years and eventually returns to its original condition. The resulting ecological damage may or may not be significant.
3. "Permanent change" - a modification to the environment which because of its permanence, results in some ecological damage.

The other important factor, of course, in assessing ecological damage, is the relative importance and magnitude of the event in relation to other events and sizes of disturbances, in particular those randomly and periodically occurring in nature. In reviewing the effects of construction on the environment, therefore, these time definitions and relative effects will become important.

The CEQ specification provided the following list of alternative configurations for consideration as an offshore port:

1. a 5-nested Single Point Mooring with central platform (Location # 1);
2. a platform, breakwater, and supertanker berthing facilities (Location #2, Alternative A) and;
3. an island, breakwater, berthing facilities for transshipment tankers, and supertanker berthing facilities. (Location # 2 Alternative B).

In addition, each alternative would also include a pipeline to shore for transport of crude oil. The environmental effects of each alternative and of the shore pipeline are discussed separately below.

Location No. 1 (Single Point Mooring System and Platform)

A conceptual sketch of the system is shown in Figure VII-1. The location would be about 20 or so miles off the coast. The central platform would be about 1 acre (50,000 ft^2) in size and somewhat minuscule in relation to its surroundings. In fact, its size would be typical of some offshore oil drilling rigs in the Gulf (currently about 8,200 are in place).

The elements of the concept for this location would have very little effect (temporary or permanent) on the environment. The central platform, if stable, would be supported on piles driven into the underlying material until the desired vertical resistance is achieved. Very small permanent change in the bottom would result. Howell, et al (1971) listed deposited debris, splitting, and vibration by pile driving

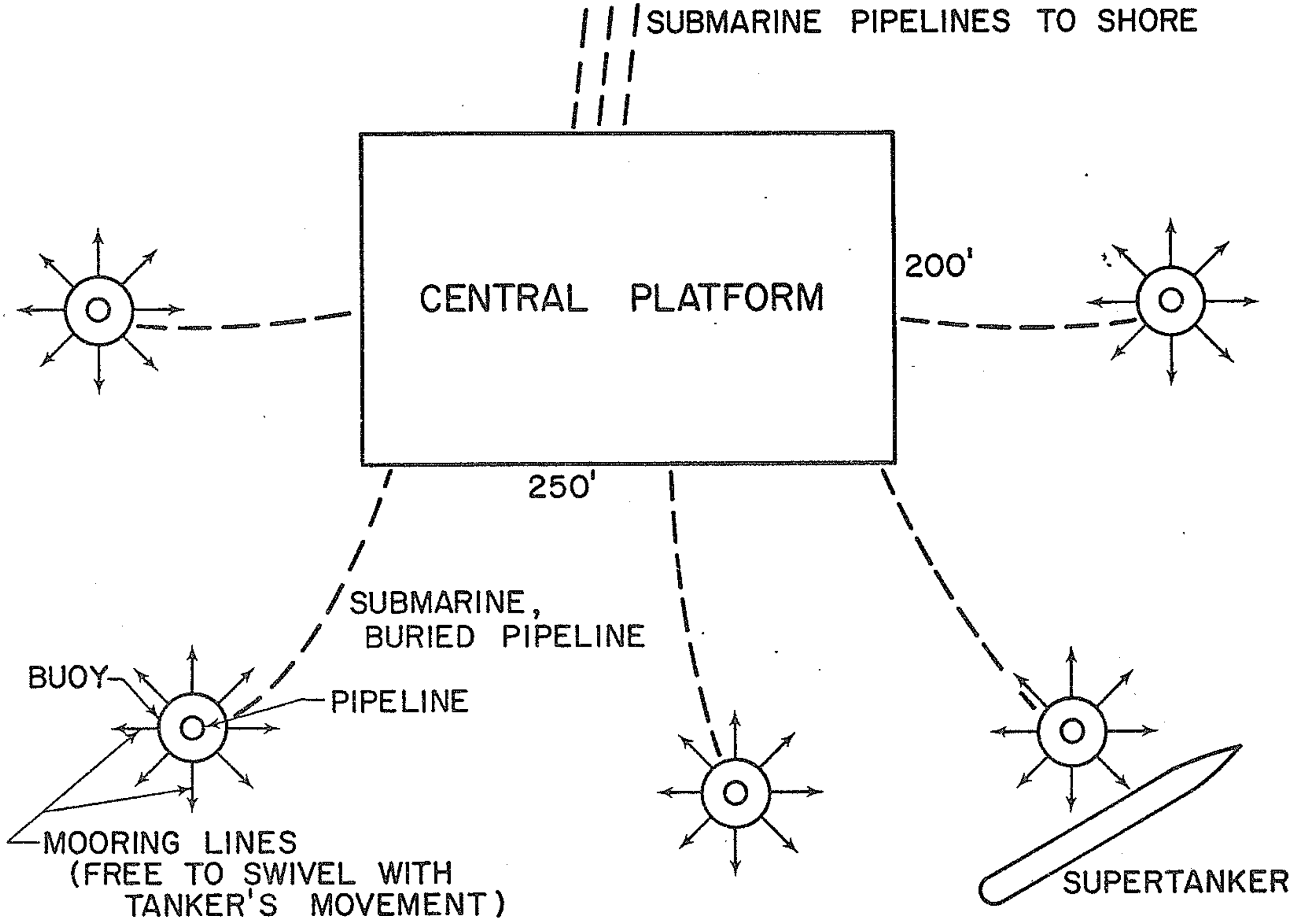


Figure VII-1. Single Point Mooring System and Platform.

hammers as possible sources of concern for platforms built on coral reefs. These are considered unimportant in this case. These investigators also considered a fixed platform on piles less damaging than one built by the jack-up technique. Some minor and very local increase in water turbidity may also result during the pile placement process. Its effect would be considered temporary and unimportant.

Floating mooring points will have no effect (Rounsefell, 1972) and their lines will be insignificant. Also, since the submerged, buried pipelines from the mooring points to the central platform only cover a relatively short distance, the relative impact of their placement and burial should also be negligible. Of greater concern is their proper design, construction and maintenance to prevent oil leakage (Rounsefell, 1972). The topic of submerged, buried pipelines to shore will be reviewed more extensively in a later section of this report.

Location No. 1 does not require the construction of a breakwater nor any dredging. Consequently, construction will cause very little real change of a permanent nature and have little impact on the surroundings.

Location No. 2 (Alternative A)

This location is about 11 miles offshore and consists of about a 1 acre platform protected by a 6000 ft breakwater. Because of its location in 60 ft of water, a dredged approach channel and dredged dock area to a depth of 90 ft is required. (see Figure VII-2)

The necessary dredging will undoubtedly have the most significant ecological impact. To put the magnitude of the dredging project in

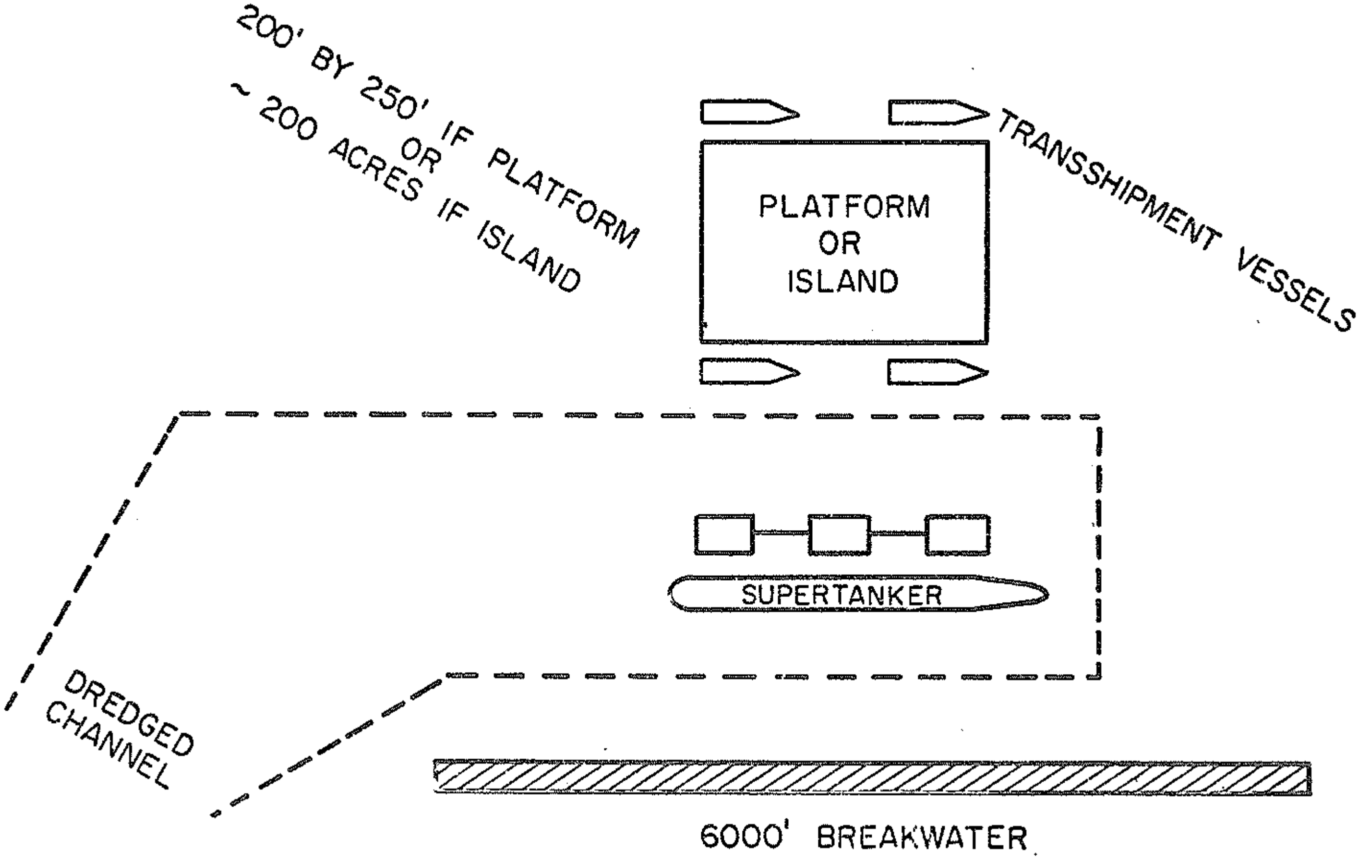
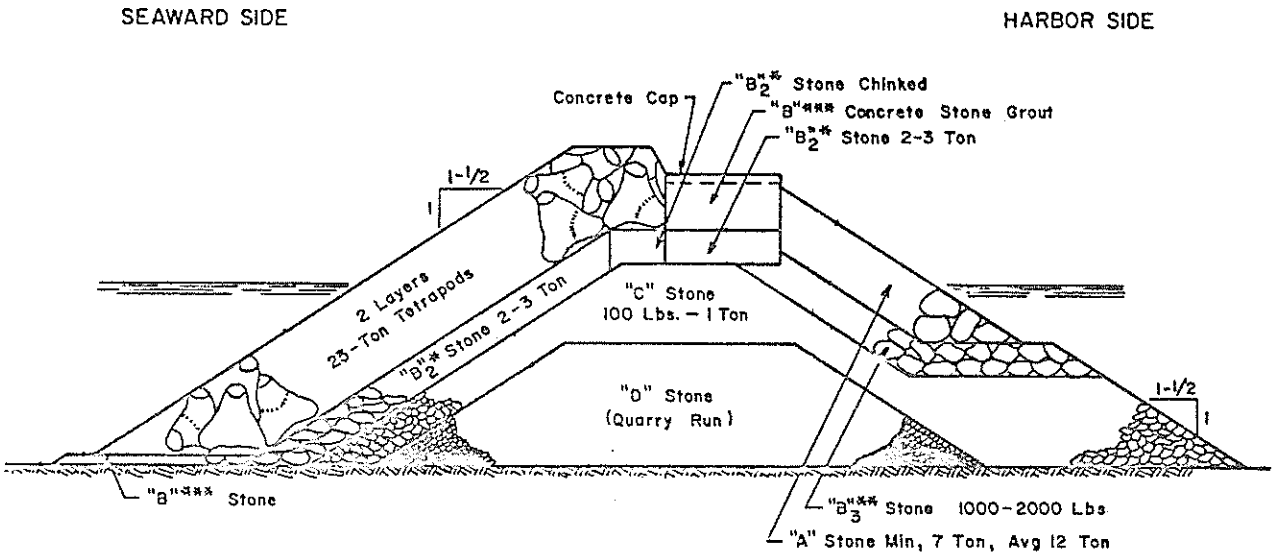


Figure VII-2. Location No. 2, Alternative A,
Platform, Breakwater, and Dredged Channel.

some perspective a few rough computations were made (Appendix D) regarding the volume of material dredged and the surface area involved. A total in situ volume of approximately 43,000,000 cu yds of material to be removed was estimated. The quantity is slightly larger than many routine dredging projects presently let and compares in magnitude with the recently completed Sabine Navigation Channel Project (30,000,000 cu yds total) on the east border of the Texas coast. The surface area involved in the dredging project is about 1300 acres or 2 sq miles. This area is about 1/2 percent of the circular area with a radius of 11 miles (shore distance of terminal site). Consequently, when viewed in these terms the magnitude of the dredging project is very normal and the surface area disturbed is relatively small when compared to the Gulf area available.

Effects of the construction of the central or supertanker platforms on the environment will be very similar to those described for Location No. 1. Only very temporary water quality changes (turbidity) are envisioned with a negligible result.

Because of its size, the breakwater will exert more influence on its surroundings, and depending upon its distance from shore can possibly exert a pronounced influence on the shoreline environment. Effects of construction can depend on the type of construction technique employed. Offshore breakwaters in the United States are usually of rubble-mound construction (CERCTR4, 1966). For deep water this would be a multi-layered, trapezoidal shaped section, built up from various grades of stone and rock and covered with very large rock, concrete blocks or tetrapods to act as armor against severe sea conditions (See Figure VII-3). Because of the size of the construction materials used, little



* "B_2" – One ton variation to 7 ton max.

** "B_3" – 1/2 ton to 1 ton min. – 7 ton max. as available.

*** "B" – 1 ton to 7 tons or to suit depth conditions at seaward toe.

Source: (CERC-TR4, Fig. 5-22, p. 344, 1966)

Figure VII-3. Typical Crossection, Offshore, Tetrapod-Rubble-Mound Breakwater

water quality effects result. Only the permanent loss of the covered bottom area will be significant. And, here again, the area is relatively minor in comparison to the total Gulf environment surrounding the site.

The purpose of the breakwater is to reduce the wave heights (energy) and therefore provide a protected area for the oil transfer process from the vessels to the stable platform. If located in the near shore region this reduced wave energy will cause some deposition of sand along the beach since longshore sand transport requires wave energy for its process. Sorensen (1972) feels that if the offshore breakwater is located at a distance greater than two breakwater lengths from the shore, its effect on the longshore sand transport process is negligible because other high energy waves have diffracted around the breakwater and are available to continue the process. Since Location No. 2 is 11 miles from shore and the breakwater is only a little over a mile long, the approximate 10 to 1 ratio in this instance will produce no difference in coastal sand transfer rates. In addition, because of the distance from shore and its size and shape relative to the surrounding Gulf waters, little effects on Gulf currents or tidal variations can be anticipated. Only very minor changes in local current patterns will result.

As previously indicated, the most significant change will be the result of bottom and water column disturbances produced by dredging. These will occur both at the time and place of material pick-up and ultimately at the disposal site. No pick-up or disposal methods presently exist which do not resuspend some additional sediment. Thus excess turbidity has emerged as the key water quality criterion for dredging.

Turbidity is defined as the optical interference with the passage of light through water. Sediment which is resuspended through dredging activity clouds the water and alters light transmission. Rounsefell (1972) lists the following effects of high turbidity:

1. reduction of photosynthetic activity;
2. smothering of animals and plants dwelling at the bottom;
3. spoiling fish spawning;
4. reduction of waste absorbing capacity;
5. reduction of shellfish feeding ability; and
6. reduction of plankton growth in freshwater ponds.

He concludes that: "... any construction projects that disturb the sediments will have, at least temporarily, a negative effect on the biota. Projects that promise to permanently increase turbidity could have far reaching effects and need to be approached with caution."

If a sediment has a significant amount of organic material, then resuspension causes a high initial biochemical oxygen demand which can lower the oxygen level. O'Neal and Sceva (1971) found dissolved oxygen levels 25% lower near the intake of a hopper dredge (Cleveland Harbor) and 35% less in the dumping area in Lake Erie.

Because of the distance from shore of the offshore terminal in consideration, the organic content (sewage, sludge, etc.) of the dredged area is likely to be minimal, hence local D.O. reduction should not be of concern. The material to be dredged should be reviewed with this factor in mind. These authors also noted that a healthy redevelopment of biological species in a dredged area is inhibited when the "volatile" solids content of bottom sediments is ten percent or higher. This brings up a very important question which has yet to be satisfactorily answered. What levels of turbidity and/or sediment concentration and bottom disturbance will produce adverse biological effects in a particular locale under a given set of environmental conditions? Relatively few research studies have been directed toward answering this question; a few that have are summarized below.

Biological Studies: One of the earliest biological studies was undertaken because of concern by oystermen over dredging near oyster reefs. Lunz (1938 a,b) performed a study for the Corps of Engineers along the South Carolina coast regarding the effects of dredging operations on oyster culture. He investigated the mortality, spawning, and weights of oyster meat as an indicator of productivity. Although complete burial was a situation that caused increased mortality, Lunz concluded that dredging did not have any deleterious effects on productivity. A later similar study in Florida by Lunz (1942) led to the same conclusions.

In 1952, Ingle investigated the effects of dredging on fish as well as shellfish in Mobile Bay, Alabama. No damage to fish or crustaceans in the dredging area was found. Oysters placed at various distances from an active dredge showed no unusual mortalities. Consequently, Ingle also concluded that only complete burial would be fatal. Oysters only 75 yards from the dredge were relatively unharmed. Ingle suggested the idea of controlled dredging to restrict the process to some prescribed distance from live oyster reefs to decrease the possibility of burial by spoil. He suggested a safe distance of 400 yards. Of course, this would depend on local conditions such as tidal currents, bottom topography, type of sediments, salinity, etc. Although no deliberate attempts were made to discover beneficial influences of dredging, Ingle noticed that oysters fattened quickly and shrimping operations concentrated in the area surrounding the active dredges. He therefore surmised that dredging might actually be beneficial to crustaceans and shellfish by stirring up organic bottom sediments.

Saila, Polgar and Rodgers (date unknown) used live lobsters to study the effects of dredged sediment dumping in Rhode Island Sound (Narragansett Bay). The sediment was clean, well-sorted sand with less than 1% organic matter and carbon. No mortality or visible evidence of distress was observed in lobsters placed 440 yards from the dredge site.

Wilson (date unknown) studied the effects of silt and turbidity in the Powder River, Oregon. Although very little evidence was presented, the author concluded that dredging was harmful because it reduced the sunlight penetration, changed the current patterns and created detritus traps and low oxygen conditions. He also objected to the loss of productive marshland resulting from filling with dredged spoil.

In a study of shell dredging as a factor in sedimentation of Galveston Bay, Texas, Masch and Espey (1967) found that dredging for shell produced an order-of-magnitude increase in suspended sediment over that produced by currents, wind, wave action, ship traffic, etc.

Their report suggested that all dredging near oyster reefs should cease when deposition was discovered.

Other recent studies have considered a wider range of organisms and have uncovered problems not previously considered. They were reviewed by Anderson (1972), whose summary is primarily responsible for the following comments. In Boca Ciega Bay Florida, Taylor and Salmon (1968) found that the type of bottom sediments were vastly different after dredging. For example, an area where 94% sand and shell existed as surface sediment prior to dredging, averaged 92% silt and clay afterwards. It was also noted that a very consolidated surface formed with the silt-clay which could smother benthic forms and be too compacted to resuspend by normal tidal action. These changes resulted in a marked difference on the settling of planktonic larvae of benthic organisms "... since the larvae exhibit a very strong substrate preference" (Anderson, 1972). Consequently, it was determined that benthic forms killed by smothering from sediments were not capable of recolonizing dredged areas for up to 10 years. Besides this reduction of number of individuals, fewer types of species were found in dredged versus undredged areas. Some rough estimates of quantities of biological resources lost due to these considerations were given in the report.

Data by Reish and Knawling (1971) support the conclusions of Taylor and Saloman. Comparing benthic polychaetes from dredged and undisturbed areas of Anaheim Bay, California, Reish and Knawling found only about 100 individuals per sample in the dredged area while around 430 could be counted in the undisturbed samples. The decrease in numbers was attributed to alterations of the habitat resulting from dredging. The time factor was not noted by Anderson (1972) in his summary review of this article.

Because the state of Maryland objected to dredging of the Delaware Canal in Chesapeake Bay, Cronin, et al., (1970) investigated the benthic changes of three dominant species (isopods, amphipods, and polychaete worms) as indicators of dredging effects. One year after dredging recovery had taken place in the disposal area but not in the channel. The high natural turbidity of the bay markedly reduced light penetration and explained the low grass production in the area. Additional turbidity produced a short term decrease in light penetration but only a temporary effect for a given area.

The question of habitat alteration was also studied by Godcharles (1971). The effects of a bucket dredge on benthic communities in Tampa and Boca Ciega Bays were of interest. The most significant factor was the failure of sea grasses to recolonize dredged areas even one year after dredging. This loss of sea grass had a chain reaction in the food chain resulting in decrease of bio-populations. It was recommended that dredging be prohibited on substrates with large sea grass growths.

Similar studies of numbers of individuals and types of species in benthic communities are currently in progress at Texas A&M University. Commercial dredging of shell in San Antonio Bay, Texas has occurred for many years. From the dredgers records, the location and time (year) of a particular dredge cut can be established. Consequently, time histories dating back 10 - 15 years can be plotted for the number of individuals present and the various types of species encountered, both in the new and older dredge cuts and in the flats where dredging has never taken place. The surface sediments in both undisturbed and dredged areas consisted of coarsely graded sand and shell fragments. Only preliminary data were available at the time of this report and could not be released. (Harper, 1972)

Several other environmental studies regarding dredging effects in estuarine and coastal waters are just beginning.

Hess (1972) described the National Offshore Mining Environmental Study (NOMES) off the coast of Massachusetts which is slated to begin in 1973. The environmental disturbances created by offshore sand and gravel mining (dredging) and beach renourishment programs will be of primary concern. Along with basic laboratory investigations, the field study will consist of (1) construction of the environmental baseline, i.e. detailed surveys of the natural oceanographic and ecological characteristics of the test area; (2) subsequent experimental dredging and monitoring to determine significant changes in baseline characteristics; and (3) continued monitoring and evaluation during the period required for natural restoration of the environment. The project will be a cooperative effort among many interested groups, including:

1. The Federal Government
    a. NOAA and all its components will spearhead the effort including:
        (1) The Marine Minerals Technology Center
        (2) The Sea Grant Program
    b. Supporting agencies will be:
        (1) Bureau of Land Management
        (2) Geological Survey
        (3) Bureau of Sport Fisheries and Wildlife

    (4) Bureau of Mines
    (5) Army Corps of Engineers
    (Coastal Engineering Research Center)
    (6) Environmental Protection Agency
    (7) Coast Guard

2. The State Agencies of Massachusetts

3. Universities both through existing Sea Grant Programs and others:
    (1) University of New Hampshire
    (2) M.I.T.
    (3) Woods Hole Oceanographic Institution
    (4) University of Massachusetts

4. Local Interests
    (1) Raytheon Corporation
    (2) New England River Basins Commission

5. National Interests
    (1) National Sand and Gravel Association
    (2) National Environmental Research Council (British)

It will be an extensively designed experiment lasting several years and costing millions of dollars.

Another project has recently begun at Oregon State University and is intended to study the ecological impacts of dredging operations along the Oregon coast estuaries (World Dredging, 1972). The objectives are to:

1. develop and test practical methods for measuring and evaluating ecological change due to dredging;

2. examine past records to possibly eliminate previous long-term effects;

3. formulate environmental dredging guidelines for the future in the Oregon coastal region.

The project is sponsored by the RANN program of the National Science Foundation.

From the above studies that have been completed, are now in progress, or are proposed, it can be concluded that much remains to be learned about the ecological impact of dredging in the coastal and offshore environment. Even after the completion at the contemplated research many unknowns will still remain. The relative magnitude of the disturbance then takes on more importance, since its exact ecological impact cannot be now determined.

Spoil Dispersion: Because some dredged sediments are heavily polluted, attention has also focused on special spoil disposal practices. Yeaple, et al., (1972) discussed the possible pretreatment of the bottom sediments with a binding agent (mercaptan) prior to dredging to reduce the hazards of mercury-contaminated spoil.

A project to use polluted spoil to create salt-marsh islands was discussed by Vittor (1972). The contamination by heavy metals and/or pesticides dictated the use of diked disposal areas. Vittor mentioned a Corps of Engineer study (Mobile District, 1968) which revealed that spoil sediments with small clay quantities only traveled 1200 feet or so from the discharge point before settling to the bottom. Obviously, the dispersion of dredged spoil in open waters and the need for diked areas is dependent on the local ability to maintain sediment in suspension - and is a function of several complex, interrelated quantities. Such factors as particle size, size distribution, shape, colloidal reaction rates, velocity patterns, water salinity, fluid viscosity, and turbulence scale all affect settling. In a natural environment these paramenters vary significantly and their interactive behavior is complex. These factors must be kept in mind when reviewing field studies involving dredged suspended sediment travel distances.

For example, Hellier and Kornicker (1962) measured the deposition depth at various times and distances from an intracoastal waterway dredging project near Aransas Pass, Texas. Cores were taken before, one week later and 18 months after dredging. After one week, 22-27 cm of sediment (11-55% silt-clay) was deposited within 0.5 miles of the dredge. Eighteen months later there was 32-33 cm present at the same stations. Effects at distances greater than 1 mile were negligible. It was noted that more sediment accumulated on the windward side of the spoil island than on the lee side after dredging. However, little or no mention of the above listed environmental and physical factors present during the tests were determined.

A similar study by Gunter, Mackin and Ingle, (1969) in Upper Chesapeake Bay reported that 90% of all material dumped into the disposal area fell out within 1,000 feet of the outlet pipe. In Ingle's (1952) paper previously discussed, it was mentioned that deposition of mud on the bottom did not extend beyond 0.23 miles from the dredge. On the other hand, O'Neal and Sceva (1971) describe a case in Chesapeake Bay where dredge spoil reportedly spread out to cover an area 5 times larger than the designated spoil area. In all these instances the necessary physical and environmental conditions present during the tests were not adequately documented to generalize the results. Consequently, conclusions based upon these studies could be greatly in error.

Two research projects regarding the dispersion and quality of dredged spoil in Galveston Bay, Texas have recently begun at Texas A&M University under the sponsorship of the Sea Grant Program. In one case the spoil effluent water and spoil sediment of one bay dredging project will be investigated to determine its pollution characteristics. The objectives are to establish baseline information and examine potential spoil treatment methods so that usability of spoil areas can be ultimately predicted. The other project will also examine a typical Galveston Bay dredging project to document the physical change to the spoil disposal area (dispersion) as a result of estuarine environmental forces (tides, waves, wind, etc.). In addition, presently used spoil placement equipment, techniques, disposal practices, and methods to select disposal sites will be reviewed.

In addition, an in-house laboratory research project is underway to investigate the flow field near the inlet pipe (cutterhead, draghead) of a hydraulic dredge. Knowledge of the interaction between the soil, fluid and flow characteristics and inlet geometry is critical to understanding how disturbed suspended matter is lost near the intake and to the proper design of shield devices for control of sediment and turbidity generation while dredging. The project is sponsored by the Center for Dredging Studies of Texas A&M University.

Questions and Unknowns: These complicated settling processes along with a number of other unanswered questions about dredging and water quality were the topics of recent articles by Basco and Dominguez (1971 a,b). One question considered was the levels to place on turbidity increase and sediment concentration that produce adverse biological effects. The Federal Government's standard of 50 JTU above background (Water Quality Criteria-1968) appears unrealistic if applied to dredging everywhere in the country. The natural biological life present in the turbid mouth of the Mississippi (1000 JTU) is completely different than that in Tampa Bay (25 JTU). A 50 JTU increase in the Mississippi River case would create very little difference in light penetration, etc. In fact, turbidity cannot even be measured in the 1000 JTU range with the necessary accuracy. (Standard Methods, 1965).

Another complication in the use of turbidity as an index is that it cannot be directly related to the quantity of suspended matter present in a given water volume. It is possible to raise the concentration of matter present without increasing the turbidity since turbidity depends on light scattering and not volumetric amount of material in suspension. In fact, turbidity can be increased by aerating a water column. Since from the above cited references, complete burial of organisms by sediment is usually fatal, use of suspended sediment concentrations and not turbidity would appear the more logical parameter.

Another unknown quantity is the relationship between the soil gradation to be dredged (soil classification index) and the quantity of suspended sediment and/or turbidity to expect at the digging site or spoil disposal area. For example, one might expect large silt-clay fractions would always be the worst condition. However, in some cases, baseball sized clay balls form in the hydraulic dredging system and settle out rapidly in the spoil area.

Also, the digging process for various types of dredging systems (hydraulic cutter, bucket ladder, hopper droghead) is very poorly documented and inadequately understood. We do not fully understand which type produces the minimal disturbance; how to operate the equipment for maximum environmental protection; and what quantities of sediment/turbidity are created at the digging site under given conditions.

Regarding the specific alternative (Location # 2, Alternative A), a major question not considered by the CEQ specification is exactly what will be done with the approach channel and dock area dredged material? In addition, although technically feasible, United States offshore dredges presently do not exist that can dig to the required 90 ft channel depth.

Maintenance dredging: If required, periodic dredging to maintain specified channel size can continually impose ecological stress on the area. The reestablished benthic communities are destroyed each time and spoil must be disposed. Fortunately, for the terminals located at site No. 2 or further offshore, continued natural shoaling of materials in the channel should be small. This is because the suspended sediment loads of rivers flushing into the Gulf will have long since settled out to form the coastal plain deltas and river shoaling areas of the estuaries. Only bottom disturbances caused by long period storm waves which "feel" bottom can cause material to be deposited in the dredged cuts. Gulf currents are too weak and erratic to resuspend material and create shoaling. Hurricanes can create relatively large surface currents. However viscous fluid effects greatly diminish the currents at the 60-90 ft depth of interest. Consequently, environmental disturbances due to maintenance dredging should be small. Detailed information regarding existing sediment transport during storm wave conditions is lacking for the Gulf regions of interest.

Summary: There is no question that because of the need for dredging the entrance channel and dock area, Location No. 2 will create some environmental and ecological change. However, information does not exist, nor have extensive, long term studies been performed on similar offshore environments, to enable factual, positive statements to be made about the ecological chain of events and secondary reactions due to the dredging activity of interest. It will be several more years before studies of the scope and complexity of the NOMES project referred to above can be possibly projected as guidelines for similar construction efforts offshore. Until then, the relative magnitude of the disturbance and environmental modifications for each construction effort must be considered along with their sum total impact on the area in question. In perspective, the volume and real extent of the required dredging is very minimal when compared to the extent of the Gulf environment. The dredged quantity compares to many previous routine dredging projects in much more valuable coastal and estuarine waters. The extent of the dredging project is much less than that routinely designated as hopper dredge spoil dumping areas by the Corps of Engineers.

It would appear that the change created by dredging would be well worth the risk, when the magnitude of the effort is related to the vastness of the Gulf environment and its capabilities for assimulating the modifications into its total system.

Location No. 2 (Alternative B)

The third and last alternative design considered is at the same location (No. 2) but uses an island for berthing of transshipment vessels instead of the platform. Dredged spoil from the approach channel and docking areas (same as alternative B) would be employed, if suitable, to construct the island. The 6000 ft breakwater would shelter the unloading area as before. A schematic of the concept is shown in Figure VII-2.

The proposed island will be approximately 200 acres in working surface area. Since the bottom area covered by the island will be permanently lost from the environment, some crude computations were made (Appendix D) to assess the volume of material required for island construction and the bottom area lost. Approximately, 24,000,000 cu yds will be required which is less than the quantity to be dredged. The bottom area covered is about 230 acres or 0.36 sq mi. This area is about one-tenth of one percent of the circular area within a radius of 11 miles (shore distance of terminal site). Obviously, when viewed in these terms, the bottom surface covered by the island is extremely small when compared to the available Gulf area. Spriggs (1971) in studying the effects of a 35 acre island to be located near Bolsa Chua Beach on the California coast concluded that because the site environment was relatively small, disturbance to marine resources would also be relatively small.

Since all elements considered in this concept are the same as Alternative A, except the island, only the effects of island construction on the environment will be reviewed. As mentioned above, the area covered by the island must be considered as permanently lost. However, the relative area involved is minor. The island could also exert an influence on the coastal shoreline processes if located within close proximity to it. However, as in the case of the breakwater effect previously discussed, this factor is insignificant. Current patterns will be altered locally to some extent, expecially in combination with the breakwater. Again, however, in perspective the real extent of the terminals' presence on Gulf currents will be insignificant and comparable to the local field changes about an airfoil in flight.

The most significant environmental distrubance that could occur would be during the actual construction of the island. Depending on the construction techniques employed and precautions taken, the turbid effluent waters returning to the Gulf from the hydraulic filling process could create excessively high turbidity and suspended sediment plumes fanning out from the construction site. These conditions could alter light transmission and smother benthic communities along with all the other effects of high turbidity previously discussed. Since the CEQ specifications suggests a 2 - 3 year construction period, this aspect of the project may "permanently" increase turbidity and have the "...far reaching effects..." that "... need to be approached with caution" (Rounsefell, 1972).

In order to obtain a feel for the possible magnitude of suspended sediment (turbidity) involved, some very preliminary and rough computations were made to estimate the maximum expected sediment concentrations near the shoreline - about 11 miles from the terminal location. Since marine reproductive activity is high along the coastal waters, a knowledge of suspended sediment (or turbidity) levels resulting from construction was considered important. All factors given or assumed along with the actual calculations have been included as Appendix D of this report. Because of the extremely limited amount of factual data available, a number of assumptions had to be made which could significantly alter the results. These were initially made on the conservative side (large sediment loads) and their influence on the results will subsequently be reviewed.

To arrive at a value of the rate at which suspended matter is lost continuously into the water column at the fill site, estimates of quantity of material lost and the construction time involved were necessary. Consequently, settling was neglected and a very conservative value of 10% of the total dredged volume to be moved was initially assumed to be lost during construction by suspension in the effluent water. Of the two year time available for construction 50% was assumed unusable (darkness, downtime, etc.). This resulted in a "point source" suspended load of 240 lb/sec or about 2 ft^3 per sec of "in situ" material moving into the Gulf waters. Although probably excessive, the value was used for the estimates.

Next, a continuous shoreward (NW) wind driven current of 2.2 ft/sec was estimated assuming a current equal to 3% of wind velocity and a 1.0 knot Gulf current in this same direction. Obviously, there are many shortcomings in this approach, but it was used nevertheless.

A Gaussian concentration distribution was assumed along with a "long" time or distance theory for statistical turbulent diffusion (Taylor, 1938, Slade, 1968), consequently the variance of the turbulent dispersion could be readily related to available turbulent dispersion coefficients. Estimates of the lateral and vertical variances were made using the most conservative values of turbulent dispersion coefficients determined in the Great Lakes field tests of Csanady, (1962). From these tests, Csanady also determined that the turbulent dispersion coefficients were essentially constant at distances beyond 1000 meters from the source (Fickian Theory of Dispersion). Hence, the distances of interest in this instance fall beyond this limitation.

Solutions of the resulting mass transport equations for three dimensional dispersion from a continuous point source in a uniform flow field are presented in most standard texts. In this instance the equations of Slade, (1968), were used and resulted in a maximum centerline concentration of about 300 mg/l (ppm) near the shore for the above assumed ideal conditions.

Before considering the relevance of this number, the assumptions used will be discussed. First the value is for a maximum at the center of a Gaussian distribution which decays rapidly on either side. Lesser currents of an unsteady nature will result in much larger values for the lateral variance and significantly reduce the maximum value obtained. The material will be "spread around more". The source will not be continuous but cyclic in nature due to work stoppages for a variety of reasons. The source value of 240 lb/sec is probably very high and does not consider ways to reduce the material in the spoil effluent waters which will be discussed later. In addition, no settling of the suspended material was considered along the eleven mile path to shore. Obviously, this fact alone can make the above computation an academic exercise.

To assess the effects of material settling out from the water column, information about the grain size distribution of the entire volume of dredged material was needed. This was not available.

However, surface core data from a number of samples taken in the terminal vicinity were available from the CEQ office. The location of the samples reviewed for this report is shown in Figure VII-4. A summary of those cores taken near Location No. 2 is recorded in the table below.

Core Sample No.	Description of Material	Percentage Silt or Clay
527	Coarse - too little to sieve	99%
528	Coarse - too little to sieve	98%
529	Coarse - too little to sieve	99%
378	---	55%
377	Sand and gravel	39%

The majority of the surface material sampled was very fine silt-clay sized particles. For estimation purposes that passing a #200 sieve (0.074 mm) was used for calculation purposes. In a 2.2 ft/sec current, it was estimated to take about 1 hour or 1.5 miles for a 0.074 mm particle to reach a bottom 60 ft below. Simple Stokian settling rates were employed. Turbulence would change these results along with other grain sizes in the distributions and salinity effects (Sakainoto, 1968). Finally, the assumptions of a point source and homogeneous, nonstratified fluid are questionable.

All of the above assumptions tend to be conservatively used and indicate the true sediment concentration at the shore resulting from island construction to be much less than 300 ppm. In fact, the majority will never reach the coastal area. For comparison purposes, although varying considerably, during storms and in various areas, the natural suspended sediment levels along the coast are approximately 50-60 ppm (Weiser, 1964).

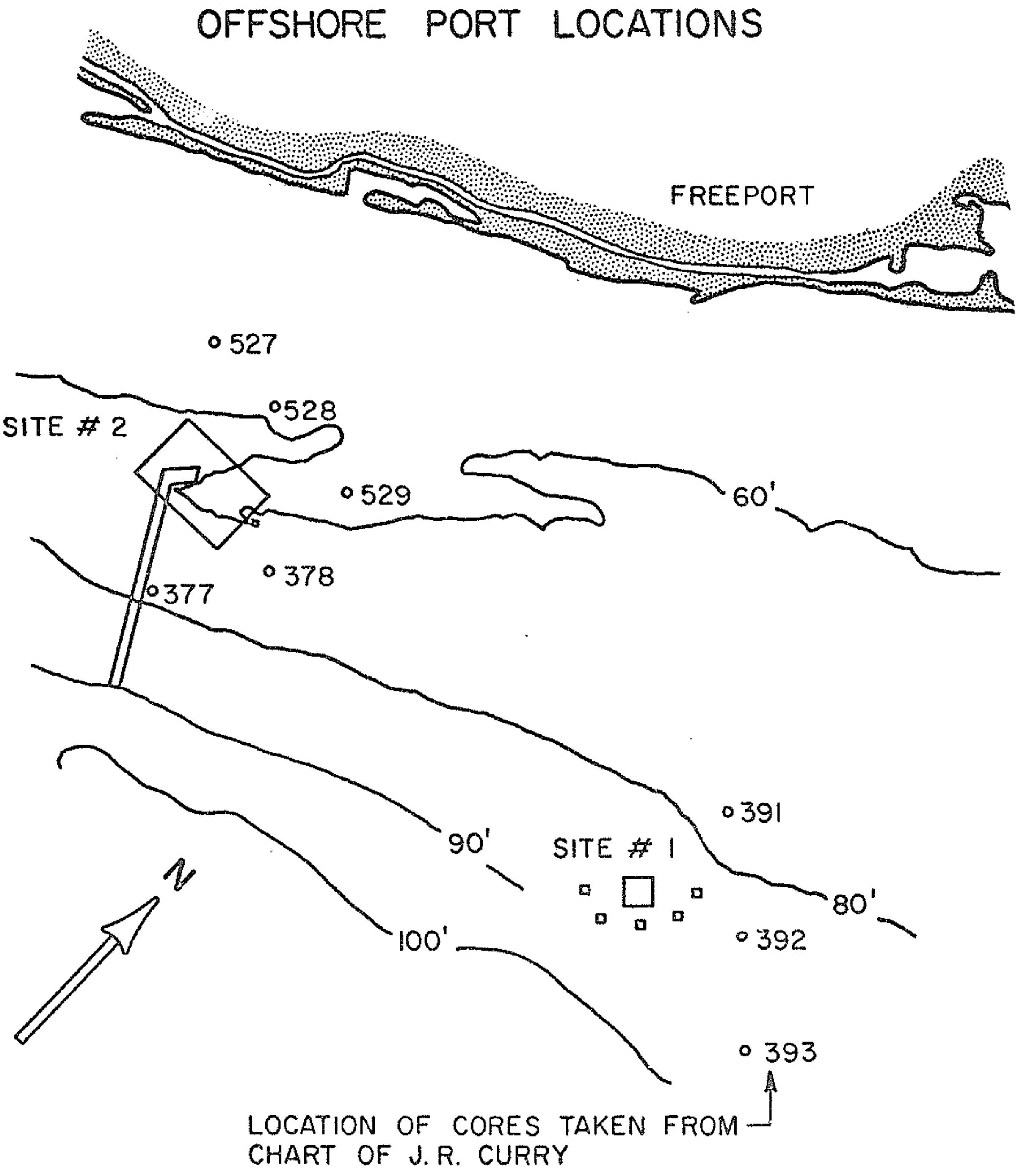


Figure VII-4. Location of Cores Taken From Chart of J. R. Curry.

Although admittedly an academic exercise, the above effort to compute a sediment concentration near shore resulting from construction served the purpose of illustrating the many areas where sufficient factual information is lacking and where more field data (soil infor. currents, etc.) and research effort must be expended.

The above computation also failed to consider any special construction techniques, use of special silt restraining barriers, and turbidity control programs that could be employed during island construction to minimize the effects on the surroundings. One such possible building method is outlined in a special report about the building of islands in the open sea by Bos Kalis Westiminster Dredging Group,(1972). It essentially consists of the construction of a breakwater dike behind which hydraulic fill is added in the protected area. The dike eventually encircles the island (except for the harbor entrance). Construction could proceed in such a manner that the fine material released during the hydraulic fill operation is retained. The use of silt restraining devices would only be practical in sheltered harbor areas. An example of an actual water quality control program for dredging and suspended sediment runoff from diked spoil areas was described by Basco and Dominquez (1971) in reference to a program initiated by the Florida Power Corporation in Tampa Bay, Florida. Roe and Williams (1970) describe the use of plastic films over bottom sediments which are cast from solvent systems.

In summary therefore, although the creation of an island at Location No. 2 (Alternative B) will result in the permanent loss of some bottom area, it is a relatively minor amount. Field information regarding the initial and secondary effects of such change are lacking.

Attempts to compute levels of suspended sediment resulting from such island construction efforts reveal many shortcomings in available knowledge required to make realistic estimates. Even so, extremely conservative estimates, when tempered with practical knowledge and the possibilities for technological control, make the likelihood of severe environmental stress due to vast suspended sediment clouds emanating from the construction site a very remote possibility.

Submarine Oil Transport Pipeline to Shore

Each of the above alternatives requires a terminal-to-shore pipeline to complete the transfer of oil from the supertanker to the shore based processing operation. The environmental consequences of this pipeline system will depend on whether the pipeline is laid out on the bottom or buried beneath the bottom surface. Both methods have ecological disadvantages. In either case however, the relative amount of bottom area changed by the construction of the pipeline is small.

Pipelines have been placed directly on the ocean floor from specially equipped lay-barge-stringer type vessels (Blumberg, *et al*., 1971 and Key, *et al*., 1970). The method is usually limited to pipes 12 inches or less in diameter. Very little environmental disturbance is created and can be considered negligible. Of greater concern with this method however, are the possibilities for pipeline damage and oil leakage resulting from dragging anchors, soil settling, and wave loads from storms. Fox (1970) described problems encountered with a pipeline for an offshore oil terminal in Bantry Bay, Ireland. It was found that places on the continental shelf were composed mostly of soft silt which soil tests indicated would not support a pipe of practical size. Concrete cradles were needed to span these areas.

The other method requires dredging a small trench in which the pipe is placed and then covered for protection. Devices such as the underwater "Seamole" can be used to cut a trench in water up to 600 ft deep that will cover a 42 inch pipe with a minimum of 3 feet of soil (Oil and Gas Journal, 1969). Obviously, the construction of the pipeline by this method will produce changes in the benthic community and create suspended sediment and/or turbidity loadings. All of the previously cited literature applicable to a dredged channel and island construction apply equally to the pipeline dredging and backfilling operations. However, the volume of material and area of disturbance are again extremely small in comparison to the total Gulf area. The most important area for concern would be the near-shore region (less than 1/2 mile offshore) of pipeline construction. A route should be considered which minimizes disturbance of bottom breeding areas and avoids polluted sediments which may be agitated during construction.

As stated by Rounsefell (1972) underwater pipelines cause only temporary damage during construction. Consequently, this part of the system is of little concern environmentally. Care must be exercised however, in the proper gathering of field data and in design to reduce the chance of breakage and leaks of the oil pipeline system.

Summary Comment

The obvious and most important effects of construction on the marine environment will result from the dredged channel and complementary island. There is no question that dredged channel cuts will have drastic changes in benthic communities and may take many years to return to normal, if ever. There is no doubt that the island will permanently remove a given area of marine bottom from productive use. In addition, during the time construction is actually taking place, the waters in the immediate surrounding area will undoubtly contain a somewhat higher sediment concentration and/or turbidity level. The question that must be addressed therefore is what is the significance of these man-made changes on the ecology of the area, and the Gulf of Mexico in general. In terms of just physical <u>area</u> affected, as pointed out throughout this section, the size of the areas involved in dredging and island construction is extremely small and relatively insignificant. Many examples could be cited of much larger changes on land (reservoirs, highway systems, airports, cities, etc.) where physical areas affected are order of magnitudes larger.

In terms of influence on the physical processes affected (tides, currents, longshore transport currents, salinity), because of the distances from shore and sizes involved, the changes suggested are insignificant. Consequently, the effects of dredging and island construction on the coastal zone physical processes and all the biological processes that are affected will be also negligible. Small changes may create large chain-like repercussions, however. The vastness of the Gulf of Mexico and the tremendous volume and capacity to asimulate slight modifications such as a small island and dredged channel, make the probability for this to occur an unlikely event - in the writer's opinion. Data are unfortunately lacking to substantiate or disprove this opinion. Therefore broad based studies such as those proposed by the NOMES project will be extremely valuable to assess the capacity of large water bodies to assimilate small biological disturbances before chain-like reactions are set off throughout the ecological cycle. The need for more baseline information is critical in this regard.

A Gulf of Mexico environmental data gathering, analysis and modeling program is planned by the Gulf Universities Research Corporation (GURC) (Lohse, 1972). The stated purpose is to provide knowledge of environmental processes and their functional relationships in order to optimize the system and resources. A significantly large part of the program is involved with data collection. For example, bottom surveys will develop data for up-to-date bathymetric maps for sediment transport studies in the Gulf. The need for more knowledge about the Gulf grew from a special conference "Issues & Programs" (1968) sponsored by GURC in 1968. Federal and State agencies participated including:

1. Bureau of Commerical Fisheries
2. Federal Water Pollution Control Administration (EPA)
3. U.S. Naval Oceanographic Office
4. U.S. Geological Survey
5. Corps of Engineers
6. Environmental Sciences Services Administration
7. Louisiana Wildlife & Fisheries Comm.
8. Florida Marine Research Laboratory
9. Texas Parks & Wildlife Department

At the conference each agency outlined its programs and research plans for problems related to the Gulf of Mexico. The theme underlying the conference was the appalling lack of baseline information about all aspects of the Gulf of Mexico.

IMPACT OF OIL SPILLS

Consideration of overall impact of potential oil spills associated with the offshore port activity should include a summation of the effects on all the environmental elements. However, it is not possible to add the effects of an oil spill between classes of environmental elements. For example, the effects on waterfowl cannot be added to the effects of marine plankton but each must be judged separately and any interactions between the classes estimated.

In a study of the effects of an accidental spill, the probability of occurrence must be included in the evaluation. The probability that a specific environmental element will be impacted is the product of the probability that the oil spill will occur times the probability that if it does occur it will reach that specific environmental element. A third factor that must be included in this evaluation is the probability that if the impact does occur, the concentration and contact time will be high enough to cause harm to the elements affected. Adequate information was not available from existing literature in many areas to accurately evaluate the impact on the environment. However, for the purpose of this preliminary environmental impact study the methodology was developed, much of the missing data assumed, and the impact estimated.

Model

In order to realistically evaluate the impact of a potential oil spill on the environment, a model of the Texas Gulf was developed. This model is not complete but its development was carried far enough for it to be useful in determining the probable impact of oil spills in this preliminary study. As shown in Figure VII-5, the model divides the Gulf waters into grid squares. The grid system is an extension of the one developed by the Texas General Land Office to subdivide offshore lands. The location of each grid square is permanently fixed and is referenced to the state plane coordinate system. Each grid element in the model represents a square area, three miles by three miles in the ocean. This is considered adequate for most purposes since the characteristics of offshore features generally change relatively slowly over geographical area. The boundary lines between offshore features are not as sharp and clearly defined as on the land.

The model is used in this study to inventory offshore elements such as water depths, variations in benthic organisms, plankton concentrations and shrimping areas. The major brown and white shrimping areas (Moffett, 1970) were coded for the model and are shown in Figures VII-6 and VII-7. By using the same grid system for the inventory of environmental elements and oil transport model, the potential effects of oil spills can be fairly accurately estimated. This approach appears to be more realistic than basing the projected impact on the worst possible situation. The model places the impact into perspective in that the <u>total Texas Gulf Coast environment</u> is considered. For example, the soluble fractions of oil from a major spill may affect the plankton in several square miles of ocean. While the magnitude of the impact of the oil on these plankton might be high, the overall importance of the impact on the Gulf plankton will be minor when compared with the 20,000 square miles of coastal waters with equal or higher plankton productivity which are unaffected.

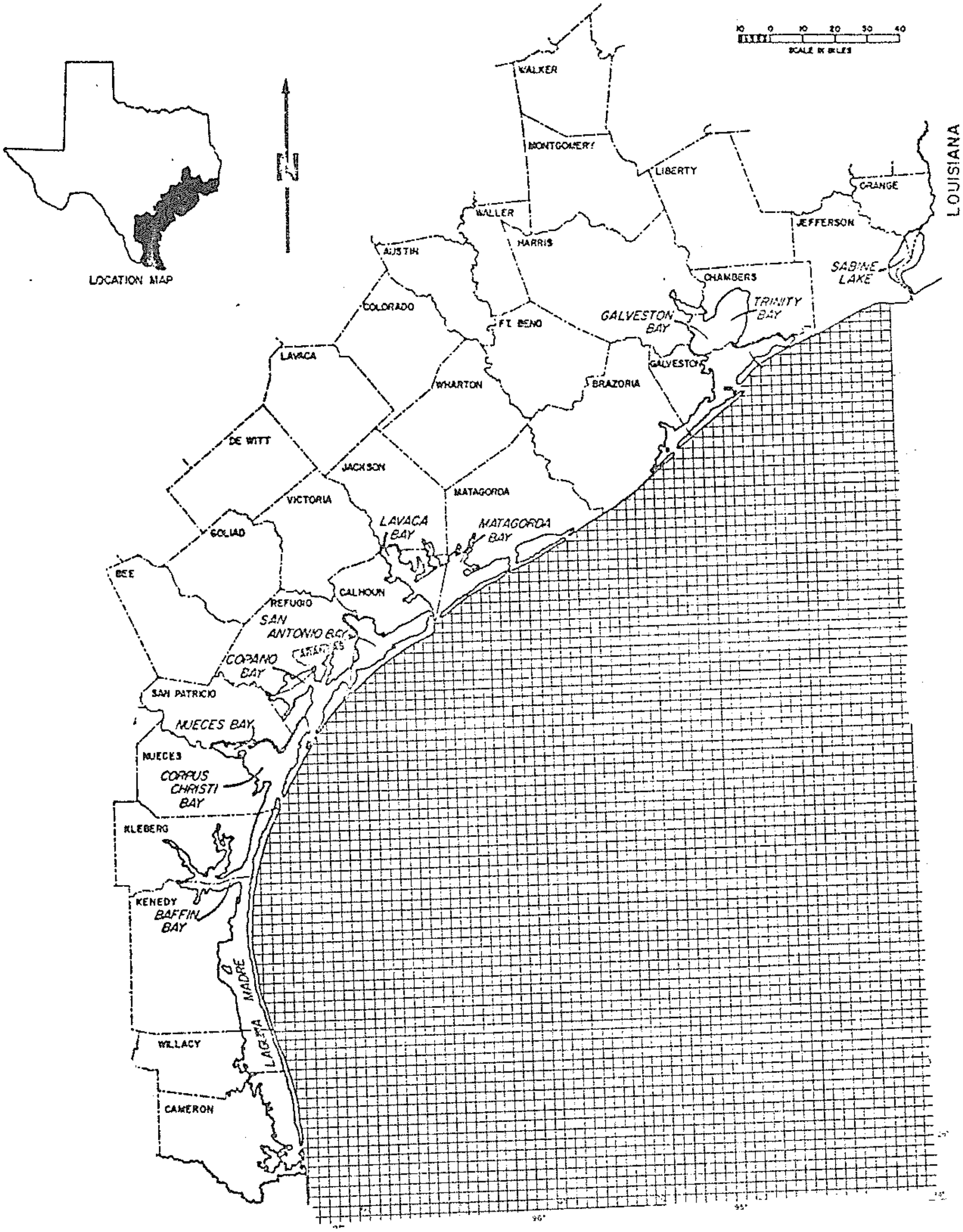


Figure VII-5. Environmental Inventory Grid.

Figure VII-6. Model of Brown Shrimping Areas Off the Texas Coast

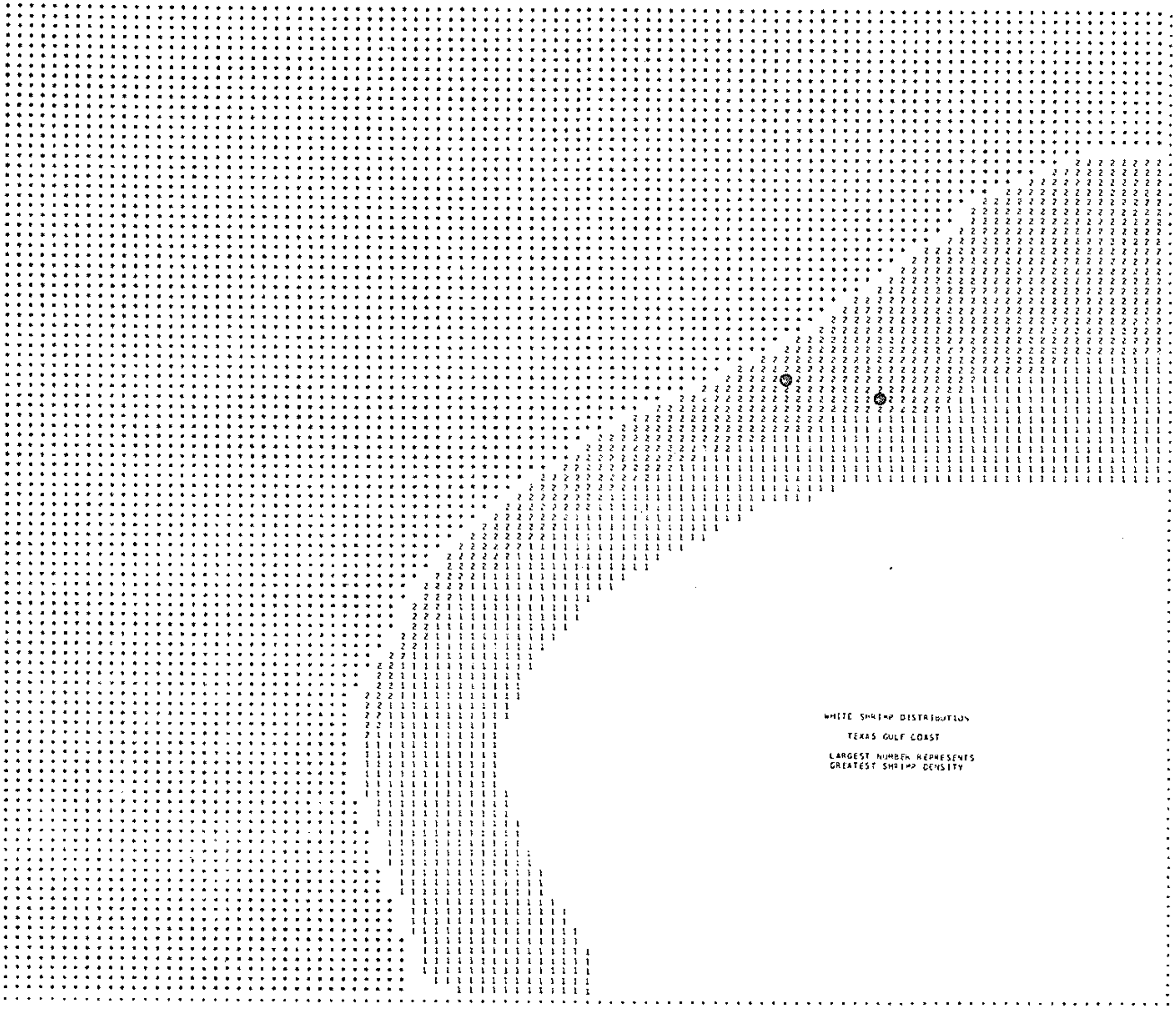


Figure VII-7. Model of White Shrimping Areas Off the Texas Coast.

The model can also be used to estimate the probability of an oil spill of a given volume and location reaching any other point on the grid. For the purposes of this study a 30,000-ton spill was assumed to occur once every 20 years. Using the wind data listed in Chapter II, and the transport and spreading model from Chapter V, the probability of the oil reaching any point in the grid was determined. Of course, the results of the model cannot be any better than the wind and current data available for the area. Figure VII-8 shows the approximate return period for oil reaching any point on the grid. A return period of 1/1000 indicates that oil from a major spill would be expected to reach that point once every 1000 years. This plot does not show the volume of oil reaching each point, the duration of time in which the oil slick is on the water surface or the character of the oil when it reaches the grid square. At least a one year record of wind and sea data collected at several locations near the port site is required in addition to oil weathering studies.

Only near the port site will the oil slick contain volatile fractions. Figure VII-9 shows the area about the offshore site for which the surface oil slick would contain volatile fractions. (The amounts of fractions 1, 3 and 4 in Table IV-1 are estimated by equation 2 of Chapter IV to be less than 1 percent of original volume for the area enclosed by the heavy line.) This plot does not indicate that the volatile fractions from an individual oil spill will affect the area outlined in Figure VII-9, but that by the time the oil in the slick crossed this line most volatile fractions will have evaporated. The volatile fractions that enter the water column on the other hand,

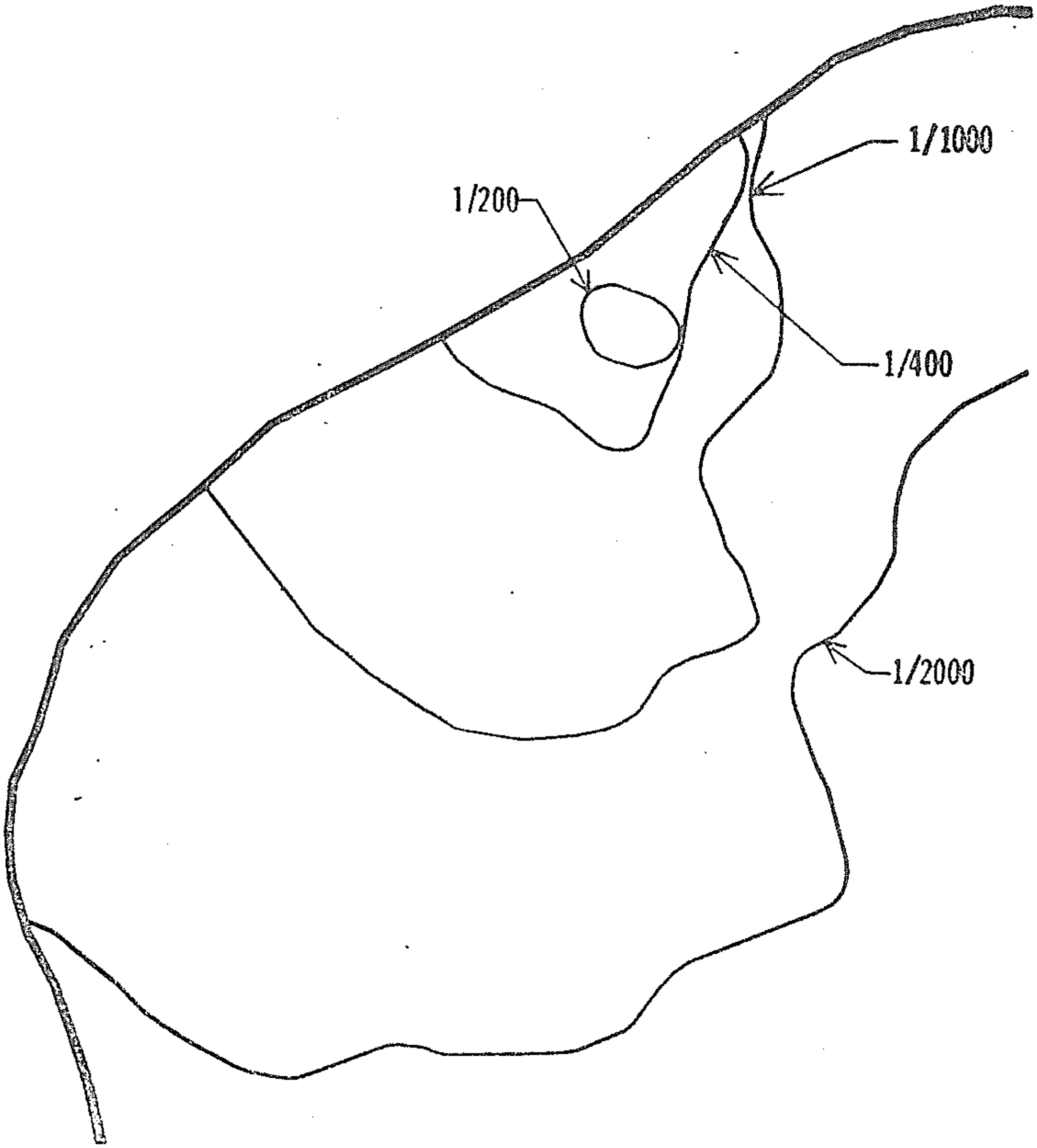


Figure VII-8. Estimated Return Period for Surface Oil Reaching a Point for 30,000-ton Spill.

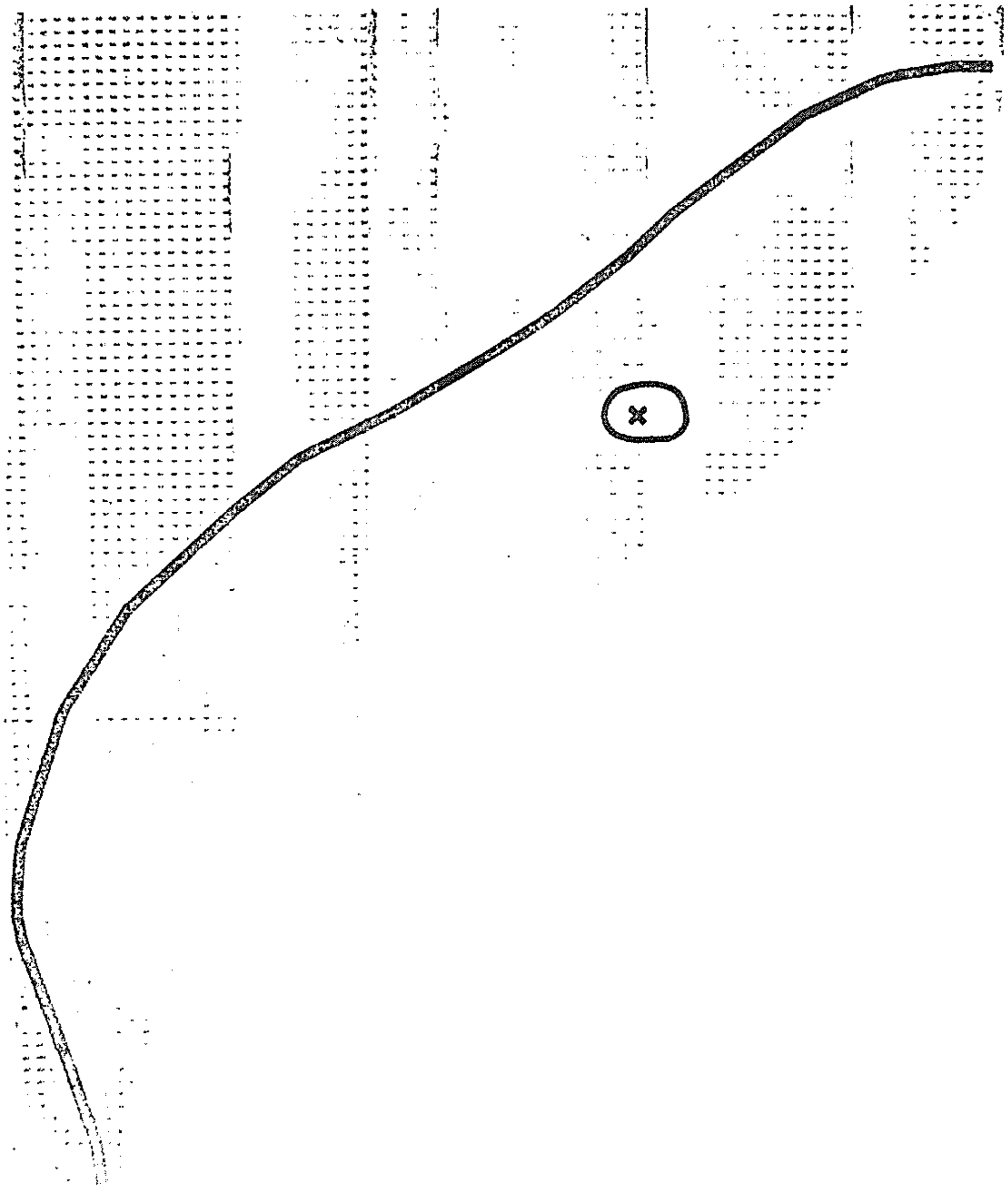


Figure VII-9. Area Influenced by Volatile Fractions in Oil Slicks.

will be transported with the water currents of the area as described in Chapter V. If adequate current data were available a model would have been developed to predict the concentrations and probability of the soluble fractions reaching any point in the grid system. The rate of biological degradation of the soluble fractions is not known and is considered very important in estimating the impact on the environment.

Under certain conditions the oil slick can reach the beach area. Figures VII-10 and VII-11 show the relative probability of oil reaching each 3-mile section of the coast directly from site 1 and site 2, respectively. It can be seen that by moving the port site further offshore the potential impact on the coast is reduced in severity directly inshore from the port site but is spread over a longer length of the coast. Thus, if a section of the coast is relatively undeveloped and unproductive, a port site located near the coast might have less impact then a port site further offshore.

Figures VII-10 and VII-11 show the relative distribution of initial contact points of offshore spills. For example if 100 spills were released at the port site, winds and currents (Chapter V) would result in approximately 60 of these reaching the coastal beaches. The lengths of the bars normal to the beach in Figures VII-10 and VII-11 represent the distribution of these 60 spills. Since the 500-ton spill is not expected to drift very far along the beach after the initial contact, these plots also represent the relative impact of the 500-ton spill on the coastal elements. The probability of the 500-ton spill reaching the estuaries environmental elements is small from either port site. A conservative estimate of the value can be made by adding up the probability of the

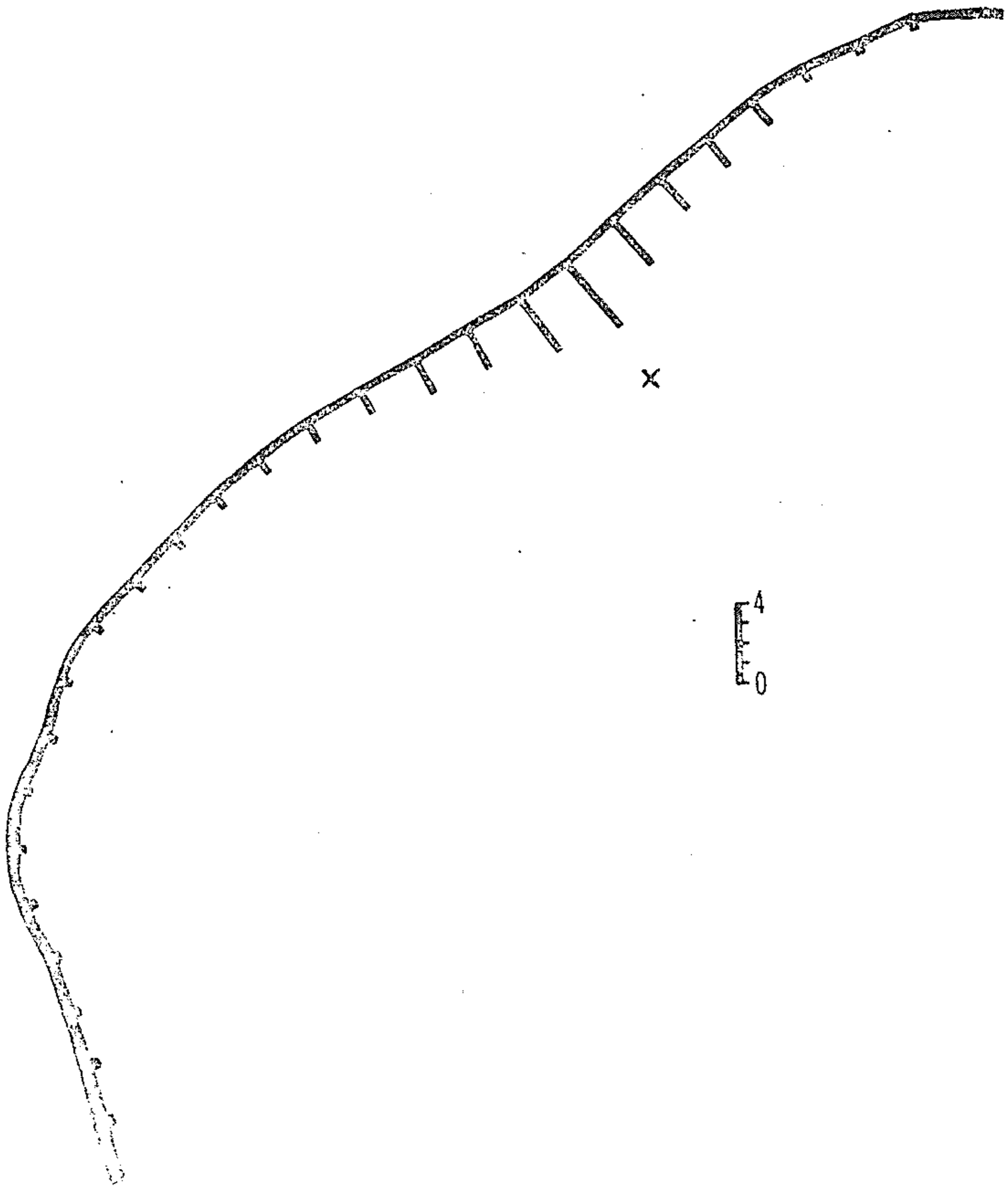


Figure VII-10. Relative Probability for Beach Impact, Port Site 1, 500-ton Spill.

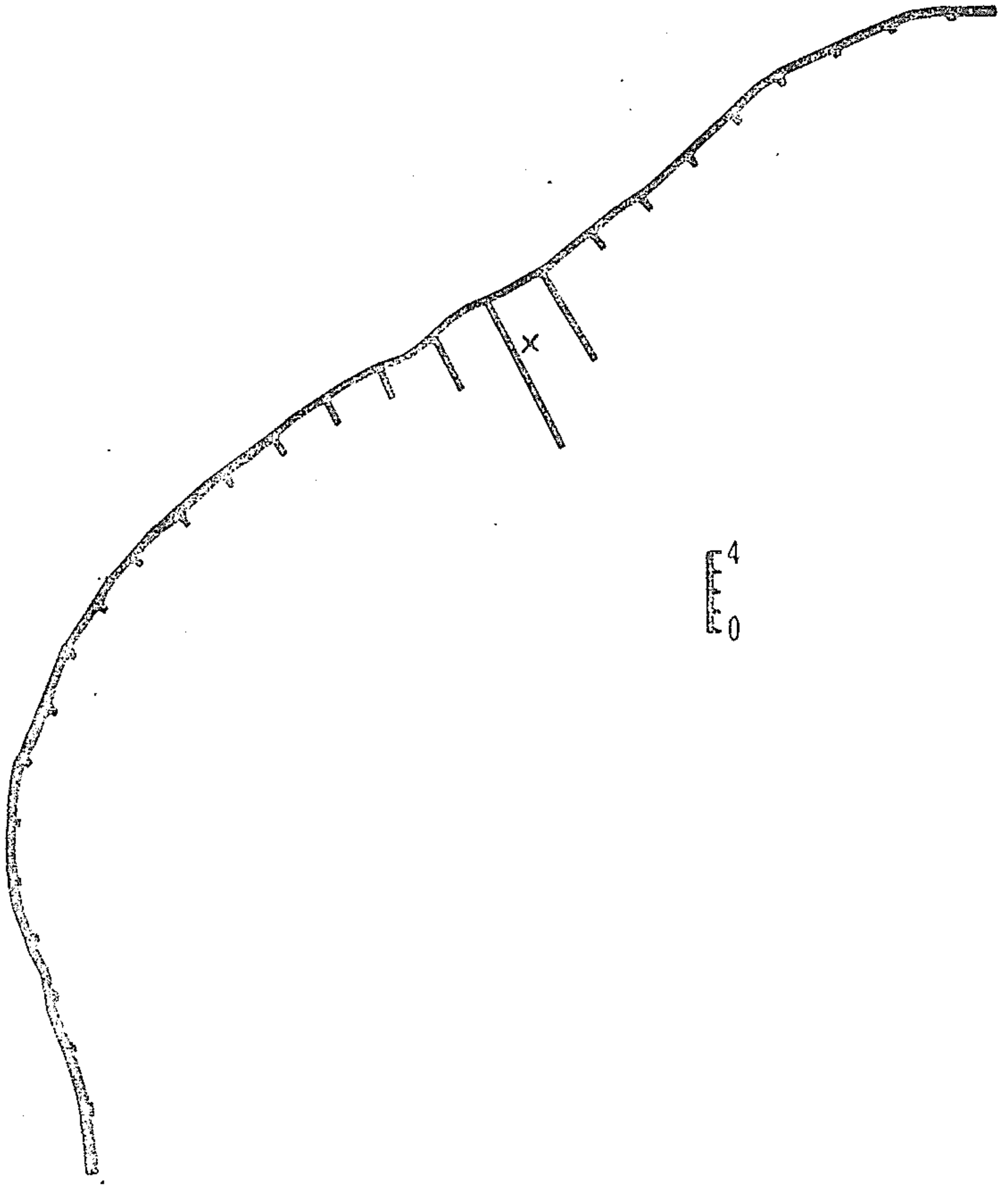


Figure VII-11. Relative Probability for Beach Impact, Port Site 2, 500-ton Spill.

oil reaching each beach section that contains an estuarine entrance. If the oil slick reaches an entrance, the amount of oil entering the estuary would be some function of the width of the entrance in proportion to the total width of the oil slick. Since most of the soluble fractions of the oil will have been lost, the main damage in the estuary will be caused by the oil on the surface. An ebb current in the entrance would reduce the amount of oil passing into the estuary while flood current would increase the oil getting into the estuary. These refinements in the model can be made when more accurate wind and current data are available; however, preliminary calculations indicate that the 500-ton spill will have little effect on the estuarine elements.

As discussed in Chapter V, the 30,000-ton spill is expected to drift along the coast for some distance before being dissipated. If the direction of drift changes every few days as might be expected during the winter and spring of the year, the plot in Figure VII-10 could also be representative of the relative impact for the 30,000-ton spill. However, if the drift is consistently in one direction, then the relative impact for the 30,000-ton spill would increase away from the site as illustrated in Figure VII-12. The basic assumption made in developing the plot in Figure VII-12 was that if the wind carried the oil slick to the right of a normal line from the terminal location to the beach, the beach drift would be to the right or towards Galveston while if the initial contact point of the slick with the beach was to the left of the normal line the beach drift would be to the left or towards Corpus Christi. Longshore currents are important to the study and should be determined to increase accuracy of predicting the movement of the oil along the coast.

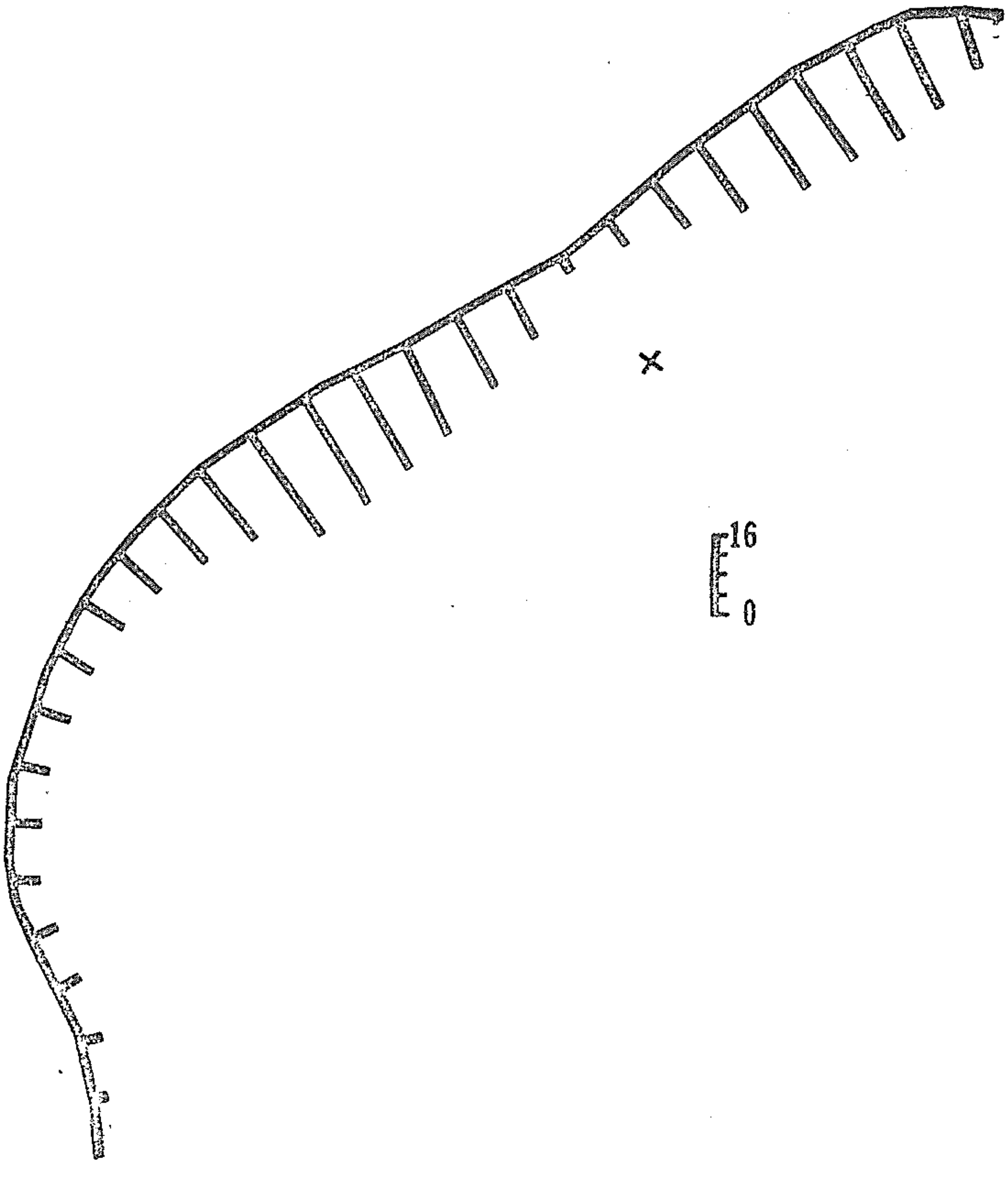


Figure VII-12. Relative Probability of Beach Impact for Constant Longshore Current, Port Site 1, 30,000-ton Spill.

The probability of oil from a 30,000-ton spill reaching the estuarine elements is high unless effective barriers are placed about the tidal inlets or oil spill control procedures are in operation along the beach. Most of the natural tidal inlets along the Texas coast are shallow and earth dams might be constructed to prevent oil from entering the estuarine system. As the oil slick moves along the coast mechanical methods should be developed that will remove the oil from the sea. Physical removal of the oil from the marine environment will have less impact than allowing the oil to drift uncontrolled. Most of the research effort for control of oil spills has been devoted to containment and removal at sea. Additional research is necessary for barriers on the tidal inlets and containment and removal of oil along the beach using sorbent materials to prevent sinking.

Assessment

In order to assess the impact of a potential oil spill on the total environment, the effects of a spill are divided into four general areas. These are 1) effects on bottom deposits and benthic organisms, 2) effects on water quality and aquatic organisms, 3) effects of the surface oil slick on coastal environmental elements and 4) effect of the evaporated fractions on the air quality.

Air Quality: A major oil spill causes a large volume of volatile hydrocarbons to be released into the atmosphere. For a 30,000-ton spill as much as half of the oil could evaporate into the air. A serious air pollution problem is not expected to result since only one of the three major elements necessary to create an air pollution problem is present. The elements necessary for a major problem are 1) pollution sources, 2) poor atmospheric transport and 3) receptors. The meteorological and topographic features of the area will favor the atmospheric mixing and the transport of material away from the source. Receptors or living things upon which effects of air pollution can be exerted are a long distance from the source. Most of the coast is rural and population concentrations occur only in a few locations.

Hydrocarbons are being discharged into the atmosphere of the Texas Coastal Zone at the rate of over a million tons per year from transportation, power generation and industrial processes (A&M Environmental Engineering, 1972). For rough estimating purposes, the annual spill volume of 500-tons and the 20-year spill volume of 30,000 tons could result in an average annual discharge rate into the atmosphere of 1000 tons per year or about 0.1% of the present discharge rate from other sources. This does not mean that the supertanker port will increase the hydrocarbon emissions by 1000 tons per year because the offshore port is expected to result in a reduction in oil spill potential in estuaries near the population centers and cause an increase in oil spill potential near the offshore port site. The offshore site will also provide more time for atmospheric dilution before reaching the receptors on shore. By moving the atmospheric pollution source away from the population centers some positive benefit for air quality in the Texas Coast can be predicted. Whether the reduction in oil spill volumes resulting from a large number of smaller vessels operating in congested estuarine waters will be offset by an increase in offshore spills is not known and will require additional study.

Bottom Sediments and Organisms: Some of the oil that is spilled on the sea surface is expected to enter the water column as soluble compounds and also as suspended particulates. The mixing depths of the soluble fractions of the oil will be a function of the turbulence in the sea but generally will be about 15 meters offshore, decreasing to about 10 meters nearshore. Only in the nearshore waters are the soluble fractions in the water column expected to extend to the bottom.

Most of the soluble oil fractions that enter the water column will do so near the spill site. By the time the water mass which contains these fractions reaches the nearshore waters where the water column mixing zone extends to the bottom, the concentration of the soluble aromatic fractions are expected to be less than 0.1 ppm and should not create a serious toxic effect on the bottom organisms. The bottom area that a single 30,000-ton spill with a 20 year return period is expected to reach is on the order of a few square miles and is very small when compared to the total environment.

The formation of suspended oil and the rate of precipitation of these oil particles from the water column will depend on the sea conditions and turbidity of the water. Under normal sea conditions deposition of oil particles is not expected to occur in any significant amounts. If it does occur it will be limited to areas near the surf zone where suspended silts are present in the water to cause sinking and sufficient turbulence is available to cause the oil and silt to come into contact.

However, by the time the oil slick reaches the nearshore waters (2 to 3 days), most of the volatile fractions are evaporated and the oil that might be deposited on the bottom is relatively nontoxic.

Water Column: Preliminary computations of the concentration of soluble oil fractions indicate that the maximum concentration will be less than 1 ppm. This value is generally below the toxicity level for adult organisms, but could perhaps affect certain larval stages (Moore, 1972). The total overall horizontal area containing some soluble fractions of oil for the largest spill is on the order of 20 square miles. This is not large when compared to the total area of the Texas Gulf Coastal waters.

Of primary concern is the effect that a major oil spill will have on the shrimp. In general, the brown adult shrimp will be on the bottom in water depths greater than 60 ft while the white adult shrimp will be on the bottom in water depths less than 60 ft. As discussed in the previous section an oil spill is not likely to have much effect on these organisms near the bottom. However, there is a two week period after the shrimp are hatched when they are free floating in the water column. During this larval period after they have hatched in the coastal waters and are in the process of drifting into the estuarine waters, they could be affected by toxic soluble oil fractions. The probability of shrimp being in the larval stage during a major spill is low. From Figures VII-6 and VII-7, the main brown and white shrimping areas each cover an area of about 8000 square miles along the Texas Gulf Coast. This area is large when compared to the area of possible impact.

Additional studies are required on the tolerance level of the shrimp larvae to the various oil fractions.

Effect of Continuous, Low-Level Oil Spill (2-3 barrels/day): The continuous low-level oil spillage at either offshore port site is likely to induce minor subtle changes (Mosser, Fisher and Wurster, 1972) in the phytoplankton and zooplankton populations in a localized area around and downstream from the port. However, because of the depth and the dilution factor neither the benthic fauna nor the larger free-swimming organisms should be significantly affected. Such spillage levels have in the past been fairly common in association with offshore drilling operations, and no noticeable effects have been reported. The effect on shoreline and coastal lagoons should be negligible since the film reaching the shallows will be thin and widely dispersed. Oil from the continuous spill is not expected to reach the shore. Biological decomposition alone should handle this level of injection.

Effect of 500-ton Spill: The 500-ton spill at either port site should spread laterally and shoreward about 60 percent of the time. The soluble fractions will probably severely damage the plankton below the slick and above the pycnocline (10-30 m in summer and 10-20 m in winter). It is assumed that little of the soluble material will penetrate the pycnocline. No permanent plankton damage should result, however, and the plankton populations should be replenished when the area is completely flushed (within a month). Some of the dead plankton would sink through the pycnocline to the bottom where it would be ingested by the benthic fishes and invertebrates which could tend to concentrate the hydrocarbons up the benthic food chains. This effect should become more pronounced shoreward as the water became shallower. Additional studies are required to determine the importance of this transport mechanism. Damage to the benthic fauna would depend upon the nature and quantities of material carried to the bottom and the sensitivity of individual species. None of the intermediate zone species is known to be endemic, however, and any minor damage incurred by the benthic fauna of the intermediate zone should be healed within a few months.

In waters shallower than 20-30 meters the benthic fauna could be affected directly by the soluble fractions as well as through ingestion of dead plankton and minute oil globules which may find their way to the bottom. Very sensitive benthic organisms could be affected from this point to the shore, and the shallower the water the greater the number of species which could be affected.

From a meter or so below the low tide mark to about a meter above the high tide mark organisms would encounter both the dilute soluble fractions and the surface-floating fractions, and mortality of intertidal, surf, beach, and jetty fauna would be high. For the 500-ton spill, the bank of mortality could extend as much as 5 miles along the coast. Repopulation of this zone would certainly occur but might require a year or more.

If the spill entered an estuary or lagoon the effects could be magnified due to the great expanse of shallow water and intertidal zones affected, as well as the exposure of great numbers of sensitive larval and juvenile organisms.

Effects on the fishes would depend to a great degree upon the biology of individual species. Large, fast-swimming species (mackerels, bonitas, jackfish, etc.) would probably leave the area before they were severely damaged. Slower swimming species would be most affected; this group includes most of the species found on the inner shelf and in the lagoonal areas. Recovery would probably take several years, particularly if the oil should enter estuaries and lagoons.

In summary, although no permanent damage is likely to result from a 500-ton spill, recovery would probably take from one month to several years depending upon 1) the group of organisms under consideration, 2) whether or not the oil hit the shore, and 3) whether or not it entered a coastal lagoon in quantity. Fauna of the inner shelf, beach zone and coastal lagoon would be most severely affected. Little is known about genetic exchange between lagoonal populations, and although no species would be eliminated, local populations could be exterminated.

Effect of a 30,000-Ton Spill: Effects of a 30,000-ton spill should generally be similar to but far more widespread and intense than those of a 500-ton spill. Oil from the 30,000-ton spill is more likely to enter the estuary than oil from the 500-ton spill. While many of the toxic fractions will have evaporated some are expected to remain and dissolve slowly into the water column. With low flushing rates, the lagoons of central and south Texas would be particularly vulnerable, and these are the areas most likely to be hit hardest. Short-term mortality would result from the direct effects of surface and soluble fractions as well as from ingestion of the materials. Long-term effects would result from substrate modification, reduction of food supplies, and masking of subtle estuarine chemical odors employed by migrating species which normally reside seasonally in the estuarine waters. Elimination of local genetic races appears probable and repopulation, even through artificial restocking efforts, would probably require several years.

In the above discussions little distinction has been made between the two designated offshore port sites, since a major spill at either site is likely to reach the coast within about two days. It appears that the greatest ecological damage anticipated from a major spill will occur in the shallow water and shore areas of the shelf, as well as in the estuaries and lagoons.

Surface Oil: The oil film on the water surface is not expected to affect the life in the water column. The rate of oxygen transfer into the water column will be reduced but in the ocean the dissolved oxygen is at or near saturation and the oil film is not expected to remain over the same water mass long enough to cause the dissolved oxygen level to become critical. The surface oil will have an adverse impact on the coastal features. The effects of the low level continuous spill are not expected to reach the shoreline and the 500-ton spill should have only minor impact on the coastal elements. The probability of any oil entering an estuary from the 500-ton spill is small. Most of the 500-ton spill will be absorbed by the offshore beaches.

Significant quantities of oil from the potential 30,000-ton spill are expected to enter the estuaries if oil spill control procedures are not in operation along the coast. Primary impact will be on the marsh areas and wildlife; however less than one square mile of marsh could absorb all the oil that is expected to enter the estuaries and the impact on the marsh should be only short term. The impact of the oil on the marsh area while longer in duration, is comparable to the accepted practice of burning the marsh areas to improve grazing.

Wildlife in the Beach Zones: In the event of a major oil spill, the beach zone would probably receive a large accumulation of oil. This oil could cause the destruction of plants and invertebrates, but would ordinarily have little impact on the other wildlife found there. Because few animals live on the beach and because most species of wildlife found there are highly mobile, they can probably avoid serious contamination by oil pollution. Some shorebirds, gulls, terns and other marine birds may become oil fouled, and some may die. However, most birds, mammals, and reptiles will avoid the oiled beaches and utilize unpolluted areas.

Wildlife on the Barrier Islands and Uplands: Oil spills will affect the wildlife of the barrier islands and the uplands in different ways. Due to their geographic location, the upland wildlife will be only slightly affected by any oil spills. Upland wildlife can avoid oil contamination by fleeing inland or migrating to other coastal uplands which are not oil fouled. These animals may suffer adverse affects from possible overcrowding, starvation and predation, but would suffer little from actual physical contamination by the oil.

Wildlife in the Estuaries and Coastal Marshes: Even though the possibility of oil reaching the estuaries and coastal marshes is low, the effects of the oil on these areas could be severe. During the winter months (October - March) when the migratory bird population is at its highest, oil in these areas could be disasterous. Because aquatic birds are very vulnerable to the effects of oil contamination, they could face starvation or forced migration if they did not die from direct contact with the oil itself. In addition, any mammals and reptiles would be forced to leave the contaminated areas, while other species, which were unable to flee, would face possible starvation and death. Furthermore, those animals which did migrate to other areas could cause overpopulation of these areas, resulting in conflict, competition, and a generally deleterious situation.

Fortunately many of the densely populated waterfowl areas will not be directly exposed to oil. Aransas Wildlife Refuge (Figure II-12) is the home of the whooping crane (Figure II-14) and is fairly well protected from an oil spill (Figure II-4). The refuge is located behind a barrier island and 25 miles from the nearest opening to the Gulf (Cavallo Pass). The major blue and snow geese wintering area is located inland from the coast near Freeport, whereas the main redhead and pintail duck wintering area is south of Corpus Christi (Figure II-14).

Waterfowl, because of their mobility, can avoid the oil. However, their mobility also increases the risk of potential contact with the oil. Not only will the waterfowl that are in the immediate area of the oil slick be affected but also those in the surrounding areas can be affected. As long as the oil slick is floating in the marsh area, it is a potential hazard to the birds within flight distance. It is necessary that the oil be cleaned up as soon as possible after an oil spill to minimize the risk to the waterfowl. Effective methods should be developed that will prevent waterfowl from flying into the area while oil spill clean up operations are in progress.

Hurricane: The surface oil slick will impact the beach and upland areas. During hurricanes which occur somewhere along the Texas coast about once every two years, the oil spill impact could extend to the hurricane high water which is about 12 ft elevation. During a hurricane most of the upland wildlife will move from the impacted area, and the overall damage of the oil on the remaining elements will be significant for only the 30,000-ton spill but even this will be minor when compared to the hurricane damage.

Summary of Oil Impact

The construction of a supertanker port off the Texas coast will increase the potential for oil spill to occur in the vicinity of the port site. At the same time, the offshore port facility should reduce the potential for oil spills to occur within the estuary. If the transport of oil from the port facility to the interior points of demand is by pipeline and not smaller vessels, the probability of oil damage to the estuarine systems will be decreased.

The estuaries have been described as being biologically the most productive areas of the marine environment. As shown in Figure VII-13, the biological productivity of the marine environment is lowest in the open ocean, increases towards the coast and reaches a maximum in the estuaries. Minimum impact from an oil spill will generally result if the spill occurs in the area of minimum productivity. The toxicity of an offshore oil spill will decrease as it approaches the higher productivity zones of the coast.

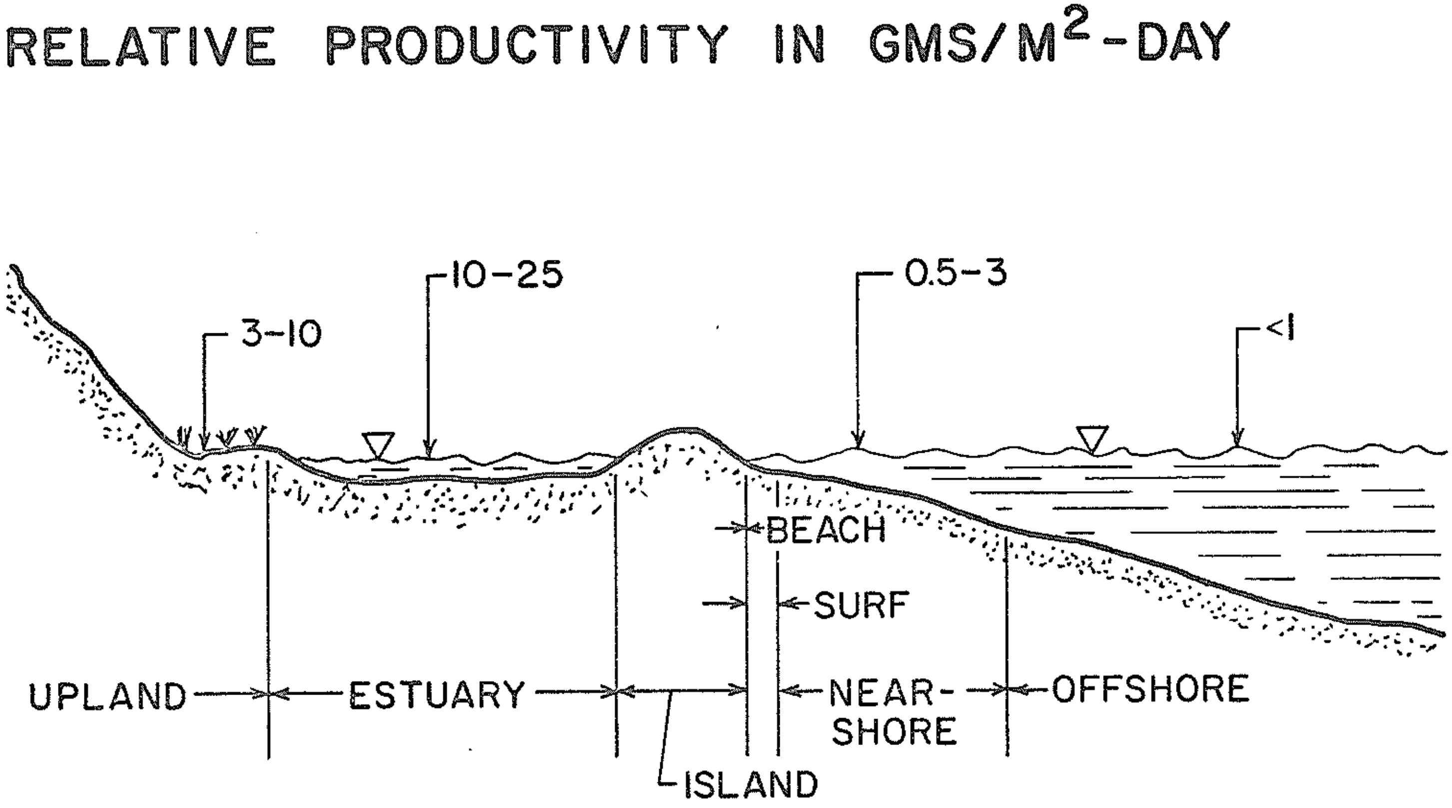


Figure VII-13. Relative Productivity of Marine Environment

If an oil spill does occur in an enclosed bay, the more toxic, soluble fractions will be at a higher concentration in the water column. Since there is less dilution water available under the oil film to reduce the concentrations of the volatile fractions in the water column, the resulting concentrations will be roughly 5 times higher in the estuary than if the same spill occurred offshore. In addition the bay will tend to increase the contact time with the organisms. Thus, an oil spill offshore will have less impact on the marine biota than an oil spill within the estuary for three reasons. First, there will be fewer marine organisms affected; second, the concentrations of toxic compounds within the water column will be lower; and, third, the contact time with the marine life will generally be less for an offshore spill.

Figure VII-14 shows the six major divisions of the marine environment which might be affected by a major oil spill. The environmental elements of the offshore region will be primarily affected by soluble oil fractions in the water column down to the thermocline but not generally affecting the bottom organisms. The concentrations of soluble oil fractions are expected to be less than the concentrations that have been shown to have an effect on adult organisms but they still might have an impact on the larval stages. The overall extent of offshore area affected by even a 30,000-ton spill is small when compared to the total Gulf area (See Figure VII-15).

Soluble oil fractions in the water column are expected to extend to the bottom in the nearshore zone. In the turbid surf zone some sinking of oil is expected to occur. While the oil is relatively nontoxic by the time it reaches the coastal elements, oil that sinks can perhaps smother some bottom organisms. Oil that does reach the coastal

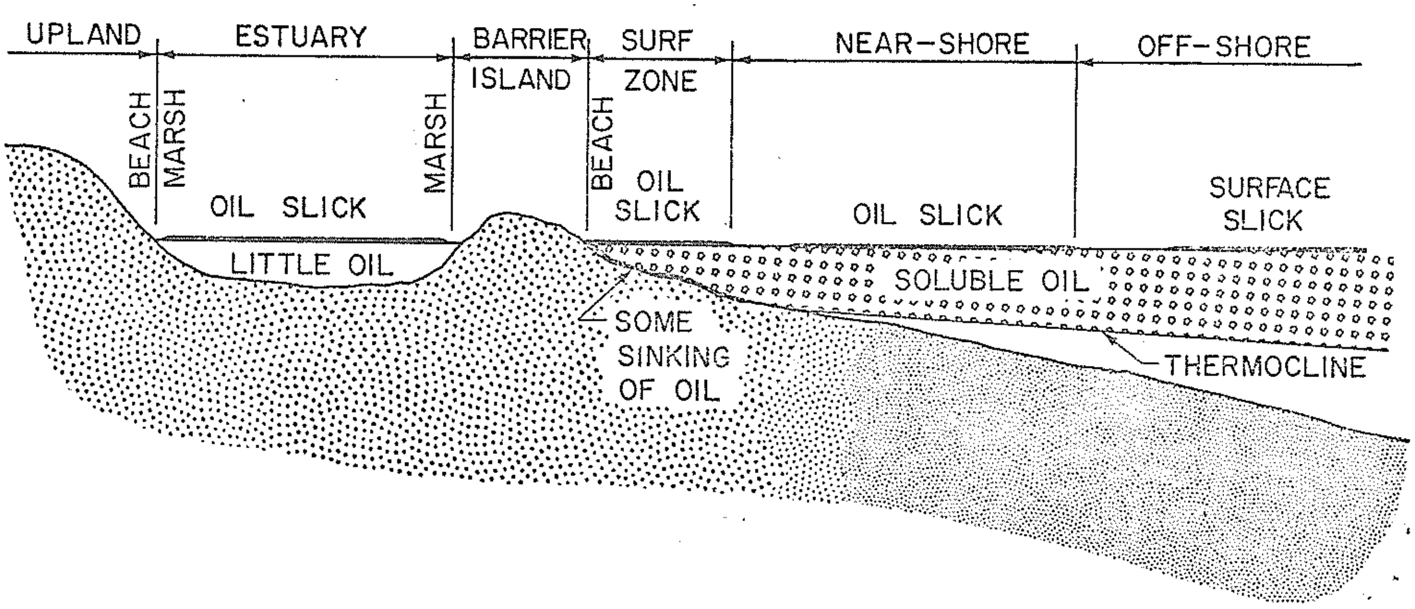


Figure VII-14. Potential Impact of an Oil Spill on the Marine Environment.

areas will have a primary impact on the marsh areas, beaches and waterfowl. Texas is fortunate to have barrier islands along much of its shoreline. These islands with relatively few tidal inlets will prevent much of the oil from entering the estuarine systems. The waterfowl will generally be protected from the oil spill by the barrier islands. If the oil spill does occur during a hurricane wildlife in the low coastal areas are expected to move to high ground before they are affected by oil from the spill.

Associated with the offshore port is the risk of a major oil spill and over a period of time this spill could occur. Once the spill occurs the oil is no longer considered a valuable resource but is an undesirable and potentially hazardous material. Efforts must be devoted towards minimizing the impact of this material on the environment. Control by containment at sea and physical removal of the oil at sea or along the beach would have the least impact on the area. In the event of a major spill, public concern over the potential impact will not permit man to ignore the situation, but will demand that actions be taken to control it.

The ocean has a capacity to utilize certain waste materials including oil. Ocean outfalls have been an accepted method of waste disposal for dissolved biodegradable materials. This reasoning has not been an accepted solution for toxic or slowly degradable materials. Letting the oil drift uncontrolled, eventually to be spread over a large enough area so that the effects on the environment are no longer measurable does not appear to be a good solution. The total damage to the environment when summed over this large area might very well be

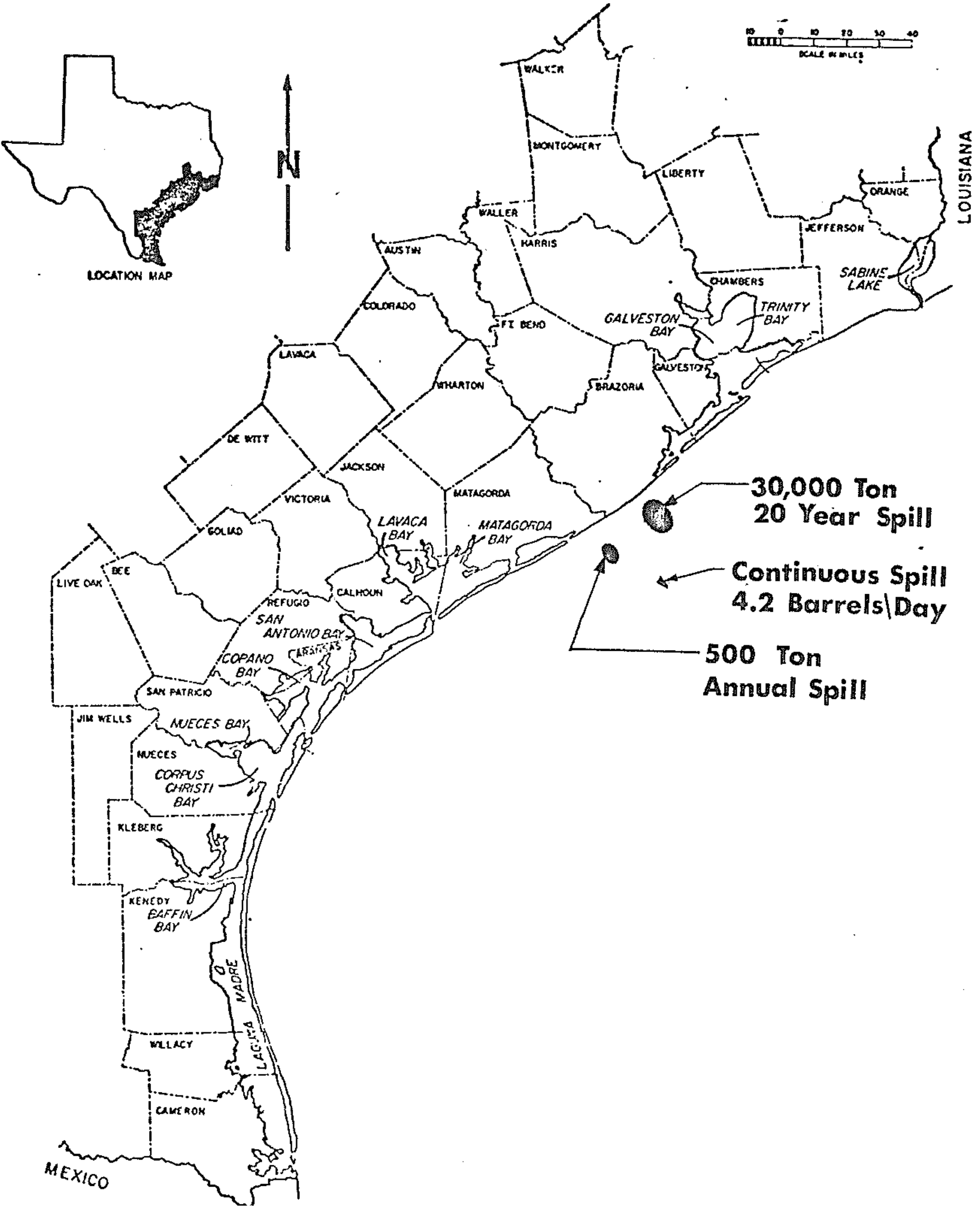


Figure VII-15. Relative Size of the Three Oil Spills.

much larger than if the impact is confined to a small coastal area.

It appears that prevailing winds and currents on the Texas coast will generally (about 60% of the time) bring a major oil spill to the coast where the oil spill will have a better chance of being controlled. The Gulf beach will act as a barrier which will aid in the removal of the oil from the sea. Floating sorbent material added to the oil slick will be required to prevent sinking in the turbid coastal waters and will aid in oil pick up along the beach. Barriers about the tidal inlets may be required to prevent oil from a large spill from entering the estuaries. The most successful way to handle an oil spill and to minimize the impact on the marine environment is to physically remove the oil from the water as quickly as possible.

Tables VII-1 and VII-2 summarize the relative impact of a supertanker port off the Texas coast with and without oil spill control procedures, respectively. While the relative impact is expressed with a number system, it is subjective. Comparing the offshore site (1) in either table with the nearshore site (2), shows that the offshore site (1) is environmentally more desirable.

Looking at the list of environmental elements in Table VII-1, those elements most seriously affected by a major oil spill without control would be the beaches, waterfowl, and food chains. Generally the beaches affected will not be those of high recreational use. Comparing Table VII-1 with VII-2, oil spill control procedures could be effective in reducing the impact on the waterfowl and nearshore sediments. However, oil spill control procedures will have little effect in limiting the impact of the soluble fractions in the water column.

The value of a matrix such as those shown in Tables VII-1 and VII-w is limited to summarizing the results and is no better than the manner in which the data were developed. In this report the methodology was developed (though not completed) for a systematic evaluation of the impact as listed below

$$\sum_{\text{Environment}}^{\text{Total}} \quad \sum^{\text{Activity}} \quad \sum_{\text{Environmental}}^{\text{Element}} P_1 \cdot P_2 \cdot P_3 \cdot \Delta \text{ ELEMENT}$$

Where P_1 is the probability that an environmentally hazardous event will occur (a function of the activity), P_2 is the probability that if this event does occur, it will reach the particular Δ environmental element under consideration (a function of the winds and currents in the offshore area and the shore topography and water depths in the coastal area) and P_3 is the probability of damage to the element if the impact does occur (a function of the element, concentration and contact time). Using this approach of looking at the total area, the impact can be placed in a better perspective. In most cases the product of the three probabilities will be very small indicating the occurrance will be unlikely to happen.

Table VII-1. Environmental Impact Matrix Without Oil Spill Controls

TEXAS
SUPERTANKER PORT STUDY
ENVIRONMENTAL IMPACT MATRIX[a]
(Without oil spill control procedures)

				ACTIVITY																			
				SITE 1								SITE 2											
				Construction		Maintainance	Operation		Oil Spills			Construction					Maintainance		Operation		Oil Spills		
				Platform	Pipeline	Pipeline	Structure	Ship Movement	Continuous	500-ton	30,000-ton	Channel & Basin	Jetty	Platform	Island	Pipeline	Dredging	Pipeline	Structure	Ship Movement	Continuous	500-ton	30,000-ton
IMPACTED	Physical Areas		1. Offshore Waters	0	1	0	0	0	1	2	3	2	0	0	0	1	2	0	0	0	1	2	3
			2. Offshore Sediments	0	1	0	0	0	0	0	1	3	0	0	1	1	3	0	0	0	0	0	1
			3. Offshore Artical Island	X	X	X	X	X	X	X	X	0	0	X	X	0	0	0	0	0	1	1	1
			4. Nearshore Waters	0	1	0	0	0	0	1	2	0	0	0	0	1	0	0	0	0	0	1	2
			5. Nearshore Sediments	0	1	0	0	0	0	1	3	0	0	0	0	1	0	0	0	0	0	1	3
			6. Beaches	0	0	0	0	0	0	1	4	0	0	0	0	0	0	0	0	0	0	1	4
			7. Barrier Island	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
			8. Coastal Wetlands	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	1	3
			9. Bays and Estuarine Water	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	1	2
			10. Bays and Estuaries Sediments	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	1	3
ELEMENTS	Biological Features	Plants	11. Phytoplankton	0	1	0	0	0	1	1	3	2	0	0	1	1	2	0	0	0	1	1	3
			12. Marsh and Grass	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	1	3
			13. Other																				
		Animals	14. Oysters	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
			15. Shrimp	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	1	2
			16. Crab	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	1	2
			17. Zooplankton	0	1	0	0	0	1	1	3	2	0	0	0	1	2	0	0	0	1	1	3
			18. Fish	0	0	0	0	0	1	1	2	1	0	0	0	0	1	0	0	0	1	1	2
			19. Reptiles	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	1	2
			20. Mammals	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
			21. Birds, Shore	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
			22. Birds, Waterfowl	0	0	0	0	0	0	1	5	0	0	0	0	0	0	0	0	0	0	1	5
		Other	23. Communities	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	2
			24. Food Chains	0	0	0	0	0	1	1	4	0	0	0	0	0	0	0	0	0	1	1	4
ENVIRONMENTAL	Cultural Factors	Land Use	25. Barren	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			26. Grazing	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
			27. Wildlife Refuges	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	1
			28. Parks	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	1	2
			29. Resort	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	1	2
			30. Residential and Commercial	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	1	2
		Aesthetics	31. Scenic Views	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	1	2
			32. Unique Physical Features	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			33. Historical or Archaeological Sites	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Activities	34. Thermal, Cooling	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
			35. Mining	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			36. Ship Transportation	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
			37. Recreation, Beach swimming	0	0	0	0	0	0	2	3	0	0	0	0	0	0	0	0	0	0	2	3
			38. Recreation, Fishing	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	1	2
			39. Recreation, Duck Hunting	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
			40. Commercial Fishing	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	1	2

[a] Based on a relative scale of 1 to 5.

X Indicates no impact possible.

Table VII-2. Environmental Impact Matrix With Oil Spill Controls

TEXAS
SUPERTANKER PORT STUDY
ENVIRONMENTAL IMPACT MATRIX [a]

(With Oil Spill Control
Procedures.)

				ACTIVITY																											
				SITE 1												SITE 2															
				Construction	Platform	Pipeline	Maintainance	Pipeline	Operation	Structure	Ship Movement	Oil Spills	Continuous	500-ton	30,000-ton	Construction	Channel & Basin	Jetty	Platform	Island	Pipeline	Maintainance	Dredging	Pipeline	Operation	Structure	Ship Movement	Oil Spills	Continuous	500-ton	30,000-ton
IMPACTED	Physical Areas		1. Offshore Waters		0	1		0		0	0		1	2	3		2	0	0	0	1		2	0		0	0		1	2	3
			2. Offshore Sediments		0	1		0		0	0		0	0	1		3	0	0	1	1		3	0		0	0		0	0	1
			3. Offshore Artical Island		X	X		X		X	X		X	X	X		0	0	X	X	0		0	0		0	0		1	1	1
			4. Nearshore Waters		0	1		0		0	0		0	1	2		0	0	0	0	1		0	0		0	0		0	1	2
			5. Nearshore Sediments		0	1		0		0	0		0	1	2		0	0	0	0	1		0	0		0	0		0	1	2
			6. Beaches		0	0		0		0	0		0	1	2		0	0	0	0	0		0	0		0	0		0	1	2
			7. Barrier Island		0	0		0		0	0		0	0	0		1	0	0	0	0		0	0		0	0		0	0	0
			8. Coastal Wetlands		0	0		0		0	0		0	0	1		0	0	0	0	0		0	0		0	0		0	0	2
			9. Bays and Estuarine Water		0	0		0		0	0		0	0	0		0	0	0	0	0		0	0		0	0		0	0	2
			10. Bays and Estuaries Sediments		0	0		0		0	0		0	0	1		0	0	0	0	0		0	0		0	0		0	0	2
ELEMENTS	Biological Features	Plants	11. Phytoplankton		0	1		0		0	0		1	1	2		2	0	0	1	1		2	0		0	0		1	1	2
			12. Marsh and Grass		0	0		0		0	0		0	0	1		0	0	0	0	0		0	0		0	0		0	0	2
			13. Other																												
		Animals	14. Oysters		0	0		0		0	0		0	0	0		0	0	0	0	0		0	0		0	0		0	0	0
			15. Shrimp		0	0		0		0	0		0	0	1		0	0	0	0	0		0	0		0	0		0	0	1
			16. Crab		0	0		0		0	0		0	0	1		0	0	0	0	0		0	0		0	0		0	0	1
			17. Zooplankton		0	1		0		0	0		1	1	2		2	0	0	0	1		2	0		0	0		1	1	2
			18. Fish		0	0		0		0	0		1	1	2		1	0	0	0	0		1	0		0	0		1	1	2
			19. Reptiles		0	0		0		0	0		0	0	1		0	0	0	0	0		0	0		0	0		0	0	1
			20. Mammals		0	0		0		0	0		0	0	0		0	0	0	0	0		0	0		0	0		0	0	0
			21. Birds, Shore		0	0		0		0	0		0	0	1		0	0	0	0	0		0	0		0	0		0	0	1
			22. Birds, Waterfowl		0	0		0		0	0		0	1	2		0	0	0	0	0		0	0		0	0		0	1	2
		Other	23. Communities		0	0		0		0	0		0	0	2		0	0	0	0	0		0	0		0	0		0	0	2
			24. Food Chains		0	0		0		0	0		1	1	4		0	0	0	0	0		0	0		0	0		1	1	4
ENVIRONMENTAL	Cultural Factors	Land Use	25. Barren		0	0		0		0	0		0	0	0		0	0	0	0	0		0	0		0	0		0	0	0
			26. Grazing		0	0		0		0	0		0	0	0		0	0	0	0	0		0	0		0	0		0	0	0
			27. Wildlife Refuges		0	0		0		0	0		0	0	1		0	0	0	0	0		0	0		0	0		0	0	1
			28. Parks		0	0		0		0	0		0	0	1		0	0	0	0	0		0	0		0	0		0	0	1
			29. Resort		0	0		0		0	0		0	1	2		0	0	0	0	0		0	0		0	0		0	1	2
		Aesthetics	30. Residential and Commercial		0	0		0		0	0		0	1	2		0	0	0	0	0		0	0		0	0		0	1	2
			31. Scenic Views		0	0		0		0	0		0	1	2		0	0	0	0	0		0	0		0	0		0	1	2
			32. Unique Physical Features		0	0		0		0	0		0	0	0		0	0	0	0	0		0	0		0	0		0	0	0
			33. Historical or Archaeological Sites		0	0		0		0	0		0	0	0		0	0	0	0	0		0	0		0	0		0	0	0
		Activities	34. Thermal, Cooling		0	0		0		0	0		0	0	1		0	0	0	0	0		0	0		0	0		0	0	1
			35. Mining		0	0		0		0	0		0	0	0		0	0	0	0	0		0	0		0	0		0	0	0
			36. Ship Transportation		0	0		0		0	0		0	0	1		0	0	0	0	0		0	0		0	0		0	0	1
			37. Recreation, Beach swimming		0	0		0		0	0		0	1	2		0	0	0	0	0		0	0		0	0		0	1	2
			38. Recreation, Fishing		0	0		0		0	0		0	1	2		0	0	0	0	0		0	0		0	0		0	1	2
			39. Recreation, Duck hunting		0	0		0		0	0		0	0	1		0	0	0	0	0		0	0		0	0		0	0	1
			40. Commercial Fishing		0	0		0		0	0		0	1	2		0	0	0	0	0		0	0		0	0		0	1	2

a] Based on a relative scale 1 to 5.
X Indicates no impact possible.

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CHAPTER VIII

CONCLUSIONS AND RECOMMENDATIONS

This study has been conducted for the Council on Environmental Quality through the Texas A&M University Sea Grant College Program, part of the National Oceanic and Atmospheric Administration. Two port sites, port facilities, three classes of oil spills (continuous 2-4 barrels per day; 500-ton, annual spill and 30,000-ton, 20-year spill) and the types of oil (African and Middle East crude) were given to the study team by the Council on Environmental Quality. The study was limited to existing data which were found to be lacking in many areas.

An interdisciplinary study team consisting of nine members was formed from various divisions of the University. The following conclusions and recommendations were developed by the team. It should be pointed out however, that the team does not unanimously support all the conclusions and recommendations.

1. _Texas is fortunate in having barrier islands along much of the coast. These islands will tend to protect the bays and estuaries from the effects of a potential offshore oil spill._

Barrier islands extend along approximately 300 miles of the 370 mile-mile Texas Gulf coast. The small tidal action on the coast has resulted in a few small tidal poenings through the islands. The largest inlets are the entrances to Matagorda Bay and San Luis Pass (see Figure II-2 through II-9); this is the most critical section of the coast. Studies will be required to develop oil spill control barriers to be utilized in the event of a spill near the tidal inlets. Earthen dikes may be feasible across many of the smaller inlets.

2. Winds and sea conditions in the western Gulf are such that oil spill containment and control are feasible much of the time.

Approximately 40 percent of the time the waves in the Gulf are less than 2 feet high and 80% of the time they are less than 5 feet. Present technology in oil spill control procedures is limited to the control of about 500 tons of oil in sea conditions of less than 5 feet.

It appears that the winds will drift a potential offshore oil spill towards the coast approximately 60 percent of the time. The beach will act as a barrier and will allow the control of the 30,000-ton spill if adequate contingency plans exist. Oil spill control procedures can be established along the coast and the oil can be physically removed from the marine environment. It is felt that the short term impact on a relatively small area of coastal zone is preferred to the long term, widespread impact of allowing the oil to drift uncontrolled at sea.

The ocean has a capacity to utilize certain waste materials including oil. Ocean outfalls have been an accepted method of waste disposal for dissolved biodegradable materials. This reasoning has not been an accepted solution for toxic or slowly degradable materials. Letting the oil drift uncontrolled, eventually to be spread over a large enough area so that the effects on the environment are no longer measurable does not appear to be a good solution. If uncontrolled, the total damage to the environment when summed over this large area might very well be much larger than if the impact is confined to a small coastal area.

3. <u>The offshore supertanker port should reduce the potential for oil spills to occur within the estuaries</u>.

The construction of a supertanker port off the Texas coast will undoubtedly increase the potential for oil spills to occur in the area near the site; however, it should substantially decrease the danger of an oil spill in the estuaries. The estuaries have been described as being biologically the most productive areas of the marine environment. This is particularly true in Texas. Thus, by shifting the potential impact from the estuary to the coastal beach areas or offshore, the supertanker port facility might reduce the potential damage to the total coastal environment. Because of barrier islands, an offshore oil spill most likely will create short term problems on beaches, which appear to be preferable to long term effects that might occur if the oil spill occurs in the bays or estuaries.

The biological productivity of the marine environment is lowest in the open ocean, increases towards the coast and reaches a maximum in the estuaries. The toxicity of an offshore oil spill decreases as it approaches the coast. If an oil spill is to occur, it will have less impact if it occurs offshore and approaches the coast rather than occurring in highly productive areas.

An oil spill inside the estuaries would result in higher concentrations of the more toxic fractions of oil in the water column than a similar spill offshore. In the shallow bays there will be less water available for dilution. In addition, the slow flushing characteristics of the estuarine systems will result in a longer contact time with the marine organisms.

4. Oil spill containment and control procedures must be a planned and integral part of the port activity.

The impact of the supertanker port on the environment should be maintained within acceptable limits if adequate safeguards are provided. These include operating procedures to minimize oil spill potential, failsafe oil transfer hardware, containment devices around the vessels at port, emergency plans and equipment for oil spill containment and removal at sea, equipment and materials for removal and disposal of oil along and on the beach, and development of barriers about the tidal inlets. Plans are required for disposal of cleanup oil,and disposal sites should be designated. While these systems are not 100 percent effective, under most conditions they can reduce the potential impact. Improvements are expected in the future for these devices and additional research is necessary. A plan to close the Texas inlets to keep oil out of the estuarine systems is a plausible idea and its feasibility should be investigated.

5. The impact on the environment of construction for the offshore site (Site 1) will be minimal.

The offshore port facility was assumed to be a 5-nested single point mooring system with a central platform. The environmental effects of the construction of the central platform supported by legs or piles would be temporary and unimportant. The floating moorings points and their lines will have essentially no effect on the environment. The dredging and backfilling operations for the pipeline will cause a temporary disturbance of a small region (less than one-half mile) of the pipeline construction. This small area affected only temporarily by turbidity when compared to the natural turbidity in the nearshore waters appears insignificant.

6. The impact of construction for the offshore port site (Site 1) will be less than the impact of the nearshore site (Site 2).

The nearshore port facility was assumed to be located in 60 feet of water and would require a dredged channel to a 90 feet depth, 1000 feet wide and thirteen miles long. The necessary dredging associated with the approach channel and dredged dock area will have the most significant ecological impact for this site. The effects of initial construction would be temporary but maintenance will be necessary. The sediment transport at these depths is not known, therefore, the amount of maintenance dredging cannot accurately be estimated.

Two alternate types of port facilities were proposed for the nearshore site - the platform with essentially no environmental impact of construction and a 200-acre island. Associated with both alternatives is a 6000-ft breakwater. The site is still far enough offshore so that the port facility and breakwater will not affect the longshore current and sediment transport. The breakwater and island would provide some protection for control of minor oil spillage at the port site. However, the nearshore site (Site 2) is not as environmentally feasible as the offshore site (Site 1).

7. The locations selected for this study seem to be well chosen from an environmental standpoint.

There are no major estuary entrances directly inshore from the site. The closest major inlet is San Luis Pass (West Bay), 25 miles to the northeast, and the major inlet to the southwest is Covallo Pass (Matagorda Bay), 50 miles away. Winds and currents will probably carry the oil that is not contained at sea to beaches that are relatively unused for recreation compared to those along other sections of the coastal zone.

8. The continuous, low-level operational oil spill will have minimal impact on the marine environment.

The low-level continuous spill, if it materializes, will only affect the area in the immediate vicinity of the port site and is not expected to reach the shore. The soluble fractions from the thin film will have adequate dilution water to prevent damage to the organisms in the water column. Spillage at this level was common in association with past offshore drilling operations and no noticeable effect has yet been reported or is expected. On initial assessment biological decomposition should be able to handle this level of oil injection.

9. <u>There is no reason that the spill volumes used in this study should be attained</u>.

Adequate design of ships and port facilities, use of fail-safe devices, development of operating procedures to avoid spills, and use of the navigational safety equipment available, will probably prevent the occurrence of spills of the volumes used in this study.

10. <u>The annual 500-ton spill is not expected to affect the estuaries, and oil spill control procedures could be expected to be effective most of the time</u>.

Winds and currents are expected to drive the oil towards the coast approximately 60 percent of the time. Present control and containment technology can be effective in containing much of the spill volume at sea about 80 percent of the time in the relatively calm Gulf waters. The oil that reaches the shore approximately 2 to 3 days later will be relatively non-toxic. Concentrations of the more toxic, soluble fractions in the water column are expected to be below the level that have been shown to have an adverse effect on marine organisms. The oil that is not contained at sea and reaches the coast is expected to be absorbed by the sandy coastal beach and has little chance of entering the estuaries. The impact on the waterfowl is expected to be minimal since they will be protected by the barrier islands most of the time.

11. The potential 30,000-ton spill could cause severe environmental damage, unless adequate control and containment procedures are included as a part of the port design and operation.

It is felt that present technology can be utilized to reduce the impact of the 30,000-ton spill. Damage will still occur but it is not considered irreversible or permanent. The effects of the soluble fraction of the oil on the water column organisms will be small. The concentration levels of the toxic compounds are expected to be below the levels that affect adult organisms but might affect the larval stages.

If the oil does reach the beach it is expected to travel along the coast with the longshore current until it is absorbed by the sandy beach and estuaries. Oil spill control procedures can be established along the beach whereby sorbent material is added to the slick and both the sorbent material and oil are removed along the beach. Plans for disposal of this material should be developed prior to operation of the offshore port. Fortunately most of the waterfowl concentrations are not near major estuary inlets and are naturally fairly well protected from the impact of a major offshore oil spill; however, plans for barriers across the tidal inlets should be developed in order to minimize the potential impact.

12. <u>If oil is spilled, it will require 2 to 3 days travel time to reach the shore</u>.

The 2 to 3 days travel time required for the oil to reach the coast will allow time to react, time to establish control procedure and deploy containment barriers, and time for evaporation of most of the more toxic fractions of oil. By the time the oil that is not contained at sea reaches the more productive coastal environment, it will be relatively nontoxic.

13. <u>Proceed with caution</u>.

There is no environmental reason for not pursuing the project further with designs, better environmental studies and contingency plans. Environmental field studies are necessary to collect data lacking for this study and develop baseline data. In the final evaluation secondary environmental effects should also be considered.

APPENDIX A

PHYSICAL FEATURES OF THE COASTAL AREA

DESCRIPTION OF ENVIRONMENTAL RESOURCES

Included in this section of the Appendix is a detailed description of the physical features of the coastal zone and their interaction with various biological elements. The inventory of physical features was conducted according to the coding listed in Table A-1. Much of the descriptive information for each item in Table A-1 was from a study conducted on the Management of Bay and Estuarine Systems Coastal Resources Management Programs, Office of the Governor (Fruh, *et al.*, 1972).

Table A-1. Inventory of Physical Features in the Coastal Zone.

1.0 BAYS, LAGOONS, ESTUARIES

- 1.1 Enclosed Bay
- 1.2 River Influenced Bay
- 1.3 Tidally Influenced Open Bay
- 1.4 Wind-Tidal Flats
- 1.5 Mobile Bay-Margin Sands
- 1.6 Grass Flats
- 1.7 Reef and Reef Related Areas - Living
- 1.8 Reef and Reef Related Areas - Dead
- 1.9 Tidal Inlets and Tidal Delta

2.0 COASTAL WETLANDS

- 2.1 Salt Marsh
- 2.2 Freshwater Marsh
- 2.3 Swamp

3.0 MADE LAND AND SPOIL

4.0 COASTAL BARRIERS

- 4.1 Beach and Shoreface
- 4.2 Fore-Island Dunes and Vegetated Barrier Flats
- 4.3 Active Dunes
- 4.4 Washover Areas
- 4.5 Tidal Flats

5.0 COASTAL UPLANDS

- 5.1 Stabilized, Vegetated Dunes and Sand Flats
- 5.2 Unstabilized, Unvegetated Dunes
- 5.3 Fresh Water Lakes, Ponds, Sloughs, Playas
- 5.4 Mainland Beaches
- 5.5 Highly Forested Upland Areas

BAYS, LAGOONS, AND ESTUARIES

Bays, lagoons, and estuaries are water masses which occupy river valleys and elongate areas between barrier islands and the mainland, and are inseparably part of a more complex coastal system including sediment substrate, marginal sources of sediment and fresh water, subaquerous vegetation, benthonic, nektonic, and planktonic organisms, tide and wind generated currents and waves, dissolved salts, and suspended colloidal sediment particles. Bays and estuaries occupy a position that is physically, biologically, and chemically transitional between the open marine environment and the fluvial system. Geologically, bays and estuaries are evolving, transient environments which display slow but natural change; biologically these areas and adjacent marshes are highly productive, delicately balanced ecosystems; and chemically the water mass is susceptible to external modification.

Enclosed Bay

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

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

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

River Influenced Bay

These are low salinity areas (less than 10%) at the heads of bays where rivers discharge fresh water and nutrients. Bottom sediments adjoining river mouths are primarily laminated pro-delta muds and sandy muds with mottled mud distal of the pro-delta. These areas generally grade into open bay and display a low species diversity. Common clams include *Rangia*, *Palymesoda*, and *Macoma*. The snail *Littoridina* is common in some localities. Crustaceans include *Callinectes* and *Marcobrachium*. Ostracods are abundant on the soft, muddy, organic rich bottoms. Foraminifers are not abundant in this zone, but a few including *Candona*, *Darwinula*, and *Physocypria* are characteristic of the pro-delta subfacies in some bays. The brown shrimp (*Penaeus aztecus*) and white shrimp (*P. setiferus*) use these areas (along with the associated marsh) for development through the juvenile stages. Destruction of these upper bay shallows or significant changes in the quality of the fresh water discharge, particularly changes in temperature or the introduction of toxins, could promote extinction of valuable commercial and recreational species.

Depths in these upper bay areas range from 3 to 7 feet. Turbid waters entering these areas from the associated rivers cause a decrease in light penetration and thus a lower level of photosynthetic activity. These fresh waters are usually high in humic acids from upstream runoff. Turbidity, low salinity, and low pH values from humic acids preclude significant growth of oysters and other sessile benthonic shellfish. On the other hand, these conditions are favorable for young shrimp which feed largely on fine organic detritus flushed in from the rivers.

Tidally Influenced Open Bay

These areas (6 to 12 feet in depth) encompass the lower ends of bays where tidal influence is great and salinities range from 20 to 35%. They display good circulation, and the substrates generally are mottled mud. Species diversity is relatively high. The number of species increases and the number of individuals of each species decreases as the salinity increases. In some bays a few species of *Foraminifera* make up large percentages of the bottom sediment. Benthonic filter feeders and burrowers (deposit and filter feeders) are important organisms in this estuarine area, and bottom sediments are strongly bioturbated.

Common infaunal deposit feeders include the clams (Nuculana, Mulinia, and Abra). Nassarius, Polinices, and Retusa are probably the most abundant snails in open bays.

Wind-Tidal Flats

These extensive flats occur on the back side of barrier islands south of St. Joseph Island and on the landward side of Laguna Madre from mean sea level to about plus 3 feet. Flats are flooded by wind-driven lagoon and bay water either during northers, or by persistent southeasterly spring and summer winds. These areas are dominantly sand, although they become muddy in depressed areas in the "land-cut" portion of the coast immediately south of Baffin Bay. Algal blooms during intermittent inundation result in thin algal mats which bind the sediment into a tough substrate; gypsum and other salts are common in the more depressed and/or restricted areas. High temperatures in the thin sheet of water on the tidal flats restrict biologic activity.

Mobile Bay-Margin Sands

These shallow bay-margin areas (depth to 6 feet) of high current activity and rapid sand transport are sites of significant deposition. The sand supply is predominantly from eroded flood tidal deltas, storm washover fans, and older eroded coastal plain sediments incised by bay waves. These marginal areas support locally sparse marine grasses (Thalassia, Diplanthera) and display variable temperatures and salinities. The rather diverse pelecypod fauna includes Aequipecten, Trachycardium, Mercenaria, Chione, Curtopleura, Tagelus, and Ensis. The two clams, Mulinia and Anomalocardia, inhabit these shallow sandy areas in Baffin Bay. Many carnivorous and grazing snails, such as

Thais and Busycon, are also present. Crustaceans including isopods, ostracodes, (Cytherura, Paradoxostoma, Perissocytheridea), mud shrimp (Callianassa), and a variety of crabs, including Callinectes, inhabit these shoal areas. Fish such as Black Drum (Pogonias cromis) feed here on molluscs. Species diversity increases near tidal inlets where there is greater mixing of bay waters with the more normal marine waters of the Gulf.

Grass Flats

These are shallow subaqueous flats (1 to 5 feet in depth) principally along the margins of bays and lagoons, although grassflats extend across the entire shallow northern Laguna Madre bottom. Next to marshes, marine grassflats produce more in terms of species diversity and standing crop than any other estuarine zone. Practically all motile estuarine and most sessile forms can be found at or near the grassflats. At one time or another literally hundreds of vertebrate and invertebrate species use the grassflats as a home, or as a retreat, where they can rest, eat, and escape predators.

Grassflats are composed of moderate to dense growth of Ruppia, Thalassia, and Diplanthera marine grasses. A calcareous green algae, Acetabularia, is common in these areas. Temperatures may vary considerably but the dense grass aids in maintenance of satisfactory ranges for many organisms. Such areas have salinities ranging from 20 to 35% and are characterized by a diverse mollusk assemblage, including the grazing and carnivorous snails Cerithium, Cerithidea, Modulus, Vermicularia, and Melampus. Common clams include Atrina, Tagelus, Laevicardium, Cytropleura, Tellina, and Amygdalum. Grassflats are feeding grounds for numerous aquatic animals including many commercial and game fish, such as menhaden (*Brevoortia*), croaker (*Micropogon*), spot (*Leiostomus*), mullet (*Mugil*), and trout (*Cynoscion*). Valuable crustaceans include postlarval and juvenile white shrimp (*Penaeus setiferous*), brown shrimp (*P. aztecus*), and pink shrimp (*P. durarom*). The blue crab (*Callinectes*), spends a major part of its life history feeding on organic detritus available in the marine grassflat.

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

Reef and Reef Related Areas - Living

These submerged mounds, elongate ridges and adjacent flanking areas (up to several miles in length) of the colonial oyster *Crassostrea virginica* and associated reef organisms occur in varying concentration in all major bays with the exception of Laguna Madre and Baffin Bay. Reefs are ridged structures which locally baffle or restrict circulation and commonly exhibit orientation perpendicular to prevailing currents. Reef crests may grow to the water surface and may be exposed during low tide. Oyster reefs and associated areas serve as valuable feeding grounds for many varieties of commercial and game fish and crabs. These are productive environments economically and constitute one of the major resource areas of the bay ecosystem.

The bulk of a reef is composed of the shells of dead oysters and other organisms, but epifaunal, nektonic, and some vagrant benthonic organisms inhabit the living reef surface. Along with the oysters are many associated molluscs including *Anomia*, *Anachis*, *Mitrella*; several epizoans including barnacles (*Balanus*) and *Brachidontes*; and several varieties of coral and bryozoans. Normal oyster reef salinities range from 10 to 30% with water depths of up to 8 feet. Oysters can live and grow in normal marine salinities of 30 to 35%, but under these conditions several oyster predators, including the oyster drills *Thais* and *Urosalpinx*, also flourish. High salinity oyster reefs contain *Ostrea Equestris*.

Reef and Reef-Related Areas - Dead

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

Tidal Inlet and Tidal Delta

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

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

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

COASTAL WETLANDS

Salt Marsh

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

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

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

MADE LAND AND SPOIL

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

COASTAL BARRIERS

These highly permeable sand bodies are elongate parallel to the shoreline and are separated from the mainland by lagoons and estuaries. Local relief of the islands is from sea level to 50 feet; width is from 0.5 to 3 miles. Barriers are composed of a variety of wind, vegetational, and storm units.

Beach and Shoreface

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

Fore-Island Dunes and Vegetated Barrier Flats

These units are grass-covered, stabilized dunes (from 5 to 50 feet high) and sand flats between the beach and bayside marshes or tidal flats. This area includes most of the exposed barrier island. Low rainfall and persistent wind prohibit growth of stabilizing grasses on central and southern Padre Island. Fore-island dunes are also absent to poorly developed on Matagorda Peninsula where the beach and barrier flat are in juxtaposition. Stabilized blowouts occur behind fore-island dunes, producing a hummocky, ramplike surface. Vegetation consists of salt-tolerant grasses, rare mesquite (*Prosopis*), and live oak (*Quercus virginiana*) trees.

Active Dunes

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

Washover Areas

These are local areas from 1/4 mile to 3 miles wide which channel hurricane flood tides across the barrier islands into bay areas. Many washovers occupy sites of abandoned tidal channels;

others are caused by storm tides where fore-island dunes are poorly developed or weakened by blowouts. During major storms, these are areas of intense current activity with scour of large volumes of sand on the seaward side of the island and deposition in the channels and/or on the back side of the island.

Tidal Flats

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

COASTAL UPLANDS

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

Stabilized, Vegetated Dunes and Sand Flats

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

Unstabilized, Unvegetated Dunes

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

Fresh Water Lakes, Ponds, Sloughs, Playas

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

Mainland Beaches

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

Highly Forested Upland Areas

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

TABULATION OF ENVIRONMENTAL RESOURCES

Table A-2 is a summary of the general physical elements tabulated by shoreline segments. As described in Chapter II of this report, each segment is 3 miles long and extends from the beach back to the hurricane high water (assumed to be the 12-foot contour). The shoreline segments are numbered (Column 1 of Table A-2 labeled K) from 1 to 124 starting with 1 at the south near Brownsville and ending at 124 at Sabine Pass in the north. Columns 2 through 6 of the table list: 1) the area in square miles of 2) total area in segment, 3) area of bays and estuaries within each segment, 4) area of barrier island, 5) area of marsh, and 6) the area of uplands to the hurricane high water. The distribution of the marsh areas was determined by remote sensing techniques using NASA's high altitude color infrared photography at a scale of 1:120,000.

Table A-2. Area in Square Miles of Coastal Resources.

RESOURCES INVENTORY OF THE TEXAS COASTAL ZONE

K	AA	BA	CA	DA	EA
1	50.0	21.0	3.0	2.0	24.0
2	44.3	9.9	2.2	0.5	31.7
3	31.8	19.2	1.4	0.0	11.2
4	24.6	22.0	2.1	0.0	0.5
5	24.3	22.0	2.1	0.0	0.2
6	24.3	22.0	2.1	0.0	0.2
7	26.2	24.6	1.2	0.0	0.4
8	27.2	25.8	1.2	0.0	0.2
9	28.1	22.8	1.2	5.0	0.0
10	35.3	24.6	1.9	9.0	0.0
11	41.7	27.0	2.2	6.0	6.5
12	39.1	31.5	1.9	4.5	1.2
13	38.2	29.7	2.5	6.0	0.0
14	43.0	26.5	2.2	6.5	7.8
15	41.4	22.0	2.2	0.0	17.2
16	28.5	20.3	3.0	0.0	5.2
17	27.0	21.0	3.0	0.0	3.0
18	25.9	20.7	3.3	0.0	1.9
19	25.9	20.4	3.7	0.0	1.8
20	28.2	22.2	3.4	0.0	2.6
21	35.4	24.3	3.0	0.0	8.1
22	40.5	21.3	3.0	0.0	16.2
23	41.7	25.8	3.0	0.0	12.9
24	38.3	21.0	3.0	0.0	14.3
25	34.2	12.7	3.0	0.0	18.5
26	33.7	14.4	2.8	0.0	16.5
27	34.5	12.5	2.7	0.0	19.3
28	28.4	8.9	2.7	0.0	16.8
29	20.9	8.8	2.8	0.0	9.3
30	42.6	25.8	3.1	0.0	13.7
31	42.6	25.8	3.1	0.0	13.7
32	14.8	7.6	4.2	0.0	3.0
33	12.4	6.4	4.6	0.0	1.4
34	13.5	7.5	4.5	0.0	1.5
35	15.1	8.8	4.9	0.0	1.4
36	16.0	9.9	4.5	0.0	1.6
37	16.0	9.7	4.9	0.0	1.4
38	16.5	9.4	5.5	0.0	1.6
39	16.2	11.2	4.3	0.0	0.7
40	42.5	26.2	4.2	0.0	12.1
41	90.0	54.0	4.9	22.0	9.1
42	66.1	53.4	4.0	0.0	8.7
43	52.8	36.2	4.6	0.0	12.0

Table A-2. Continued.

44	25.7	14.1	6.8	0.0	4.8
45	17.2	11.0	5.5	0.0	0.7
46	21.6	15.1	3.6	3.0	0.0
47	21.4	15.1	3.3	0.0	3.0
48	21.4	14.7	4.8	0.0	1.9
49	38.2	23.4	7.5	3.0	4.3
50	40.2	31.3	9.9	0.0	0.0
51	35.1	22.8	9.9	3.0	0.0
52	32.6	10.1	7.5	10.0	5.0
53	25.5	9.0	7.5	7.2	1.8
54	24.6	7.5	9.7	6.0	1.4
55	29.1	17.5	6.3	4.0	1.3
56	55.2	39.0	4.0	0.0	12.2
57	66.0	49.9	5.2	0.0	10.9
58	57.6	25.6	6.7	0.5	24.8
59	25.5	11.8	6.7	3.0	4.0
60	24.4	13.1	4.9	6.4	0.0
61	24.8	14.1	4.8	5.8	0.1
62	21.2	13.3	6.4	1.5	0.0
63	99.0	55.1	4.9	23.0	16.0
64	36.8	32.3	2.7	1.8	0.0
65	47.7	38.2	3.0	1.0	5.5
66	56.1	50.5	2.8	2.0	0.8
67	54.4	41.2	2.7	1.0	9.5
68	43.8	25.3	3.1	3.0	12.4
69	34.0	21.5	3.3	2.8	6.4
70	25.7	12.2	2.7	9.0	1.8
71	30.2	11.7	2.4	10.5	5.6
72	26.5	8.5	2.7	15.0	0.3
73	27.0	6.9	2.1	3.0	15.0
74	23.7	6.8	3.4	3.0	10.5
75	21.3	12.7	3.0	6.0	0.0
76	19.5	10.1	3.3	5.4	0.7
77	19.5	9.0	3.6	4.6	2.3
78	22.6	6.0	3.0	5.5	8.1
79	21.0	4.5	1.6	5.8	9.1
80	21.0	4.5	0.9	3.0	12.6
81	18.7	0.0	0.0	0.0	18.7
82	18.7	0.0	0.0	4.0	14.7
83	19.5	1.0	0.9	7.0	10.6
84	21.7	1.6	2.5	13.5	4.1
85	21.0	0.0	0.0	11.5	9.5
86	24.0	0.0	0.0	12.0	12.0
87	26.7	0.0	0.0	9.0	17.7
88	29.4	0.0	0.0	14.0	15.4
89	34.3	0.0	0.0	17.0	17.3
90	38.4	1.4	0.9	18.0	18.1
91	38.2	3.9	2.7	16.5	15.1
92	32.1	5.7	4.6	10.0	11.8
93	28.2	8.5	4.6	5.5	9.6
94	29.1	13.8	3.0	6.5	5.8

Table A-2. Continued.

95	28.5	12.7	3.0	4.5	8.3
96	26.5	7.5	4.2	3.0	11.8
97	36.6	7.5	4.9	6.0	18.2
98	37.1	9.0	5.2	7.3	15.6
99	31.5	8.8	6.6	8.0	8.1
100	40.2	7.5	6.7	1.5	24.5
101	29.1	16.5	5.6	1.0	6.0
102	85.2	37.9	6.0	0.0	41.3
103	96.0	57.8	5.1	0.0	33.1
104	81.7	57.7	5.5	0.0	18.5
105	58.0	49.7	6.5	0.5	1.3
106	112.8	89.0	6.0	4.5	13.3
107	47.5	33.6	8.0	1.9	4.0
108	27.0	12.0	6.5	15.0	0.0
109	36.5	0.0	0.0	36.5	0.0
110	34.9	0.0	0.0	20.0	14.9
111	29.9	0.0	0.0	24.1	5.8
112	26.1	0.0	0.0	21.0	5.1
113	27.0	0.0	0.0	13.5	13.5
114	27.0	0.0	0.0	24.1	2.9
115	27.0	0.0	0.0	14.0	13.0
116	27.0	0.0	0.0	16.0	11.0
117	27.0	0.0	0.0	23.5	3.5
118	27.0	0.0	0.0	27.0	0.0
119	27.0	0.0	0.0	21.0	6.0
120	27.0	0.0	0.0	12.0	15.0
121	27.0	0.0	0.0	4.0	23.0
122	27.0	0.0	0.0	27.0	0.0
123	21.5	0.0	0.0	21.5	0.0
124	52.0	37.0	0.0	15.0	0.0
TOTAL	4245.4	2092.3	404.3	738.2	1020.3

APPENDIX B

BIOLOGICAL INVENTORY

Included in this Appendix are detailed biological inventories too extensive to be included in Chapter II. Table B-1 through B-5 are bird listings and inventories for the National Wildlife Refuges. Table B-6 is a listing of the mammals on the Texas coast while Tables B-7 through B-11 are detailed mammal inventories for the five National Wildlife Refuges on the Texas coast. Table B-12 lists the amphibians and reptiles of the coastal zone while Table B-13 lists the benthic macro-faunal assemblages of the northwestern coast of the Gulf of Mexico.

Figures B-1 through B-10 show the distribution of several of the more important wildlife game species in Texas.

Table B-1. Birds on the Texas Coast.

Birds	National Wildlife Refuges																Padre Island National Seashore
	Anahuac				Aransas				Brazoria				Laguna Atascosa				Species Observed
	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	
Gaviformes (The Loons)																	
Arctic Loon																	*
Common Loon				u	r		r	r					r		r	r	✓
Podicipediformes (The Grebes)																	
Eared Grebe	c		c	c	u	r	o	c			r	u	u	o	c	c	✓
Horned Grebe				o	u		u	u				o			o	o	✓
Least Grebe *					u	u	u	o					u	c	u	u	✓
Pied-billed Grebe	c	a	c	c	c	u	c	c	c	u	c	c	c	u	a	a	✓
Western Grebe													r			r	
Red-necked Grebe					accidental												
Procellariformes (Tubenoses)																	
Audubon's Shearwater																	✓
Pelecaniformes (Pelicans and Their Allies)																	
Anhinga			u	o	r	r	r				u	u	o	o	o		*
Blue-faced Booby																	✓
Brown Booby																	✓
Double-crested Cormorant			c	c	u	u	c	c		o	u	u	u	c	c	a	✓
Olivaceous Cormorant	u	u	u	o	u	u	r	r			r	r	u	u	u	u	✓
Magnificent Frigate Bird					o	u			o		o		r			r	✓
Brown Pelican *					r	r	r	r					accidental				✓
White Pelican	c		c	a	c	u	c	c	c		c	c	c	c	c	c	✓
White-tailed Tropic Bird																	✓

Table B-1. Page 2

Ciconiiformes (Herons and Their Allies)																	
American Bittern	c		c	o	o		o	o			u	u	o		o	u	√
Least Bittern	c	ċ	c		o		o	o	u	u̇	o		o	u	o	o	*
Cattle Egret	a	a	a	o	c	c	c	c	u	c	c	u	u	c	c	u	√
Common Egret	c	c	c	c	c	c	c	c	c	c	c	c	c	u	c	u	√
Reddish Egret *		o			u	u	u	o		u	u						√
Snowy Egret	c	c	c	c	c	c	c	u	c	c	c	c	c	c	c	c	√
Gloss Ibis					r	r	r										
Gannet																	√
Black-crowned Night Heron	c	ċ	c	u	o	ȯ	u	o	c	c	c	a	u	ȯ	u	u	√
Great Blue Heron	c	c	c	c	c	ċ	c	c	c	c	c	c	c	ċ	a	c	√
Green Heron	c	ċ	u	r	u	o	u	o	u		u	o	u	u	o	o	√
Little Blue Heron	u	u	u	u	u	u	u	u	c	c	c	u	u	c	c	u	√
Louisiana Heron	c	c	c	c	c	c	c	o	c	c	c	c	c	c	c	c	√
Yellow-crowned Night Heron	c	ċ	c	o	o	o	r	r	u		u		u	o	u	o	√
White Ibis	c	a	a	u	u	u	u	o		c	c	o	u	c	u	u	√
White-faced Ibis	c	a	a	u	c	c	u	o		c	c	u	u	c	u	u	√
Wood Ibis *		a	a		u	c	u				c		u	u		u	√
Roseate Spoonbill *	c	a	a	u	u	c	c	u		c	c	c	u	u	u	r	√
Anseriformes (Waterfowl)																	
Bufflehead	o			o	u		c	c			u	u	u		c	c	√
Canvasback	u		u	a	u		c	u	o		u	u	u		c	c	√
Black-bellied Tree Duck													c	ċ	o	o	√
Fulvious Tree Duck	o	r	c		u	u	u	o		o			u	u	o	u	√
Masked Duck		ṙ	r								r		r	r	r	r	√
Mottled Duck	c	ċ	a	c	c	ċ	c	c	c	ċ	c	c	c	ċ	c	c	√
Ring-necked Duck	u		u	u	u		u	u			u	u	o		o	u	√
Ruddy Duck	c	ṙ	c	u	u		u	u			u	u	u		c	c	√
Wood Duck			r	r			o			r						r	√
Gadwall	c		c	a	c		c	c	a		a	a	c	o	c	c	√
Common Goldeneye				o	o		o					o				r	√
Blue Goose	u		a	a	c		c	c	c		a	a	c		c	c	√

Table B-1. Page 3

Canada Goose	o		c	a	a		a	a	c	a	a	a		a	c	√
Snow Goose	u		a	a	c		c	c	c	a	a	a		a	c	√
White-fronted Goose	o		c	a	o		u	u	c	c	c	o		c	c	√
Mallard	c		a	a	c		c	u	c	c	c	u		u	u	√
Hooded Merganser			r	r			r	r		u	u			r	u	√
Red Breasted Merganser	a			u	o	r	u	u				o		u	u	√
Oldsquaw	accidental															*
Shoveler	o		a	a	c		a	c	a	a	a	c	o	a	a	√
Whistling Swan					accidental						o					√
Pintail	c		a	a	c	r	c	a	a	a	a	u	u	a	a	√
Redhead	o		o	o	c	o	c	c		u	u	c	o	a	a	√
Greater Scamp				r				r			o			r	r	√
Lesser Scamp	c		c	a	u		c	c		c	c	u		c	c	√
Surf Scoter												accidental				
White-winged Scoter					accidental						o					√
Blue-winged Teal	a	ṙ	a	u	c	r	c	c	ȧ	a	u	u	u̇	a	u	√
Cinnamon Teal				o	o		o	o	u	u	u	u		o	u	√
Green-winged Teal	c		a	a	u	o	u	c	a	a	a	u	o	a	u	√
American Widgeon	c		c	a	c		a	a	c	c	c	u	o	a	a	√
Ross' Goose	r		r	r	accidental							r			r	
Common Merganser								o								
Black Duck			o	o	u		u	u				accidental				
Falconiformes (Vultures, Hawks, and Falcons)																
Caracara				r	c	ċ	c	c	r	r	r	c	ċ	c	c	√
Bald Eagle			o	o	u	u	u	u			r				r	*
Golden Eagle			r	r	accidental										r	*
Peregrine Falcon *	o		o	o	r		r	o	r	r	r	c		u	u	√
Black Hawk															r	√
Prairie Falcon *					accidental							accidental				√
Aplomado Falcon					accidental							accidental				√
Broad-winged Hawk	u		u		c		c					u		u		√
Cooper's Hawk	o		o		u	o	u	c	u	u		u	o	u	u	√

Table B-1.   Page 4

Ferruginous Hawk	accidental				u		u	o					o		o	u	√
Harlan's Hawk							o	o				r	accidental				*
Harris' Hawk					accidental								a	c	a	a	√
Marsh Hawk	c	ṙ	c	c	c		c	c	c	o	c	c	a	o	a	a	√
Mexican Black Hawk																	√
Pigeon Hawk	r		r		o		o	o			r		o		o	o	√
Red-shouldered Hawk	o	o	o	o	u	u	u	u	u		u	o	o	o	o	o	√
Red-tailed Hawk			c	c	c	ċ	c	c	u		u	u	u		u	c	√
Rough-legged Hawk			r	r	u		u	o				r					√
Sharp-skinned Hawk	o		o		u		o	c	r		r		u		o	u	√
Sparrow Hawk			c	c	c	u	c	c	u		u	u	c	o	a	a	√
Swainson's Hawk	u		u		c	o	c	o	u		u		c	o	c	o	√
White-tailed Hawk *					c	ċ	c	c					c	ċ	c	c	√
White-tailed Kite			r	r	r						r		u	u̇	c	c	√
Osprey	o		o		u		u	u	u		u	o	u			u	√
Black Vulture	c	u	u	u					u	o	u	u	c	c	c	u	√
Turkey Vulture	c	c	c	c					c	u	c	c	a	ċ	a	a	√
Mississippi Kite	o		o		o								r				
Zone-tailed Hawk																r	
Swallow-tailed Kite					r								accidental				
Galliformes (Gallinaceous Birds)																	
Bobwhite	c	ċ	c	c	a	ȧ	a	a	c	ċ	c	c	a	ȧ	a	a	√
Chachalaca													u	u̇	u	u	*
Scaled Quail																	√
Turkey					c	ċ	c	c					r	r	r	r	*
Greater Prairie Chicken *					accidental												
Gruiformes (Cranes and Their Allies)																	
American Coot	a	ȯ	a	a	c	o	c	c	c	u̇	a	a	a	u̇	a	a	√
Sandhill Crane				r	c		c	c	c		a	a	c		c	c	√
Whooping Crane *					u		u	u									*
Common Gallinule	a	ȧ	a	u	c	u	c	c	u	ċ	a	u	o	ȯ	o	o	√

Table B-1. Page 5

Purple Gallinule	c	ȧ	u		u	u			u	u̇	u		o	ȯ			√
Black Rail	r		r	r					r	ṙ	r	r					*
Clapper Rail	c	ċ	c	c	u	u̇	u	u	u	u̇	u	u			r	r	√
King Rail	c	ċ	c	c	accidental				u	u̇	u	u	o	ȯ	o	o	√
Sora	u		u	u	u		u	u	u		u	u	u	ṙ	c	u	√
Virginia Rail	u		u		accidental				u		u	u					*
Yellow Rail	u		r	r							r	r					
Charadriiformes (Shorebirds, Gulls, and Alcids)																	
American Avocet	u		c	o	c	u	c	u	u		c	u	c	ȯ	c	c	√
Long-billed Curlew	c		c	c	c	c	c	c	c		c	u	c	c	a	c	√
Long-billed Dowitcher	a		a	c	a	u	c	u	c		a	c	a	u	a	c	√
Short-billed Dowitcher	u		u	u													√
Dunlin	a		a	c	a	u	a	c	c		a	c	a	u	a	c	√
Hudsonian Godwit	o				o								r				√
Marbled Godwit	c		c	u	u	o	u	u				r	u	u	u	u	√
Bonaparte's Gull					o		o	o						o	u	r	*
California Gull	accidental																*
Franklin's Gull			o		a		a	u	c		c		a		a		√
Herring Gull	c		u	c	c	o	c	u	u		u	u	c	o	c	c	√
Laughing Gull	a	a	a	c	c	c	c	c	c	c	c	c	a	ȧ	a	c	√
Ring-billed Gull	c		c	c	c	o	c	c	c		c	c	c	o	c	a	√
Parasitic Jaeger																	√
Killdeer	c	ċ	c	c	c	ċ	c	c	c	ċ	c	c	ċ	ċ	c	c	√
Knot	o		o			o	o							u	u		√
American Oystercatcher					o	o	r	r								r	√
Red Phalarope															r		
Northern Phalarope							r	r							r		√
Wilson's Phalarope	c		c		c	u	o		u		u		u	c	u		√
Gull-billed Tern	c	c	c	o	u	u̇	c	u	u		u		c	ċ	c	u	√
American Golden Plover	a		r		u		u	r	u		u		u			r	√
Black-bellied Plover	c		c	u	c	c	a	c	u	u	u	u	a	c	a	c	√
Mountain Plover					accidental				o				o		u	o	*
Piping Plover		o	o		o	o	c	o					u	o	o	u	√

Table B-1. Page 6

Semipalmated Plover	u		u		o	u	c	o	u		u		u		u	u	√
Snowy Plover		r			c	o	c	o			r						√
Upland Plover	c		c		u		u		u		u		u		u		*
Wilson's Plover					c	ċ	c	o		ċ			a	ȧ	c	o	√
Ruff																	*
Sanderling	u	o	u	u	c	o	c	c					o	u	u	u	√
Baird's Sandpiper	u		u		c	u	c						o		o		*
Buff-breasted Sandpiper	o		o		u	o	u				u		u	o	u		
Least Sandpiper	c		c	u	c	c	c	c	c		c	c	c	u	c	u	√
Pectoral Sandpiper	a		a		c	o	c	o	c		c		c	o	c	o	√
Semipalmated Sandpiper	a		a	c	a	c	a	c	c		c	c	a	a	a	c	√
Solitary Sandpiper	a		a	c	a	c	a	c	c		c	c	a	a	a	c	√
Spotted Sandpiper	c		c	u	c	u	c	o	u	ȯ	u	u	u	u	u	u	√
Stilt Sandpiper	a		a		u	c	u		c	u	c	o	u	c	u	o	√
Western Sandpiper	a		a	c	c	u	c	c	c		c	u	a	u	c	c	√
White-rumped Sandpiper	u				c	o	c	o	u				u		u		*
Black Skimmer	u	u	u	r	c	ċ	c	u	u	c	c		c	ċ	c	u	√
Common Snipe	c		c	c	c		c	c	c		c	c	u		u	u	√
Black-necked Stilt	c	ċ	c		c	ċ	c		c	ċ	c		u	ċ	u	o	√
Black Tern	a		a		c	c	c	r	a		a		c	c	a	o	√
Cabot's Tern																	√
Caspian Tern	u	u	u	u	c	c	c	c	u		u	u	c	c	c	c	√
Common Tern	o		o	r	u		u	o	u		u	u	c		c	u	√
Forster's Tern	c	c	c	c	c	ċ	c	c	c	c	c	c	c	u̇	c	c	√
Least Tern	a	ȧ			c	c	c	r	c	c	c		c	ċ	c	o	√
Noddy Tern																	*
Roseate Tern																	√
Royal Tern	u	u	u	u	u	u	u	u					u	u̇	u	o	√
Sooty Tern																	√
Ruddy Tern																	√
Whimbrel	o		r		u	u	u				r		c	o	o		√
Willet	c	ċ	c	c	c	ȧ	a	c	c	ċ	c	u	c	ȧ	a	c	√
American Woodcock					accidental												*
Greater Yellowlegs	a		a	c	a	u	a	u	c		c	u	a	u	a	c	√

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Lesser Yellowlegs	a		a	c	c	u	a	u	c		c	c	a	u	a	c	√
Ruddy Turnstone	o		o	o	o	o	u	o	u		u		u	o	u	u	
Sandwich Tern		o			u	u	u	r					u	u	u	o	
Jacana												r				r	
Columbiformes (Pigeons and Doves)																	
Ground Dove			r		u	u̇	u	u		r			c	ċ	c	c	√
Inca Dove					u	u	u	u					r	r			√
Mourning Dove	c	ċ	c	c	a	ȧ	a	a	c	ċ	u	u	a	ȧ	a	a	√
Rock Dove			r														√
White-fronted Dove													u	u	u	u	√
White-winged Dove	r		r		accidental					r			c	ċ	u		√
Red-billed Pigeon													r	r	r		*
Cuculiformes (Cuckoos, Anis, and Roadrunners)																	
Groove-billed Ani *					accidental								u	u̇	u	o	√
Black-billed Cuckoo	o				o		o		r				o				√
Yellow-billed Cuckoo	c	u̇			c	ċ	o		c	ċ	c		c	c	o		√
Roadrunner					u	u̇	u	u					c	ċ	c	c	√
Strigiformes (The Owls)																	
Barn Owl	u	u̇	u	u	u	u	u	u				o	u	u̇	u	u	√
Barred Owl								u				o					*
Burrowing Owl			o	o			u	u	o	o	o	o			u	u	√
Great-horned Owl	u	u	u	u	u	u̇	u			ȯ	o	o	u	u̇	u	u	√
Screech Owl					u	u̇	u	u					u	u̇	u	u	*
Short-eared Owl			u	u	u			u				u				u	*
Caprimulgiformes (The Goatsuckers)																	
Chuck-will's-widow	c		c		u		u				r		u			u	√
Common Nighthawk	a	ȧ				ȧ	c		c	ċ	c			ȧ	a		√
Lesser Nighthawk						ċ	u							u̇	u		√
Pauraque *					c	ċ	c	u					c	ċ	c	c	√
Whip-poor-will	u		u		u		u						r				√

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Apodiformes (The Hummingbirds)																	
Black-chinned Hummingbird													u				*
Blue-throated Hummingbird																	√
Buff-bellied Hummingbird *					accidental									r			√
Ruby-throated Hummingbird	u		u		c		c		u	u	u		c		c		√
Rufous Hummingbird																	*
Chimney Swift	r		r		c		u		u	u	u		c		o		√
Coraciiformes (The Kingfishers)																	
Belted Kingfisher	c		c	u	u		u	u	u	o	u	u			u	u	√
Green Kingfisher																r	
Piciformes (The Woodpeckers)																	
Red-shafted Flicker			c	o	o		o	u								r	*
Yellow-shafted Flicker					u		u	u	u		u	u			o	o	√
Yellow-bellied Sapsucker			o		o		o	u	u		u	u	o			o	*
Golden-fronted Woodpecker					c	ċ	c	u					a	ȧ	a	a	√
Ladder-backed Woodpecker					c	ċ	c	c					a	ȧ	a	a	√
Red-bellied Woodpecker	o	o			accidental				u	u	u	u					
Pileated Woodpecker									r								
Red-headed Woodpecker					o			o	r								
Passeriformes (Perching Birds)																	
Brewer's Blackbird				a	a		a	a	c		c	c	c	u	c	c	√
Redwinged Blackbird	a	ȧ	a	a	a	ȧ	a	a	a	ȧ	a	a	a	ȧ	a	a	√
Yellow-headed Blackbird	r		r		r		r						o		o	o	√
Eastern Bluebird					u	o	u	u					o		o	u	*
Mountain Bluebird								o					r			r	*
Bobolink	r				r		r										√
Indigo Bunting	c		c		a		c		c		c		a		u		√
Lark Bunting	accidental				r		r	r					o		o	o	*
Painted Bunting	u	u̇			a	ȧ	c		u	o	u		a	u̇	u		√
Cardinal	o		o		a	ȧ	a	a	c	ċ	c	c	c	ċ	c	c	√
Catbird	c		c		u		u		c		u		u			u	√

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Yellow-breasted Chat	u		u		u		u		u				u	ċ			√
Brown-headed Cowbird	c	u̇	c	a	c	ċ	c	a	c	ċ	c	c	c	ċ	a	a	√
Red-eyed Cowbird																	√
Brown Creeper				u				o			r	r					√
Dickcissel	a	ċ			u	u̇	u		u	u̇	u		a	ȯ	c		√
House Finch																	*
Purple Finch																	*
Arcadian Flycatcher													u		u		*
Ash-throated Flycatcher																	√
Great-crested Flycatcher	u		u		c	u	c		u		u	o	u			u	√
Kiskadee Flycatcher													u	u̇	u	u	√
Least Flycatcher					u		u						c		c		*
Olive-sided Flycatcher	r		u		u		c				u		u		u		√
Scissor-tailed Flycatcher	c	u̇	c		a	ċ	a		c	ċ	c		a	ċ	a		√
Traill's Flycatcher									u		u						*
Vermillion Flycatcher	o		o				u	u	u		u	u	ċ		c	u	√
Western Flycatcher																	√
Weid's Crested Flycatcher													c	ċ			√
Yellow-bellied Flycatcher	u		u		r		o										√
Blue-gray Gnatcatcher	c		c	u	u	r	u	u	c		c	c	u	o	u	u	√
American Goldfinch				o	u		u	c			u	u	u		u	u	*
Lesser Goldfinch													r			r	√
Boat-tailed Grackle	a	ȧ	a	a	u	u̇	u	u	c	ċ	c	c	a	ȧ	a	a	√
Blue Grosbeack	c		c		ċ		c		u		u		c	ċ	c		√
Blue Jay			u		o			o	u	u	u	u	r			r	*
Green Jay													u	u̇	u	u	
Oregon Juneo					accidental												*
Slate-colored Juneo				o				o								r	*
Eastern Kingbird	c	u̇	c		a		a		c	ċ	c		a		a		√
Tropical Kingbird *					accidental								u	u̇	o		√
Western Kingbird	o		o		u		o		o				u				√
Golden-crowned Kinglet			o					o								u	√
Ruby-crowned Kinglet			u	o	u		u	c	c		c	c	o		u	u	√
Horned Lark	c	u̇	c	c	c	ċ	c	c	c	ċ	c	u	c	ċ	c	c	√

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McCown's Longspur																	*
Purple Martin	c	ċ			o	o	r		u	u̇	u		u		o		√
Eastern Meadowlark	a	ȧ	a	a	a	ȧ	a	c	c	ċ	c	c	c	ċ	c	c	√
Western Meadowlark	o		o	o	u	u	u	u					o			u	√
Mockingbird	u	u̇	u	u	a	ȧ	a	a	c	ċ	c	c	a	ȧ	a	a	√
Red-breasted Nuthatch					accidental												*
Baltimore Oriole	u		u		c		c		c		c		c		u		√
Black-headed Oriole													u	u̇			*
Bullock's Oriole					c		u						u	u̇			*
Hooded Oriole													c	ċ			*
Orchard Oriole	c	ċ	u		c	ȯ	c		c	u̇	c		u	o	o		√
Western Wood Pewee													u		u		
Ovenbird					o		o		u								√
Eastern Wood Pewee	u		u		c		c		u		u		a		a		√
Eastern Phoebe			c	o	u		u	c	u		u	u	c			c	√
Say's Phoebe			r		o			o					u		u	u	*
Sprague's Pipit			r	r	u			u	r		r	r				u	√
Water Pipit	u		c	c	o		u	c	c		c	c	o		c	c	√
Pyrrhuloxia					accidental								o	r	o	o	*
White-necked Raven													o	u̇	o	o	√
American Redstart	c		c		c		u		u		u		c		o		√
Painted Redstart																	*
Robin			o	o	c		u	a	c		c	c	u		c	u	√
Loggerhead Shrike	c	u̇	c	c	u		u	c	c	ȯ	c	c	c		c	c	√
Pine Siskin																u	*
Baird's Sparrow																r	*
Black-throated Sparrow					accidental								c	ċ	c	u	*
Botteri's Sparrow													c	ċ	c		*
Cassin's Sparrow					o	u̇	o						c	ċ	c	o	*
Chipping Sparrow			o		o		r	u					u		u		√
Clay-colored Sparrow					accidental								u		u	u	*
Field Sparrow					u		u	c					o		o	u	*
Fox Sparrow																	*
Grasshopper Sparrow					u		u	c	r	ṙ	r	r	o		u	u	√

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Harris' Sparrow			r														*
House Sparrow	c	ċ	c	c	u	u̇	u	u	u	u̇	u	u	c	ċ	c	c	√
Lark Sparrow	o		o		c	ċ	c	c	o		o		c	c	c	c	√
LeConte's Sparrow	u			u					r		r	r				u	√
Lincoln's Sparrow	u		u	u	c		c	c	u		u	u	o		c	c	√
Olive Sparrow													u	u̇	u	u	*
Savannah Sparrow	a		a	a	c		c	c	c		c	c	a		a	a	√
Seaside Sparrow	a	ȧ	a	a	c	ċ	c	c	c	ċ	c	c				o	*
Song Sparrow	u		u	o	u		u	u				r	u		u	u	√
Swamp Sparrow	c		c	c	c		u	u	c		c	c	u		o	u	*
Vesper Sparrow	u		u		c		c	a	u				c		c	c	*
White-crowned Sparrow			u		u		u	u					u		u	u	√
White-throated Sparrow			u	u	u		u	u	u		u		o			u	√
Starling	c	u̇	c	c	c		c	a	u	u̇	u	u			o	o	*
Black Swallow																	√
Barn Swallow	a		a		a	o	a						a	o	a		√
Bank Swallow	u		u		c		c		a		a		u	u	u		
Cliff Swallow	u		u		c	o	c		u				u	u	o		√
Rough-winged Swallow	u		u		c	o	u		a		a		a	u	c		√
Tree Swallow	a		a		c		c	o	a		a	o	c		c	u	√
Violet-green Swallow	accidental																√
Western Tanager					r		r										*
Scarlet Tanager	u				c		u		r				r				√
Summer Tanager	u		u		c	ȯ	c		r				o	ȯ			√
Brown Thrasher	u		c	u	u		u	u	u		u	u	r			r	√
Curved-billed Thrasher													a	ȧ	a	a	√
Long-billed Thrasher													u	u̇	u	u	√
Sage Thrasher			r		accidental						r		o		o	o	*
Gray-cheeked Thrush	u		u		accidental				u				u				√
Hermit Thrush			o	o	u		u	c					u		u	u	√
Swainson's Thrush	c		c		u		o		u				u				√
Wood Thrush	u		u		u		o		c				u				√
Black-crested Titmouse					u	u̇	u	u					u	u̇	u	u	√
Green-tailed Towhee																u	*
Rufous-sided Towhee				u			o	u								r	*

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Veery	o	o						r				r				√
Verdin												c	ċ	c	c	*
Bell's Vireo				o	o	o										*
Philadelphia Vireo	o			o		o		u		r		u				√
Red-eyed Vireo	u	u		c		c		u		u						√
Solitary Vireo		o		o		o		r		r				u	u	*
Warbling Vireo				c	o	c		u				u				*
White-eyed Vireo	u	u		u	u̇	u	u	u	o	u		c	ċ	c	c	√
Yellow-throated Vireo				u		u		r		r		u				*
Audubon's Warbler																√
Bay-breasted Warbler	u			c		u		u		u		r				√
Black-and-white Warbler	u	u		c		c		u		u	r	c		c	u	√
Blackburnian Warbler	o			c		u						u				√
Blackpoll Warbler												r				√
Black-throated Green Warbler	c	c		c		c				u		o		u	u	√
Blue-winged Warbler	o							u				u				*
Canada Warbler				c		c		u		u		u		u		√
Cape May Warbler																√
Cerulean Warbler				accidental				u				o				√
Chestnut-sided Warbler	u			c		u		u		u		r				√
Connecticut Warbler																*
Golden-winged Warbler				u		u		u								*
Hooded Warbler	u			c		o		u		u		u				√
Kentucky Warbler	u			c		u		u				o		o		√
Magnolia Warbler	c	c		c		u		c		c		u				√
Mourning Warbler																√
Myrtle Warbler			c	u		u	u	u		u	u	c		a	c	*
Nashville Warbler	u	u		a		a		u		u				o	u	√
Orange-crowned Warbler		u	o	u		u	u	u		u	u			c	o	√
Palm Warbler				r				u				o				√
Parula Warbler	o			c		u		r				u				√
Pine Warbler				u		o	u									√
Prairie Warbler		r		r												*
Prothonotary Warbler	u	u		u		o		r				u				√
Swainson's Warbler																*
Tennessee Warbler	c	c		c		c									u	√

Table B-1. Page 13

Wilson's Warbler					u		u		u		u	o				u	√
Worm-eating Warbler	o								u				u				√
Yellow Warbler	c		c		c		c		u		u		c				√
Yellow-throated Warbler	o				u		u		u							o	√
Louisiana Waterthrush	u		u		u		u		u				r				*
Northern Waterthrush	c		c		u		u		u		u		u				√
Cedar Waxwing					c		r	u					u			u	√
Bewick's Wren					c	ċ	c	c					c	ċ	c	c	√
Cactus Wren					accidental								c	ċ	c	c	*
Carolina Wren					u	u̇	u	u					u	u̇	u	u	√
House Wren			u		c		c	c	u		u	u			c	c	√
Long-billed Marsh Wren	u	u̇	u	u	u		u	c	c		c	c			u	u	√
Short-bellied Marsh Wren	c		c	c	u		u	u	c		c	c			u	u	√
Winter Wren			r														*
Yellowthroat	c	u̇	c	c	c		c	u	c	o	c	c	ċ		c	u	√
Cave Swallow																	√
White-collared Seedeater													r	r	r	r	
Black-throated Blue Warbler	r																
Common Grackle				c					u	u	u	u					
Rose-breasted Grosbeak	c								u		u		u				
Sharp-tailed Sparrow	o	ṙ	o	o	u		u	c				o				r	
Townsend's Warbler	accidental																
Common Crow					accidental				u		u	u					
Tufted Titmouse					accidental				u	u	u	u					
Carolina Chicadee					accidental				u	u	u	u					
Gray-headed Junco					accidental												
Black-headed Grosbeak					r												
Rusty Blackbird					o			o									
Bronzed Cowbird					u	u̇	u	c					c	ċ	u	u	
Rock Wren																r	
Varied Bunting													r	ṙ			

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Explanation of Symbols:

Season and abundance are coded as follows:

a - abundant
c - common
u - uncommon

o - occasional
r - rare

S March - May
S June - August
F September - November
W December - February

Accidental - out of normal range.

Those species marked with a ˙ nest on the refuge.
Those species marked with a * are rare and endangered species.

Bureau of Sport Fisheries and Wildlife, 1969, Birds of the Anahuac National Wildlife Refuge, U.S. Department of the Interior, Fish and Wildlife Service, Refuge Leaflet 223-R, U.S. Government Printing Office, Washington, D. C., October.

Bureau of Sport Fisheries and Wildlife, 1971, Birds of Aransas, U. S. Department of the Interior, Fish and Wildlife Service, RL-126-R-5, U. S. Government Printing Office, Washington, D. C., March.

Bureau of Sport Fisheries and Wildlife, 1969, Birds of the Brazoria National Wildlife Refuge, U. S. Department of the Interior, Fish and Wildlife Service, Refuge Leaflet 238, U. S. Government Printing Office, Washington, D. C., October.

Bureau of Sport Fisheries and Wildlife, 1969, Birds of the Laguna Atascosa National Wildlife Refuge, U.S. Department of the Interior, Fish and Wildlife Service, Refuge Leaflet 125-R4, U. S. Government Printing Office, Washington, D. C., June.

National Park Service, 1971, Padre Island Fact Sheets, U. S. Department of the Interior, National Park Service, Corpus Christi, Texas.

Table B-2. Bird Inventory of Anahuac National Wildlife Refuge.

	January - April		May - August		September - December	
	Average Total Est. Days Use	Average Peak Concentration	Average Total Est. Days Use	Average Peak Concentration	Average Total Est. Days Use	Average Peak Concentration
I. Waterfowl (Geese, Ducks, Coots)						
Geese	998,503	25,771	305	275	1,533,633	41,428
Ducks	954,789	18,518	29,544	821	2,611,967	122,102
Coots	34,145	465	5,024	115	47,264	630
II. Water and Marsh Birds						
	90,744	1,664	126,816	2,054	109,509.5	2,205
III. Shorebirds, Gulls, and Terns						
	54,000	1,528	63,573	1,808	54,881	1,819
IV. Doves and Pigeons						
	195	5	767	19	477	15
V. Predaceous Birds						
	6,342	93	2,199	27	6,955	456

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[1] Figures obtained from the Narrative Reports of the 1970 and 1971 Annual Reports of the Anahuac National Wildlife Refuge. All numbers rounded off to the nearest whole number.

Table B-3. Bird Inventory of Aransas National Wildlife Refuge.[1]

	January - April		May - August		September - December	
	Average Total Est. Days Use	Average Peak Concentration	Average Total Est. Days Use	Average Peak Concentration	Average Total Est. Days Use	Average Peak Concentration
I. Waterfowl (Geese, Ducks, Coots)						
Geese	275,583	6,562	--	--	706,827	19,848
Ducks	900,515	18,720	48,796	838	1,706,514	26,566
Coots	194,138	4,600	--	--	328,562	5,638
II. Water and Marsh Birds						
	(2)	4,736	(2)	3,399	(2)	7,958
III. Shorebirds, Gulls, Terns						
	(2)	8,238	(2)	7,463	(2)	7,818
IV. Doves and Pigeons						
	(2)	2,068	(2)	820	(2)	803
V. Predaceous Birds						
	(2)	1,479	(2)	1,280	(2)	1,211
VI. Upland Game Birds						
	(2)	955	(2)	1,558	(2)	1,120

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[1] Figures obtained from the Narrative Reports of the 1970 and 1971 Annual Reports of the Aransas National Wildlife Refuge. All numbers rounded off to the nearest whole number.

(2) Figures were not available.

Table B-4. Bird Inventory of Brazoria National Wildlife Refuge.[1]

	January - April		May - August		September - December	
	Average Total Est. Days Use	Average Peak Concentration	Average Total Est. Days Use	Average Peak Concentration	Average Total Est. Days Use	Average Peak Concentration
I. Waterfowl (Geese, Ducks, Coots)						
Geese	239,458	14,527	42	2	301,339	7,275
Ducks	273,134	5,223	14,364	382	585,487	7,366
Coots	26,755	556		1,264	18,897	655
II. Water and Marsh Birds	50,403	1,542	58,708	1,787	47,010	1,698
III. Shorebirds, Gulls, Terns	44,757	2,262	49,248	1,943	52,425	2,439
IV. Doves and Pigeons	687	24	4,137	79	606	13
V. Predaceous Birds	3,656	85	1,194	29	2,686	89

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[1] Figures obtained from the Narrative Reports of the 1967, 1968, 1969, 1970 and 1971 Annual Reports of Brazoria National Wildlife Refuge. All numbers rounded off to the nearest whole number.

Table B-5. Bird Inventory of Laguna Atascosa National Wildlife Refuge.[1]

	January - April		May - August		September - December	
	Average Total Est. Days Use	Average Peak Concentration	Average Total Est. Days Use	Average Peak Concentration	Average Total Est. Days Use	Average Peak Concentration
I. Waterfowl (Geese, Ducks, Coots)						
Geese	930,956	12,913	--	--	536,917	9,306
Ducks	4,467,983	113,940	324,393	16,983	6,714,363	113,141
Coots	2,789,203	107,625	95,297	1,590	10,657,354	186,214
II. Water and Marsh Birds						
	73,626	1,520	41,251	658	87,370	2,148
III. Shorebirds, Gulls, Terns						
	472,896	13,767	348,793	14,491	818,435	14,550
IV. Doves and Pigeons						
	383,033	3,841	609,336	4,740	343,875	4,444
V. Predaceous Birds						
	18,212	215	14,695	166	18,453	241
VI. Upland Game Birds						
	(2)	4,847	(2)	4,551	(2)	4,551

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[1] Figures obtained from the Narrative Reports of the 1970 and 1971 Annual Reports from Laguna Atascosa National Wildlife Refuge. All numbers rounded off to the nearest whole number.

(2) Figures were not available.

Table B-6. Mammals of the Texas Coast.

TERRESTRIAL MAMMALS [1]

Marsupialia	Pouched Mammals
Opossum	*Didelphis marsupialis*
Insectivoria	Insect-eaters
Eastern Mole	*Scalopus aquaticus*
Short-tailed Shrew	*Blaring brevicauda*
Little Short-tailed Shrew	*Cryptotis parva*
Crawford Shrew	*Notiosorex crawford*
Chiroptera	Bats
Georgia Bat	*Pipistrellus subflavus*
Big Brown Bat	*Eptesicus fuscus*
Hoary Bat	*Lasiurus cinereus*
Red Bat	*Lasiurus borealis*
Yellow Bat	*Lasiurus intermedius*
Evening Bat	*Nycticeius humeralis*
Guana Bat	*Tadarida mexicana*
Carnivora	Flesh-eaters
Raccoon	*Procyon lotor*
Coati	*Nasua narica*
Long-tailed weasel	*Mustela frenata*
Mink	*Mustela vison*
* River Otter	*Lutra canadensis*
Spotted Skunk	*Spirogale putorius*
Striped Skunk	*Mephitis mephitis*
Gulf Coast Hog-nosed Skunk	*Conepatus leuconotus*
Badger	*Taxidea taxus*
Gray Fox	*Urcyon cinereoargenteus*
Coyote	*Canis latrans*
* Red Wolf	*Canis rufus*
Ocelot	*Felix pardalis*
Cougar	*Felix conculor*
Jaguarundi	*Felix yagouaroundi*
Bobcat	*Lynx rufus*
Feral House Cat	*Felix domesticus*
Rodentia	Gnawing Mammals
Thirteen-lined Ground Squirrel	*Citellus tridecemlineatus*
Mexican Ground Squirrel	*Spermophilus mexicanus*
Spotted Ground Squirrel	*Citellus spilosoma*
Eastern Gray Squirrel	*Sciurus carolinensis*
Fox Squirrel	*Sciurus niger*
Eastern Flying Squirrel	*Glaucomys volans*

Plains Pocket Gopher	Geomys bursarius
South Texas Pocket Gopher	Geomys personatus
Merriam Pocket Mouse	Perognathus merriami
Hispid Pocket Mouse	Perognathus hispidus
Ord Kangaroo Rat	Dipodomys Ordi
Beaver	Castor canadensis
Short-tailed Grasshopper Mouse	Onychomys leucogaster
Long-tailed Harvest Mouse	Reithrodontomys fulvescens
Pigmy Mouse	Baiomys taylori
Deer Mouse	Peromyscus maniculatus
White-footed Mouse	Peromyscus leucopus
Cotton Mouse	Peromyscus gossypinus
Northern Rice Rat	Oryxomys palustrus
Coues Rice Rat	Oryxomys couesi
Hispid Cotton Rat	Sigmodon hispidus
Florida Wood Rat	Neotoma floridana
Gray Wood Rat	Neotoma micropus
* Muskrat	Ordatra zibethicus
House Mouse	Mus musculus
Root Rat	Rattus rattus
Norway Rat	Rattus norvegieus
Nutria	Myocaster coypus
Lagomorpha	Pikas, Hares, and Rabbits
California Jack Rabbit	Lepus californicus
Eastern Cottontail	Sylvilagus floridanus
Audubon Cottontail	Sylvilagun auduboni
Swamp Rabbit	Sylvilagus aquaticus
Artiodactyla	Even-toed Hoofed Mammals
Peccary or Javelina	Dicotyles tajacu
White-tailed Deer	Odocoileus virginianus
Xenothera	Sloths and Armadillos
Nine-banded Armadillo	Dasypus novemcinctus

MARINE MAMMALS [2]

Pinnipedia	Seals
* West Indian Seal	*Monachus tropicalis*
Sirenia	Manatees
* West Indian Manatee	*Trichecus manatus*
Cetacea	Whales
* Sperm Whale	*Physeter catadon*
* Pygmy Sperm Whale	*Kogia breviceps*
Dwarf Sperm Whale	*Kogia simus*
Gulf Stream Beaked Whale	*Mesoplodon europaeus*
Goose-beaked Whale	*Ziphius cavirostris*
Pygmy Killer Whale	*Feresa attenuata*
Pilot Whale	*Globicephala macrorhyncha*
Atlantic Killer Whale	*Orcinus orca*
Rough-toothed Dolphin	*Steno bredanensis*
Common Finback Whale	*Balaenoptera physalus*
False Killer Whale	*Pseudorca crassidens*
Spotted Dolphin	*Stenella plagiodon*
Cuvier's Dolphin	*Stenella frontalis*
Bottlenose Dolphin	*Tursiops truncatus*
Blue Whale	*Balaenoptera musculus*
Black Right Whale	*Balaena glacialis*

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[1] From the Mammals of Texas by Davis, 1966.

[2] From Annotated Checklist and Key to the Cetaceans of Texas Waters by Schmidly and Reeves, 1972.

* Rare or endangered species.

Table B-7. Inventory of Mammals, Anahuac National Wildlife Refuge.[1]

Species	Average Population
Opossum	38
Raccoon	63
Mink	15
* River Otter	20
Striped Skunk	5
Red Wolf	6
Bobcat	5
* Muskrat	3,700
* Nutria	5,000
Cottontail Rabbit	300
* Swamp Rabbit	1,250
Armadillo	23
Spotted Skunk	1

[1] Figures obtained from the Narrative Reports of the 1970 and 1971 Annual Reports of Anahuac National Wildlife Refuge. All numbers rounded off to the nearest whole number.

*Mammals living in an aquatic habitat.

Table B-8. Inventory of Mammals, Aransas National Wildlife Refuge.[1]

Species	Average Population
White-tailed Deer	3,292
Javelina	330
Coyote	160
Bobcat	150
Raccoon	5,000
Opossum	725
Striped Skunk	525
* Nutria	153
Fox Squirrel	350
Cottontail Rabbit	1,000
Black-tailed Jack Rabbit	800
Red Wolf	35

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[1] Figures obtained from the Narrative Reports of Aransas National Wildlife Refuge. All numbers rounded off to the nearest whole number.

*Mammals living in an aquatic habitat.

Table B-9. Inventory of Mammals,
Brazoria National Wildlife Refuge. [1]

Species	Average Population
* Muskrat	19
Raccoon	39
Red Wolf	5
Bobcat	3
* Nutria	119
Striped Skunk	9
Eastern Cottontail	17
Black-Tailed Jack Rabbit	3
* Swamp Rabbit	8
Armadillo	30
Opossum	10
* River Otter	5
* Beaver	4(2)

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[1] Figures obtained from the Narrative Reports of the 1967, 1968, 1969, 1970, and 1971 Annual Reports of Brazoria National Wildlife Refuge. All numbers rounded off to the nearest whole number.

(2) Current population estimate based on other tracks.

* Mammals living in an aquatic habitat.

Table B-10. Inventory of Mammals,
Laguna Atascosa National Wildlife Refuge. [1]

Species	Average Population
White-Tailed Deer	953
Javelina	113
Armadillo	80
Ground Squirrel	1,150
Opossum	300
Pack Rat	6,500
Raccoon	500
Bridled Weasel	35
Skunk	25
Badger	10
* Nutria	68
Coyote	78
Jaguarundi	5
Ocelot	10
Jack Rabbit	300
Cottontail Rabbit	1,200
Pocket Gopher	100
Mountain Lion	1
Bobcat	28

[1] Figures obtained from the Narrative Reports of Laguna Atascosa National Wildlife Refuge. All numbers rounded off to the nearest whole number.

* Mammals living in an aquatic habitat.

Table B-11. Mammals on Padre Island.[1]

TERRESTRIAL MAMMALS

Opossum
Eastern Mole
Yellow Bat
Mexican Free-tailed Bat
Raccoon
Badger
Striped Skunk
Coyote
Gray Fox
Spotted Ground Squirrel
Thirteen-lined Ground Squirrel
Texas Pocket Gopher
Merriam Pocket Mouse
Ord Kangaroo Rat
Fulvous Harvest Mouse
Grasshopper Mouse
Eastern Rice Rat
Cotton Rat
House Mouse
Black-tailed Jackrabbit
Eastern Cottontail
Javelina
White-tailed Deer
Nine-banded Armadillo

MARINE MAMMALS

Beaked Whale
Sperm Whale
Pygmy Sperm Whale
Bottle-nosed Dolphin
Spotted Dolphin
Atlantic Killer Whale
Short-finned Blackfish

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[1] From Padre Island National Seashore Mammal Checklist, National Park Service, 1971.

Table B-12. Amphibians and Reptiles of the Texas Coastal Zone.[1]

AMPHIBIANS

Salamanders	
Lesser Siren	*Siren intermedia*
Marbled Salamander	*Ambystoma opacum*
Small-Mouthed Salamander	*Ambystoma texanum*
* Tiger Salamander	*Ambystoma tigrinum*
Black-Spotted Newt	*Notophthalmus meridionalis*
Common Newt	*Notophthalmus viridescens*
Amphiuma	*Amphiuma means*
Southern Dusky Salamander	*Desmognathus auriculatus*
Dwarf Salamander	*Eurycea quadridigitata*
Anurans (Frogs and Toads)	
Plains Spadefoot	*Scaphiopus bombifrons*
Couch's Spadefoot	*Scaphiopus couchi*
* Eastern Spadefoot	*Scaphiopus holbrooki*
Cricket Frog	*Acris crepitans*
* Green Treefrog	*Hyla cinerea*
Spring Peeper	*Hyla crucifer*
Squirrel Treefrog	*Hyla squirella*
Northern Gray Treefrog	*Hyla versicolor*
Southern Gray Treefrog	*Hyla chrysoscelis*
Spotted Chorus Frog	*Pseudacris clarki*
Strecker's Chorus Frog	*Pseudacris streckeri*
Western Chorus Frog	*Pseudacris triseriata*
Green Toad	*Bufo debilis*
* Texas Toad	*Bufo speciosus*
* Gulf Coast Toad	*Bufo valliceps*
Woodhouse's Toad	*Bufo woodhousei*
Crawfish Frog	*Rana aerolata*
Bullfrog	*Rana catesbeiana*
Green Frog	*Rana clamitans*
Pickerel Frog	*Rana palustris*
* Leopard Frog	*Rana pipiens*
Eastern Narrow-Mouthed Toad	*Gastrophryne carolinensis*
Great Plains Narrow-Mouthed Toad	*Gastrophryne olivacea*
Sheep Frog	*Hypopachus cuneus*

REPTILES

Turtles	
* Common Snapping Turtle	*Chelydra serpentina*
Alligator Snapping Turtle	*Macroclemys temmincki*
* Yellow Mud Turtle	*Kinosternon flavescens*
* Eastern Mud Turtle	*Kinosternon subrubrum*

Table B-12. Page 2

Stinkpot	*Sternothaerus odoratus*
* River Coote	*Chrysemys concinna*
Cooter	*Chrysemys floridana*
* Pond Slider	*Chrysemys scripta*
Chicken Turtle	*Deirochelys recticularia*
* Diamondback Terrapin	*Malaclemys terrapin*
* Eastern Box Turtle	*Terrapene carolina*
Western Box Turtle	*Terrapene ornata*
* Texas Tortoise	*Gopherus berlandieri*
* Smooth Softshell	*Trionyx muticus*
Spring Softshell	*Trionyx spiniferus*
* Loggerhead	*Caretta caretta*
* *Green Turtle*	*Chelonia mydas*
* *Atlantic Ridley*	*Lepidochelys olivacea*
* *Leatherback*	*Dermochelys coriacea*
Crocodiles and Alligators	
* *Alligator*	*Alligator mississippiensis*
Lizards and their Allies	
Mediterranean Gecko	*Hemidactylus turcicus*
Texas Banded Gecko	*Coleonyx brevis*
* Green Anole	*Anolis carolinensis*
Spot-Tailed Earless Lizard	*Holbrookia lacerata*
* Keeled Earless Lizard	*Holbrookia propinqua*
* Texas Horned Lizard	*Phrynosoma cornutum*
Texas Spring Lizard	*Sceloporus olivaceus*
Eastern Fence Lizard	*Sceloporus undulatus*
Rose-Bellied Lizard	*Sceloporus variabilis*
Short-Lined Skink	*Eumeces brevilineatus*
Five-Lined Skink	*Eumeces fasciatus*
Broad-Headed Skink	*Eumeces laticeps*
* Great Plains Skink	*Eumeces obsoletus*
Prairie Skink	*Eumeces septentrionalis*
* Ground Skink	*Lygomosa laterale*
* Texas Spotted Whiptail	*Cnemidophorus gularis*
* Six-Lined Racerunner	*Cnemidophorus sexlineatus*
* Slender Glass Lizard	*Ophisaurus attenuatus*
* Four-Lined Skink	*Eumences tetragrammus*
* Eastern Spotted Whiptail	*Cnemidophorus sacki*
Serpents (Non-Venomous)	
* Texas Blind Snake	*Leptotyphlops dulcis*
* Glossy Snake	*Arizona elegans*
* Racer	*Coluber constrictor*
Ringneck Snake	*Diadophis punctatus*
* Indigo Snake	*Drymarchon corais*
Corn Snake	*Elaphe guttata*

Table B-12. Page 3

* Common Rat Snake	*Elaphe obsoleta*
Mud Snake	*Farancia abacura*
* Western Hognose Snake	*Heterodon nasicus*
* Eastern Hognose Snake	*Heterodon platyrhinos*
Night Snake	*Hypsiglena torquata*
* Prairie Kingsnake	*Lampropeltis calligaster*
* Common Kingsnake	*Lampropeltis getulus*
* Milk Snake	*Lampropeltis triangulum*
* Coachwhip	*Masticophis flagellum*
Striped Whipsnake	*Masticophis taeniatus*
* Green Water Snake	*Natrix cyclopion*
* Plain-Bellied Water Snake	*Natrix erythrogaster*
* Broad-Banded Water Snake	*Natrix fasciata*
* Graham's Water Snake	*Natrix grahami*
* Diamond-Backed Water Snake	*Natrix rhombifera*
Glossy Water Snake	*Natrix rigida*
* Rough Green Snake	*Opheodrys aestivus*
* Bullsnake	*Pituophis melanoleucus*
Long-Nosed Snake	*Rhinocheilus lecontei*
* Mountain Patch-Nosed Snake	*Salvadora grahamiae*
Great Plains Ground Snake	*Sonora episcopa*
* Brown Snake	*Storeria dekayi*
* Flat-Headed Snake	*Tantilla gracilis*
* Plains Black-Headed Snake	*Tantilla nigriceps*
* Checkered Garter Snake	*Thamnophis marcianus*
* Western Ribbon Snake	*Thamnophis proximus*
* Common Garter Snake	*Thamnophis sirtalis*
Lined Snake	*Tropidoclonion lineatum*
* Rough Earth Snake	*Virginia striatula*
Serpents (Venomous)	
* Coral Snake	*Micrurus fulvius*
Copperhead	*Agkistrodon contortix*
* Cottonmouth	*Agkistrodon piscivorous*
* Massasanga	*Sistrurus catenatus*
* Pygmy Rattlesnake	*Sistrurus miliarius*
* Western Diamondback Rattlesnake	*Crotalus atrox*
Timber Rattlesnake	*Crotalus horridus*

[1] From Rawn and Gehlback, 1972.

*Species which have been found on the National Wildlife Refuges or on Padre Island National Seashore.

Those species whose <u>common names</u> are underlined are rare or endangered species.

Table B-13. Benthic Macro-Faunal Assemblages.[1]

A. FRESHWATER

1. *Freshwater assemblage* (shallow coastal waters; soft bottom; salinity 0.1 ppt or less)

Porifera
Myenia crateriformis, *Trochospongilla leidii*

Ectoprocta
Pectinatella magnifica

Gastropoda
Amnicola spp., *Physa spp.*

Pelecypoda
Anodonta gibbosa, *A. imbecillus*, *Elliptio arctatus*, *E. crassidens*, *Lampsilis anodontoides*, *L. claibornensis*, *Micromya lienosa*, *M. vibex*, *Quadrula succissa*, *Sphaerium partumeium*

Crustacea
Procambarus clarkii

B. LAGOONAL

2. *Marine influenced river assemblage* (shallow; soft bottom; salinity fluctuating daily or irregularly, 0.0 - 1.0 ppt; with or without emergent vegetation along the margins)

Porifera
Trochospongilla leidii

Cnidaria
Cordylophora lacustris

Ectoprocta
Plumatella repens

Annelida
Laeonereis culveri, *Polydora sp.*

Gastropoda
Amnicola sp., *Neritina reclivata*, *Physa spp.*

Pelecypoda
Congeria leucophaeta, *Rangia cuneata*

Table B-13. Page 2

Crustacea
Asellus attenuatus, *Balanus amphitrite niveus*, *Balanus improvisus*, *Callinectes sapidus*, *Carcinogammarus mucronatus*, *Corophium crassicorne*, *Crangonyx gracilis*, *Crassidisca lunifrons*, *Macrobrachium ohione*, *Mysis stenolepis*, *Palaemonetes pugio*, *Rithropanopeus harrissii*, *Sphaeroma terebrans*, *Uca minax*, *Uca pugnax*

3. *River influenced low-salinity bay assemblage* (shallow; soft bottom; salinity approximately 0 - 10 ppt; bordered by emergent vegetation)

Gastropoda
Littoridina sphinctostoma

Pelecypoda
Macoma mitchelli, *Polymesoda carolinensis*, *Rangia cuneata*, *Rangia flexuosa*

Crustacea
Callinectes sapidus, *Macrobrachium spp.*

4. *Freshwater and low salinity marsh assemblage* (shallow; soft bottom with vegetation cover; salinity approximately 1 - 10 ppt)

Plants
Spartina alterniflora, *Thalassia testudinum*

Gastropoda
Littorina irrorata, *Neritina reclivata*

Crustacea
Cambarus spp., *Uca pugilator*

5. *Enclosed bay or inter-reef assemblage* (deeper; soft bottom; salinity approximately 10 - 20 ppt)

Gastropoda
Retusa canaliculata (dead)

Pelecypoda
Brachiodontes recurvus, *Crassostrea virginica*, *Ensis minor*, *Lucina pectinata*, *Macoma constricta*, *Mulinia lateralis*, *Nuculana concentrica*, *Tagelus plebius*

Echinodermata
Amphiodia limbata

6. Lower bay shallow and bay margin assemblage (shallow region at edge of bay; soft bottom with vegetation; salinity approximately 10 - 20 ppt)

   Plants
   Gracillaria confervoides, Ruppia maritima, Spartina alterniflora, Thalassia testudinum

   Gastropoda
   Littorina irrorata, Littorina ziczac, Melampus bidentatus, Melampus coffeus, Nassarius vibex, Neritina virginea, Siphonaria pectinata

   Pelecypoda
   Aequipecten irradians, Chione cancellata, Mercenaria m. campechiensis, Ostrea edulis, Tagelus divisus, Trachycardium muricatum

   Crustacea
   Clibanarius vittatus, Palaemonetes spp., Rithropanopeus harrissii, Uca spp.

7. Lower bay or open sound center assemblage (shallow to relatively deep; soft bottom; salinity approximately 15 - 30 ppt)

   Cnidaria
   Astrangia astraeiformis

   Gastropoda
   Fasciolaria distans, Nassarius acutus, Nassarius vibex, Polinices duplicata, Retusa canaliculata

   Pelecypoda
   Abra aequalis, Corbula contracta, Mulinia lateralis, Nuculana concentrica, Ostrea equestris, Trachycardium muricatum

   Crustacea
   Heterocrypta granulata, Hexapanopeus angustifrons

   Echinodermata
   Arbacia punctulata, Mellita quinquiesperforata

8. Low salinity oyster reef assemblage (relatively shallow; bottom hard, probably of old reef; salinity approximately 5 - 15 ppt)

   Gastropoda
   Crepidula plana

Table B-13. Page 4

Pelecypoda
Brachidontes recurvus, *Congeria leucophaeta*, *Crassostrea virginica*

Crustacea
Balanus amphitrite niveus, *Balanus eburneus*

9. *High salinity oyster reef assemblage* (relatively shallow; bottom hard, probably of old reef; salinity approximately 10 - 30 ppt. Many of the species listed here would also be in the low salinity reef biocoenosis).

Cnidaria
Aiptasia pallida

Porifera
Cliona spp.

Platyhelminthes
Sylochus inimicus

Annelida
Polydora websteri

Gastropoda
Anachis avara semiplicata, *Anachis obesa*, *Crepidula fornicata*, *Crepidula plana*, *Mitrella lunata*, *Odostomia impressa*, *Thais haemastoma floridana*

Pelecypoda
Anomia simplex, *Brachidontes exustus*, *Brachidontes recurvus*, *Crassostrea virginica*, *Ostrea equestris*

Crustacea
Balanus eburneus, *Balanus improvisus*, *Callinectes sapidus*, *Crangon heterochelis*, *Eurypanopeus depressus*, *Menippe mercenaria*, *panopeus herbstii*, *Petrolisthes armatus*

Echinodermata
Phiothrix angulata

10. *Tidal pass and inlet assemblage* (relatively deep; bottom of mud or sand; salinity fluctuating with the tides, as much as 20 - 36 ppt)

Cnidaria
Astrangia astreiformis

Scaphopoda
Dentalium texasianum

Gastropoda
Anachis avara similis, *Cerithidea pliculosa*, *Cerithium variable*, *Olivella mutica*, *Polinices duplicata*, *Thais Haemastoma floridana*

Pelecypoda
Chione cancellata, *Crassinella lunulata*, *Lucina amiantus*, *Lucina crenella*, *Tellidora cristata*

Crustacea
Menippe mercenaria

Echinodermata
Luidia clathrata, *Mellita quinquiesperforata*, *Ophiolepis elegans*

11. *Hypersaline lagoon assemblage* (relatively shallow; bottom of mud or sand; salinity widely variable with common ranges of 30 - 100 ppt, sometimes higher or much lower)

Plants
Diplanthera wrightii, *Ruppia maritima*

Annelida
Nereis pelagica occidentalis, *Polydora ligni*

Gastropoda
Aplysia dactylometra, *Cerithium variable*, *Littorina ziczac*

Pelecypoda
Aceton cadens, *Anomalocardia cuneimeris*, *Brachidontes recurvus*, *Cardium sp.*, *Crassostrea virginica*, *Mulinia lateralis*, *Tagelus gibbus*, *Tellina tampaensis*

Crustacea
Artemia salina, *Balanus amphitrite*, *Balanus eburneus*, *Callinectes danae*, *Callinectes sapidus*, *Neopanope t.* texana, *Palaemonetes intermedius*, *Penaeus aztecus*, *Podocerus brasiliensis*

12. *Open hypersaline lagoon, near inlet, assemblage* (relatively shallow; bottom of mud or sand; salinity less widely variable due to interchange with open Gulf, probably 30 - 50 ppt)

Gastropoda
Bittium varium, *Caecum pulchellum*, *Cerithidea pliculosa*, *Cerithium variable*, *Vermicularia fargoi*

Pelecypoda
Amygdalum papyria, *Anomalocardia cuneimeris*, *Laevicardium mortoni*, *Pseudocyrena floridana*

C. GULF MARGIN

13. *Open gulf jetty assemblage* (relatively shallow; jetties of stone or concrete, adjacent bottoms of mud or sand; salinity usually near marine levels, 25 or 30 - 36 ppt)

Plants
Gelidium sp., *Gracilaria sp.*, *Padina sp.*, *Ulva sp.*

Cnidaria
Bunodosoma cavernata

Gastropoda
Littorina irrorata, *Littorina ziczac*, *Siphonaria pectinata*, *Thais haemastoma floridana*

Pelecypoda
Brachidontes recurvus

Crustacea
Balanus eburneus, *Chthalalus fragilis*, *Clibinarius vittatus*, *Ligyda exotica*, *Pachygrapsus transversus*

Echinodermata
Arbacia punctulata

14. *Surf zone, sand beach, assemblage* (shallow surf zone and adjacent sand beach; salinity usually about 36 ppt)

Gastropoda
Olivella mutica, *Terebra cinerea*, *Terebra dislocata*

Pelecypoda
Donax tumida, *Donax variabilis*

Crustacea
Callinectes sapidus, *Emerita talpoida*? (or *portoricensis?*), *Ocypode albicans*

D. OPEN GULF

15. Inner shelf assemblage (relatively shallow, 2 - 12 fathoms; bottom of sand or mud or mixed sand and mud; salinity usually about 36 ppt)

Cnidaria
Renilla mulleri

Annelida
Diopatra cuprea

Gastropoda
Architectonica nobilis, *Busycon plagosum* texana, *Nassarius acutus*, *Oliva sayana*, *Phalium granulatum*, *Polinices duplicatus*, *Terebra dislocata*, *Terebra protexta*, *Thais haemastoma* floridana

Pelecypoda
Anachis obesa, *Arca campechiensis*, *Arca transversa*, *Atrina serrata*, *Chione intapurpurea*, *Corbula swiftiana*, *Dinocardium robustum*, *Dosinia discus*, *Mulinia lateralis*, *Solen viridis*, *Spisula solidissima* raveneli, *Tellina tayloriana*, *Varicorbula operaculata*

Crustacea
Arenaeus cribarius, *Calappa springeri*, *Callianassa latispina*, *Callinectes danae*, *Callinectes sapidus*, *Hepatus epheliticus*, *Penaeus aztecus*, *Penaeus duoroum*, *Penaeus setiferus*, *Persephone punctata*, *Portunus gibbesi*, *Portunus spinimanus*, *Squilla empusa*, *Xiphopeneus kryeri*

16. *Intermediate shelf assemblage* (deeper, 12 to 35 fathoms, bottom of mud or sand, salinity about 36 ppt. Some of the species listed are apparently more characteristic of mud bottoms than sand bottoms, or vice versa; these are indicated by (m) for mud bottom, and (s) for sand bottom.)

Cnidaria
Leptogorgia setacea, *Paranthus rapiformis*, *Renilla mulleri*

Annelida
Diopatra cuprea

Gastropoda
Anachis ornata (m), *Anachis saintpairiana* (m), *Antilliphos sp. (candei?)* (s), *Busycon contrarium* (m), *Busycon pyrum* (m), *Distorsio clathrata*, *Fasciolaria hunteria* (s), *Murex Fulvescens* (s), *Murex pomum* (s), *Nassarius ambiguus* (m), *Nassarina glypta* (m), *Phalium granulatum* (m), *Strombus alatus* (s), *Tonna galea*

Pelecypoda
Aequipecten gibbus gibbus (s), Aequipecten muscosus (s), Atrina serrata (m), Chione clenchi (s), Chione grus (s), Gouldia cerina (s), Lucina sombrerensis (s), Nuculana concentrica (m), Nucula proxima (m), Pandora bushian (m), Phylloda squamifera (s), Pitar cordata (m), Quadrans lintea (s), Semele purpurescens (s), Tellina georgiana (s), Varicorbula operculata (m), Yoldia solenoides (m)

Cephalopoda
Loligo Pealei, Loliguncula brevis

Crustacea
Calappa springeri, Callinectes danae, Hepatus epheliticus, Penaeus aztecus, Penaeus duororum, Penaeus setiferus, Persephone punctata, Petrochirus bahamensis, Portunus gibbesi, Portunus spinimanus, Sicyonia brevirostris, Sicyonia dorsalis, Solenocera vioscai, Squilla empusa, Trachypeneus constrictus, Trachypeneus similis, Xiphopeneus kryeri

Echinodermata
Astropecten antillensis, Clypeaster ravenelli, Luidia alternata, Luidia clathrata

17. Outer shelf assemblage (deep, 40 - 65 fathoms; bottom of soft mud; salinity 36 ppt)

Gastropoda
Conus clarki, Distorsio mcgintyi, Muricopsis hexagona, Natica canrena, Polystira albida, Sconsia striata, Turitella exoleta

Pelecypoda
Anadara baughmani, Cuspidaria ornatissima, Eucrassatella speciosa, Laevicardium fiski, Microcardium transversum, Mulinia lateralis, Nuculana jamaicensis, Pecten papyraceus, Pitar cordata, Poromya granulata, Verticordia ornata

Crustacea
Raninoides louisianense

Echinodermata
Astropecten duplicatus, Clypeaster prostratus

18. Northern gulf, calcareous bank assemblage (relatively shallow; salinity about 36 ppt)

Gastropoda
Calyptraea centralis, *Crucibulum auricula*, *Liota bairdi*

Pelecypoda
Arca umbonata, *Barbatia candida*, *Barbatis domingensis*, *Chama macerophylla*, *Corbula dietziana*, *Echinochama cornuta*, *Lima tenera*, *Papyridea soleniformis*, *Plicatula gibbosa*

19. *Northern gulf epifaunal assemblage*

Cnidaria
Aiptasia pallida, *Anthopleura krebsi*, *Astrangia astreiformis*, *hydroids* (many species, primarily *Obelia dichotoma*)

Ectoprocta
Acanthodesia sp.

Gastropoda
Crepidula fornicata, *Thais haemastoma* floridana

Pelecypoda
Brachidontes recurvus, *Ostrea equestris*

Annelida
Eupomatus sp.

Crustacea
Balanus improvisus, *Corophium sp*., *Menippe mercenaria*

20. *Upper continental slope assemblage* (deep, 65 - 600 fathoms; soft mud bottom; salinity about 36 ppt)

Gastropoda
Fusinus cowei, *Polystira tellea*, many rare species of gastropods

Pelecypoda
Astarte nana, *Cuspidaria granulata*, *Cyclopecten nanus*, *Limopsis sulcata*, *Microcardium permabile*, *Venericardia armilla*, *Verticordia fischeriana*, *Yoldia solenoides*, many rare species of pelecypods

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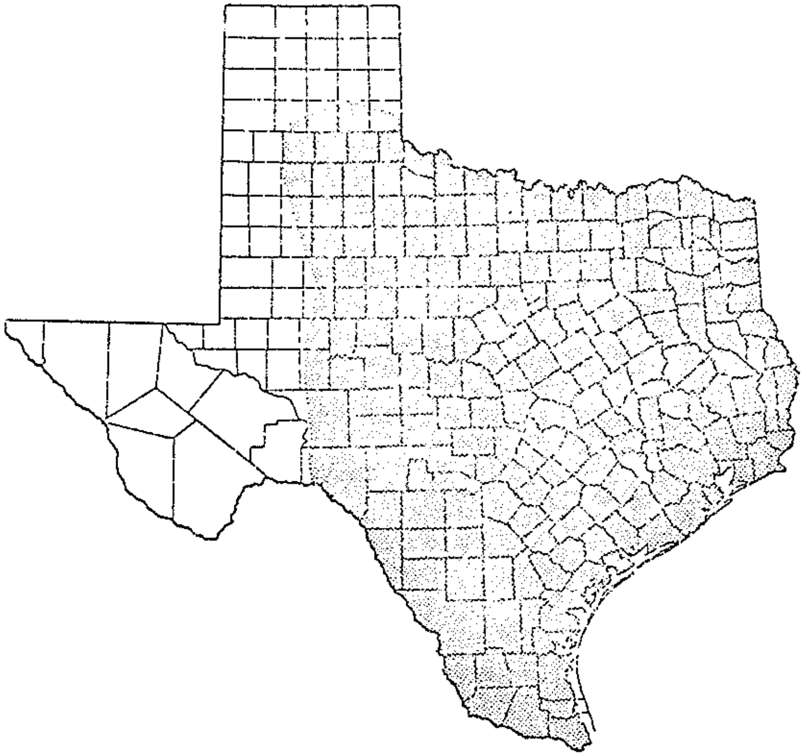
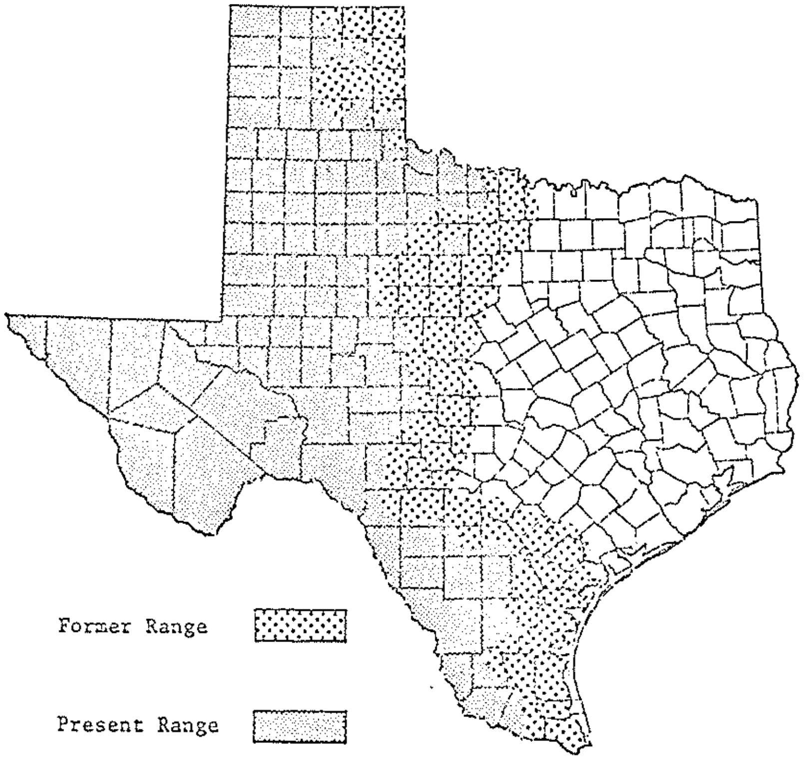
[1] Benthic macro-faunal assemblages of the northwestern coast of the Gulf of Mexico, arranged by habitat. The lists have been derived from the existing literature and have not been verified by the authors. Only the most common and characteristic organisms have been included.



Source: U. S. Study Commission - Texas, 1962.

Figure B-1. Fox Squirrel Distribution.

Figure B-2. Grey Squirrel Distribution.



Source: Texas Parks and Wildlife Species Distribution Maps.

Figure B-3. Scaled Quail Distribution

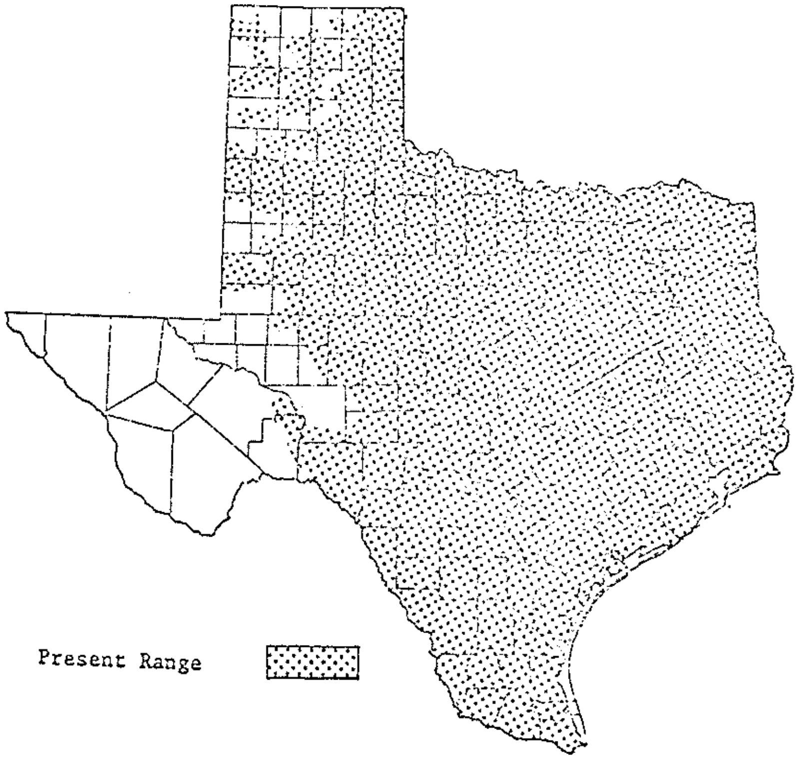
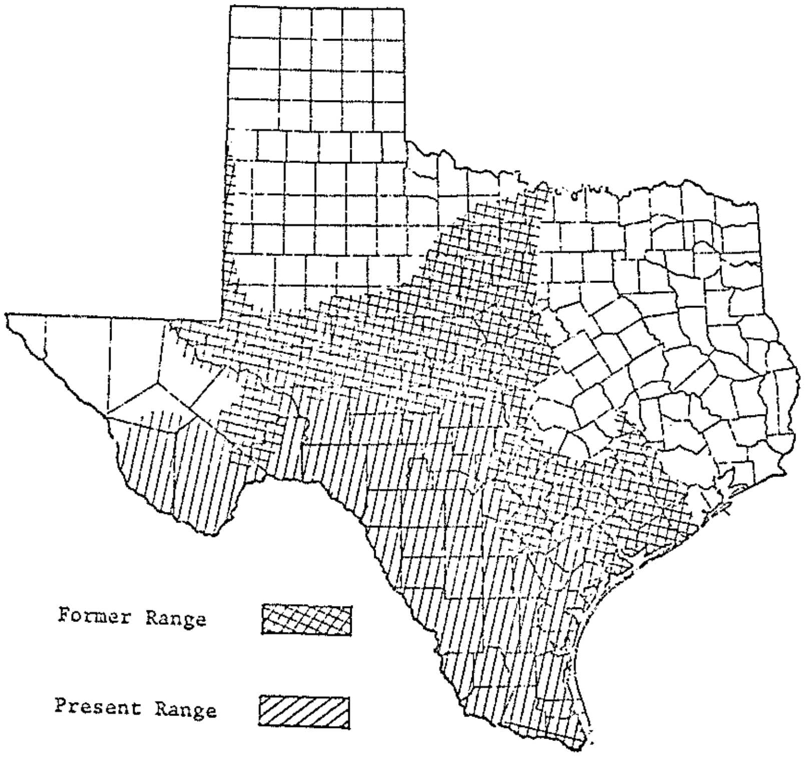


Figure B-4. Bobwhite Quail Distribution.



Source: Texas Parks and Wildlife Species Distribution Maps.

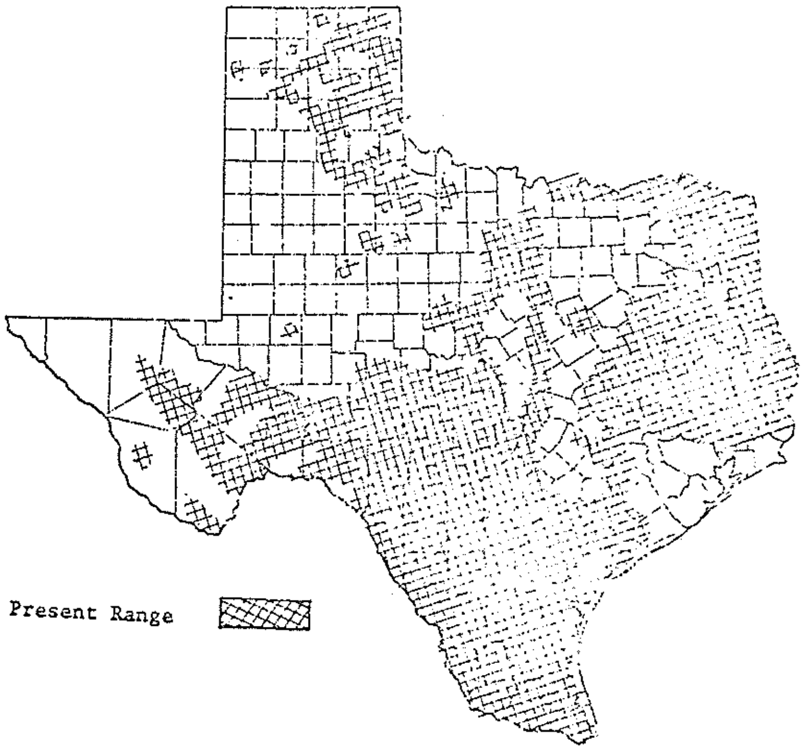
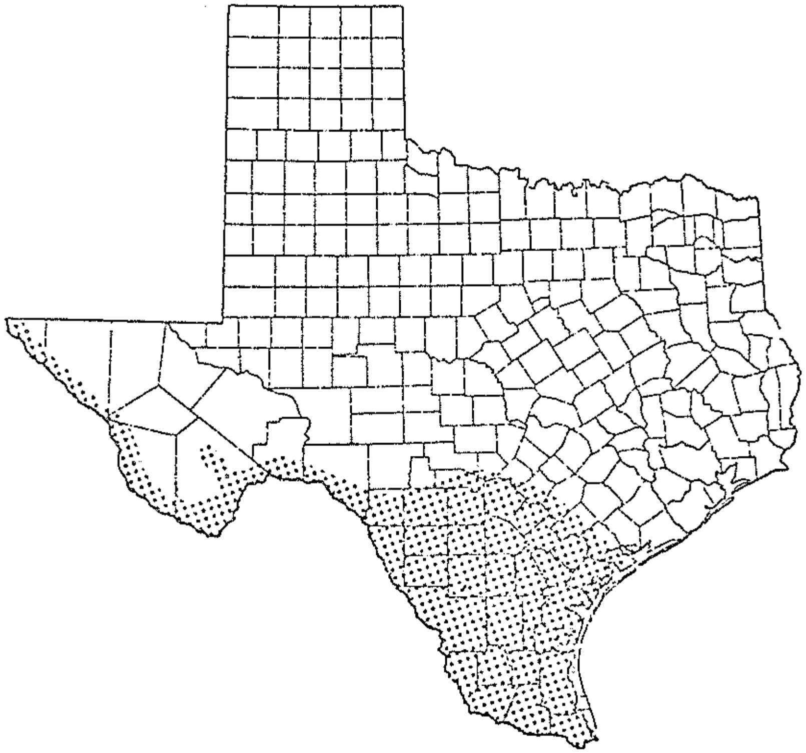


Figure B-5. Collared Pecuary (Javelina) Distribution.

Figure B-6. White-Tailed Deer Distribution.



Source: U. S. Study Commission - Texas, 1962.

Figure B-7. White Winged Dove Distribution.

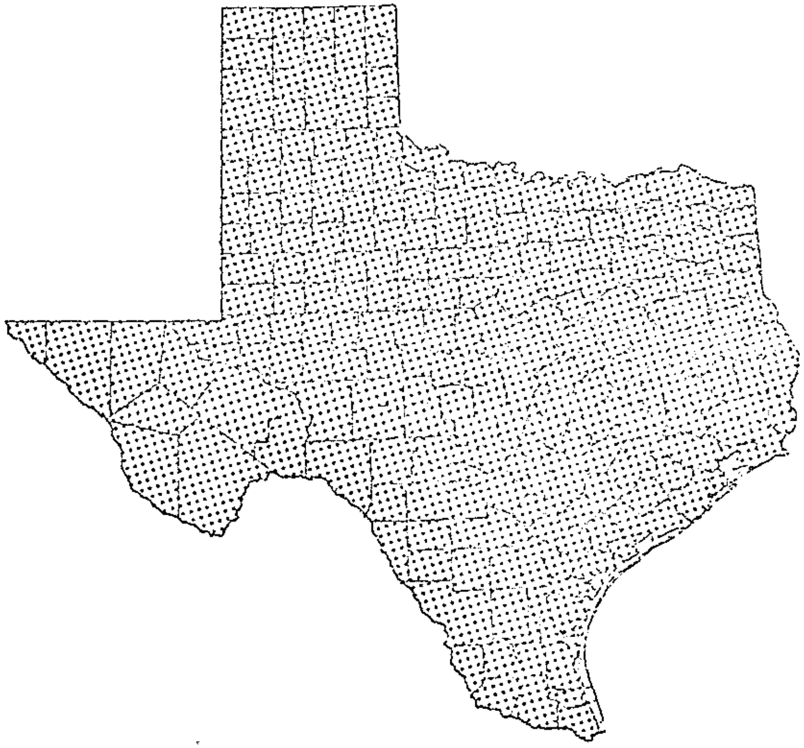
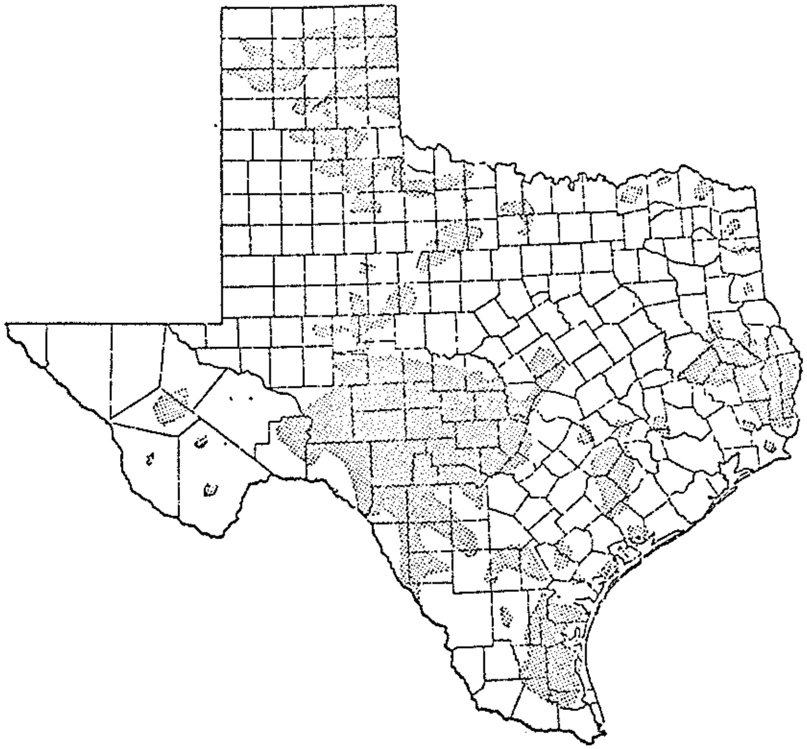


Figure B-8. Mourning Dove Distribution.



Source: Texas Parks and Wildlife Species Distribution Maps.

Figure B-9. Wild Turkey Distribution.

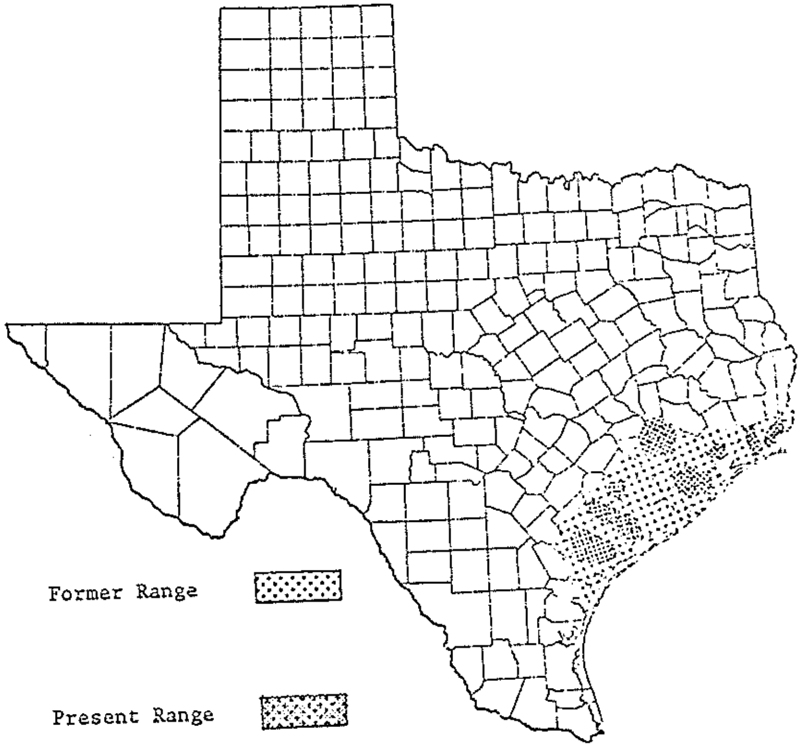


Figure B-10. Atwater Prairie Chicken Distribution.

Table B-14. Relative Value of Texas Catch of Finfish and Shellfish.

Specis	Percentage of Total Value [a]
Finfish	
Cabio (Ling)	.002
Croaker	.004
Drum	
Black	.167
Red (Redfish)	.694
Flounders	
Unclassified	.108
Groupers	.019
King Whiting (Kingfish	.008
Mullet	.005
Pompano	.002
Sea Catfish (Gafftopsail)	.004
Sea Trout	
Spotted	.512
White	.0003
Sheepshead (salt water)	.014
Snapper, Red	.710
Warsaw	
Unclassified:	
For Food	.008
For Bait Reduction and Animal Food	1.508
TOTAL FINFISH	3.768
Shellfish	
Crabs, Blue	.813
Oysters, Meats	3.408
Shrimp (Heads-On)	
Brown and Pink	76.152
White	15.848
Other	.008
Squid	.002
TOTAL SHELLFISH	96.232

[a] 1971 figures

Source: Texas and the Gulf of Mexico, Department of Marine Resources Information, Texas A&M University, 1972.

Table B-15. Relative Values of Texas
Finfish and Shellfish by Region.

Region	Percentage of Total Value	
	Finfish	Shellfish
Gulf of Mexico	65.972	90.179
Sabine Lake	-	.320
Galveston and Trinity Bays	1.284	6.564
Matagorda, East Matagorda and Lavaca Bays	2.256	1.457
San Antonio, Mesquite, Espiritu Santo Bays and Green Lake	2.037	.895
Aransas and Copano Bays	4.558	.474
Corpus Christi and Nueces Bays	1.394	.107
Baffin Bay and Upper Laguna Madre	11.296	.000036
Central and Lower Laguna Madre	11.179	.003

Source: Texas and the Gulf of Mexico, Department of Marine Resources Information, Texas A&M University, 1972.

Table B-16. Relative Value of Texas Shrimp by Region.

Region	Percentage of Total Value
Gulf of Mexico	94.309
Sabine Lake	.042
Galveston and Trinity Bays	3.330
Matagorda, East Matagorda, Lavaca Bays	1.279
San Antonio, Mesquite Espiritu Santo Bays, and Green Lake	.584
Aransas and Copano Bays	.385
Corpus Christi & Nueces Bays	.096

Source: Texas and the Gulf of Mexico, Department of Marine Resources Information, Texas A&M University, 1972.

Table B-17. Partial List of Texas Coastal Plants.

TYPHACEA			
	Typha	*latifolia*	Common cattail
GRAMINEAE			
	Andropogon	*barbinodis*	Cane bluestem
	A.	*glomeratus*	Bushy bluestem
	A.	*saccharoides*	Silver Bluestem
	A.	*virginicus*	Broomsedge bluestem
	Aristida	*oligantha*	Olkfield threeawn
	A.	*purpurea*	Purple threeawn
	A.	*roemeriana*	Roemer threeawn
	Brachiaria	*ciliatissima*	Fringed signalgrass
	Cenchrus	*incertus*	Coast sandbur
	C.	*pauciflorus*	Mat sandbur
	C.	*tribuloides*	Dune Sandbur
	Chloris	*cucullata*	Hooded windmillgrass
	C.	*gavana*	Rhodesgrass
	C.	*petraea*	Stiffleaf windmillgrass
	C.	*verticillata*	Tumble windmillgrass
	Cynodon	*dactylon*	Bermudagrass
	Digitaria	*sanguinalis*	Hairy crabgrass
	D.	*runyoni*	Dune crabgrass
	* *Distichlis*	*spicata*	Seashore saltgrass
	Echinochloa	*crusgalli*	Barnyardgrass
	E.	*crus-pavonis*	Gulf cockspur
	E.	*walteri*	Coast Cockspur
	Eragrostis	*barrelieri*	Mediterranean lovegrass
	E.	*beyrichi*	Wichita lovegrass
	E.	*curtipedicillata*	Gummy lovegrass
	E.	*intermedia*	Plains lovegrass
	E.	*oxylepis*	Red lovegrass
	E.	*sessilispica*	Tumble lovegrass
	E.	*tephrosanthos*	Gulf lovegrass
	Leptochloa	*filiformis*	Red sprangletop
	Leptoloma	*cognatum*	Fall witchgrass
	L.	*arenicola*	Sand witchgrass
	* *Monanthochoe*	*littoralis*	Shoregrass
	Panicum	*amarulum*	Shoredune panicum
	P.	*portoricense*	(Scribner-like) panicum
	Paspalum	*ciliatifolium*	Fringeleaf paspalum
	P.	*monostachyum*	Gulfdune paspalum
	P.	*plicatulum*	Brownseed paspalum
	P.	*vaginatum*	Seashore paspalum
	Schizachryrium	*scoparium* var. *littoralis*	Seacoast bluestem
	Setaria	*geniculata*	Knotroot bristlegrass
	S.	*macrostachya*	Plains bristlegrass
	S.	*lutescens*	Yellow bristlegrass

Table B-17. (Continued)

GRAMINEAE (Cont.)			
*	Spartina	alterniflora	Smooth cordgrass
*	Spartina	patens	Marshhay cordgrass
*	S.	spartinae	Gulf cordgrass
	Sporobolus	airoides	Alkali sacaton
	S.	cyrptandrus	Sand dropseed
	S.	pyramidatus	Whorled dropseed
	S.	tharpi	Padre Island dropseed
*	S.	virginicus	Seashore dropseed
	Uniola	paniculata	Seaoats
*	Zizaniopsis	miliacea	Marshmillet
CYPERACEAE			
	Cyperus	aristatus	Bearded flatsedge
	C.	esculentus	Chufa
	C.	polystachyos	Cedar flatsedge
	C.	ovularis var. retrorsus	Cylinder flatsedge
	C.	surinamensis	Tropical flatsedge
	C.	uniflorus	Oneflower flatsedge
	Dichromena	colorata	Starrush whitetop
	Eleocharis	albida	White spikesedge
	E.	caribaea	
	E.	flavescens	Pale spikesedge
	E.	montevidensis	Sand spikesedge
	E.	parvula	Dwarf spikesedge
	Frimbristylis	spadicea var. carolinianum	
	F.	spadicea var. castaneum	
	Fuirena	simples	Western unbrellasedge
	Hemicarpha	micrantha	Common hemicarpha
	Scirpus	americanus	American bulrush
	S.	supinus var. halli	
COMMELINACEAE			
	Commelina	elegans	Tropical dayflower
JUNCACEAE			
	Juncus	acuminatus	Knotleaf rush
	J.	bufonius	Toad rush
	J.	marginatus	Grassleaf rush
*	J.	roemerianus	Needlegrass rush
	J.	scirpoides	Needlepod rush
LILIACEAE			
	Allium	sp.	Onions
IRIDACEAE			
	Sisyrinchium	sp.	Blue-eyegrass
MYRICACEAE			
	Myrica	cerifera	Southern waxmyrtle

Table B-17. (Continued)

URTICACEAE		
Urtica	sp.	Nettle
POLYGONACEAE		
Eriogonum	*multiflorum*	Heartsepal wildbuckwheat
Polygonum	sp.	Smartweed
Rumex	sp.	Dock
CHENOPODIACEAE		
* *Atriplex*	*arenaria*	
Ehenopodium	*album*	Lambsquarters
* *Salicornia*	*bigelovi*	Bigelow glasswort
* S.	*perennis*	Woody glasswort
**S.	*virginica*	Virginia glasswort
* *Suaeda*	*linearis*	Annual seepweed
AMARANTHACEAE		
Amaranthus	*greggii*	Amaranth
Philoxerus	*vermicularis*	Silverhead
Tidestromia	*lanuginosa*	Wooly tidestromia
BATIDACEAE		
* *Batis*	*maritima*	Maritime saltwort
ARIZOACEAE		
Mollugo	*verticillata*	Green carpetweed
* *Sesuvium*	*maritimum*	Coast sesuvium
* S.	*portulacastrum*	Purslane sesuvium
S.	*verrucosum*	Winged sesuvium
CRUCIFERAE		
Cakile	*fusiformis*	Sea rocket
Cakile	*lanceolata* var. *geniculata*	Gulf searocket
LEGUMINOSAE		
Acacia	*farnesiana*	Huisache
Aeschynomene	*viscidula*	Sticky jointvetch
Baptisia	sp.	Wild indigo
Cassia	*fasciculata*	Prairie senna
Centrosema	*virginiaum*	Butterfly pea
Desmanthus	sp.	Bundleflower
Desmodium	sp.	Tickclover
Galactia	sp.	Milkpea
Indigofera	*leptosepala*	Western indigo
Medicago	sp.	Burclover
Neptunia	*lutea*	Yellow neptunia
Petalostemum	*obovatum*	Stinking prairie clover
Rhynchosia	*americana*	American snoutbean
R.	*reniformis*	Dollarleaf snoutbean
Schrankia	sp.	Sensitive briar
Sophora	*tomentosa*	Yellow sophora
Strophostyles	*helvola*	Trailing wildbean
Stylosants	*viscosa*	

Table B-17. (Continued)

POLYGALACEAE	
Polygala *alba*	White milkwort
EUPNORBIACEAE	
Croton *capitatus*	Woolly croton
C. *punctatus*	Gulf croton
Euphorbia sp.	Euphorbia (several)
Tragia sp.	Noseburn
MALVACEAE	
Abutilon sp.	Indianmallow
Callirhow sp.	Poppymallow
Spheralcea sp.	Globemallow
GUTTIFERAE (HYPERICACEAE)	
Hypericum sp.	St. Johnswort
TAMARICACEAE	
Tamarix *gallica*	Saltcedar
CACTACEAE	
Opuntia *lindheimeri*	Texas pricklypear
ONAGRACEAE	
Gaura sp.	Gaura
Oenothera *drummondi*	Beach evening primrose
UMBELLIFERAE	
Hydrocotyle *bonariensis*	Largeleaf parsley
PLUMBAGINACEAE	
* *Limonium* *caroliniamm* var. *nashii*	Carolina sea-lavendar
GENTIANACEAE	
Eustoma *exaltatum*	Tall prairie gentian
Sabatia *arenicola*	Sand rosegentian
ASCLEPIADACEAE	
Asclepias sp.	Milkweed
A. *viridiflora*	Green antelopehorn
CONVOLVULACEAE	
Ipomoea *per-caprae*	Soilbind morningglory
I. *stolonifera*	Fiddleleaf morningglory
POLEMONIACEAE	
Phlex *littoralis*	Seashore phlox
BORAGINACEAE	
* *Heliotropium* *curassavicum*	Salt heliotrope
H. *convolvulaceum* var. *racemosum*	Rindweed heliotrope

Table B-17. (Continued)

* AVICENNIACEAE		
Avicennia	*germinans*	Black mangrove
VERBENACEAE		
Lantana	*camara*	Lantana
Phyla	*incisa*	Sawtooth fogfruit
P.	*lanceolata*	Lanceleaf fogfruit
Verbena	spp.	Verbena
LABIATAE		
Monarda	sp.	Beebalum
Scutellaria	sp.	Skullcap
Teucrium	*cubense*	Small coast germander
SOLANACEAE		
Lycium	*carolinianum* var. *quadrifidium*	Carolina wolfberry
Physalis	*viscosa* var. *spathulaefolia*	Beach groundcherry
Solanum	*rostratum*	Buffalobur
SCROPHULARIACEAE		
Bacopa	*caroliniana*	Carolina waterhyssop
Castilleja	*indivisa*	Texas paintbrush
Gerardia	*fasciculata*	Beach gerardia
B.	*maritima*	Saltmarsh gerardia
Penstemon	sp.	Penstemon
Stemodia	*tomentosa*	Woolly stemodia
PLANTAGINACEAE		
Plantago	sp.	Plantain
CUCURBITACEAE		
Cucurbita	*foetidissima*	Buffalogourd
COMPOSITAE		
Ambrosia	*psilostachva*	Western ragweed
Aphanostephus	*skirrhobasis*	Arkansas dozedaisy
Aster	sp.	Aster
Baccharis	*halimifolia*	Sea-myrtle
B.	*salicina*	Willow baccharis
* *Borrichia*	*frutescens*	Bushy sea-oxeye
Centaurea	*americana*	American basketflower
Cirsium	*sp.*	Thistle
Conyza	sp.	Conyza
Coreopsis	sp.	Coreopsis
Croptilon	*divaricatum*	Slender goldenweed
Erigeron	*myrionactis*	Corpus Christi fleabane
Eupatorium	*betonicifolium*	Betonyleaf eupatorium
Flaveria	*oppositifolia*	Longleaf flageria

Table B-17. (Continued)

	COMPOSITAE (Cont.)	
	Gaillardia sp.	Gaillardia
	Helianthus annuus	Common sunflower
	Helianthus cucumerifolius	Cucumberleaf sunflower
	heterotheca pilosa	
	H. *subaxillaris*	Camphorweed
	Iva annua	Seacoast sumpweed
*	I. *frutescens*	Marshelder
	Liatris sp.	Gayfeather
*	*Machaeranthera phyllocephala*	
	Pluchea purpurasceno	Purple pluchea
	Ratibida sp.	Coneflower
	Senecio spartioides var. *riddelli*	Riddells groundsel
	Verbesina encolioides	Golden crownbeard

* Major plants of the salt marshes.

Sources:

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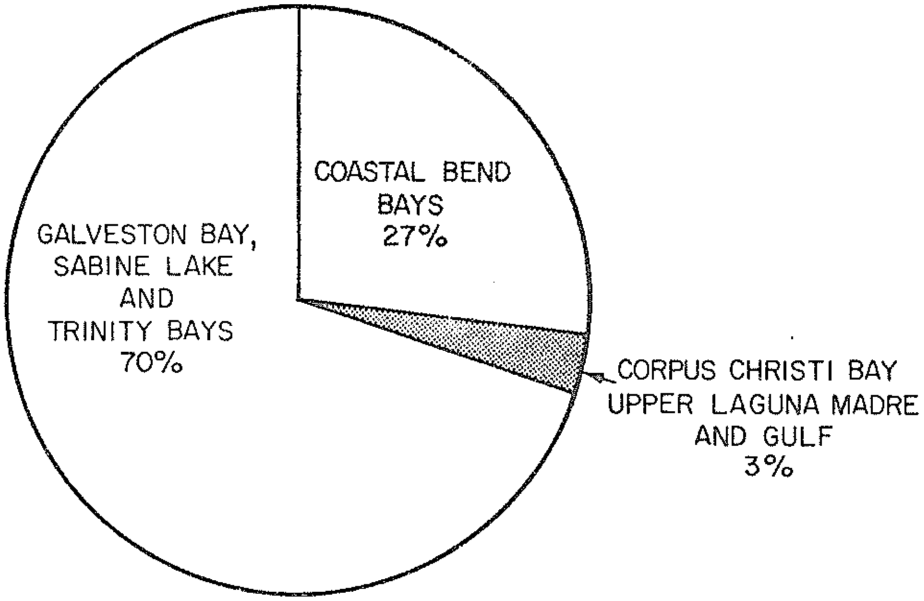
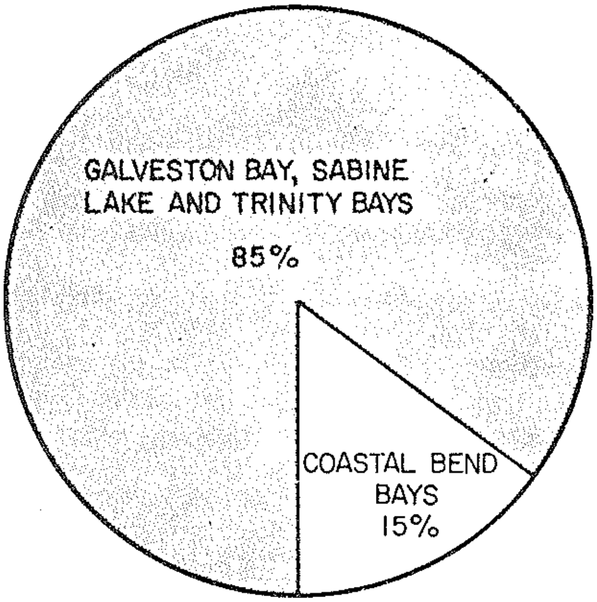


Source: Texas and the Gulf of Mexico, Department of Marine Resources Information, Texas A&M University, 1972.

Figure B-11. Distribution of Total Crab Catch in Texas, 1971.



Source: Texas and the Gulf of Mexico, Department of Marine Resources Information, Texas A&M University, 1972.

Figure B-12. Distribution of Total Oyster Harvest in Texas, 1971.

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APPENDIX C

HYDRODYNAMIC PROBLEMS CONCERNING OIL SPILLAGE IN THE OCEAN

by Takashi Ichiye

INTRODUCTION

The incident of oil spillage from the Torrey Canyon off the coast of Southern England clearly indicates that an environmental disaster is apt to occur anytime and anyplace, since the tonnage of crude oil transported by the sea increases from year to year. Oil spillage due to underwater seepage at Santa Barbara in early 1969 demonstrates that some locations are permanently threatened by large scale disruptions of the ecological system (Kolpack, 1971).

Some observations, although not systematic, show that oil spills cover the ocean in greater extents than expected and that oil slicks or films can be found even in the middle of the ocean (Blumer, 1969). It is expected that oil films may remain in the middle of the anticyclonic circulation systems of the oceans for long periods of time, since the advective effect is minimum there. This area is the source of the atmosphere-ocean heat engine because of the high rate of evaporation. The long-term effects of reduction of the evaporation rate by oil film are not known yet, but they may change the large-scale climate, as well as the ocean circulation.

Oil coverage of the zone corresponding to the northern leg of the anticyclonic circulation of the ocean appears to be less serious because of the advective effect of the rather strong eastward current. However, this zone coincides with the busiest shipping lanes both in the North Atlantic and the North Pacific Ocean. Therefore, removal of oil films or slicks by the current might be offset by the supply of spillage in this zone. Further, this zone is the primary input area of the atmospheric energy into the ocean through the wind stress of the westerlies. Therefore, decrease of the wind stress due to the oil film on the sea surface will certainly reduce the energy input to the ocean, leading to eventual slowdown of the entire oceanic circulation. (Stommel, 1965) This process is again not yet fully known.

Surprisingly, little is known about the behavior of a large-scale oil pool spilled on the ocean. Only recently Hoult (1972) published a review on this problem. One reason is that an experiment in the field is almost impossible except in case of actual accidents. The other reason is that the hydrodynamics of movement of an oil pool on the ocean involves buoyancy effect, viscosity and turbulence as well as inertia terms. This situation leads to almost equal importance of Froude and Reynolds numbers and thereby invalidates the results of small scale experiments. On the other hand, some features of the motion of an oil pool on the ocean can be simulated in an experimental flume, if dynamic similarity of the prototype and the model is carefully matched. It is necessary for this purpose to construct mathematical models before starting experimental work.

When bulk crude oil is dumped in the ocean either by a tanker accident or by a sudden seepage from an oil well, it will spread horizontally in a short period of time. The spreading may be caused by both internal and external effects. The internal effect means that the surface slope of the oil pool causes the horizontal gradient of the hydrostatic pressure, generating horizontal (outward) current in the pool. The external effect is due to the dispersive action of horizontal turbulence in the ocean which is generated by irregular motion of the wind and the ocean flow. Therefore, the external effect is a feature of the surface currents in the ocean rather than a special situation arising from dumping an oil pool. In this paper, the internal effect is treated deductively and the effect of turbulence is primarily described by the use of data obtained for other purposes (Ichiye, 1965; Okubo 1968).

BASIC EQUATIONS FOR AN OIL POOL IN THE OCEAN

For mathematical simplicity, an oil pool on the surface of the ocean is assumed to be circumsymmetric. The water of the ocean is considered motionless. Cylindrical coordinates are used to describe the movement of oil in the pool, with r the outward radical direction and z the downward vertical direction. Then the equations of motion in the radial direction and of continuity are given by

$$(\partial/\partial t + u\partial/\partial r)u = -g'\partial h/\partial r + \nu(\nabla^2 - r^{-2})u \tag{1}$$

$$r^{-1}\partial(ru)/\partial r + \partial\omega/\partial r = 0 \tag{2}$$

where u and w are the velocity components in the radial and vertical directions, respectively, h is the thickness of the oil pool, ν is the viscosity, g' is the reduced gravity defined by

$$g' = g(\rho - \Delta\rho)/\rho \tag{3}$$

$\Delta\rho$ is the density difference between the oil and water and ∇^2 is the Laplanian defined by

$$\nabla^2 = (\partial/r^2 + r^{-1}\partial/\partial r + \partial/\partial z^2) \tag{4}$$

Integrating equation (2) with z from the surface $(z = -\zeta)$ to the interface z = h, we have

$$\int_{-\zeta}^{h} r^{-1}\partial(ru)/\partial r \cdot dz + w_h - w_{-\zeta} = 0 \tag{5}$$

where w_h and $w_{-\zeta}$ denote the vertical velocity at h and $-\zeta$, respectively. The vertical velocity can be expressed by

$$w_h = u_h\frac{\partial h}{\partial r} + \frac{\partial h}{\partial t} \tag{6a}$$

$$w_{-\zeta} = -u_{-\zeta}\ (\partial\zeta/\partial r) - \partial\zeta/\partial t \tag{6b}$$

where the suffices h and ζ for u indicate the respective depth at which u is measured.

The first term multiplied by r of the r.h.s. of equation (5) becomes

$$\int_{-\zeta}^{h} \frac{\partial}{\partial r}(ru)dz \doteq \frac{\partial}{\partial r}\int_{-\zeta}^{h} rudz - ru_h\frac{\partial\zeta}{\partial r} - ru_{-\zeta}\frac{\partial\zeta}{\partial r} \tag{7}$$

Substitution of (7) and (6a) (6b) into (5) yields

$$r^{-1}\frac{\partial}{\partial r}\int_{-\zeta}^{h} rudz + \frac{\partial(\zeta+h)}{\partial t} = 0 \tag{8}$$

When $|\zeta| << h$, the second term of the r.h.s. of (8) can be replaced with $\partial h/\partial t$. Further, if the mean velocity $\overline{u}$ defined as

$$\overline{u} = h^{-1}\int_0^h u\,dz \qquad (9)$$

is introduced, equation (8) becomes

$$r^{-1}\partial(rh\overline{u})/\partial r + \partial h/\partial t = 0 \qquad (10)$$

When equation (1) is integrated with z from the surface to the interface and divided with the thickness h, we have

$$\partial\overline{u}/\partial t + h^{-1}\int_0^h u\partial u/\partial r \bullet dz = -g'\partial h/\partial r + \nu\nabla_h^2 h + h^{-1}(\tau_h - \tau_0) \qquad (11)$$

where τ_h and τ_o represent the bottom and surface stresses, respectively and ∇_h^2 is the operator defined by

$$\nabla_h^2 = (\partial^2/\partial r^2 + r^{-1}\partial/\partial r - r^{-2}) \qquad (12)$$

NON-VISCOUS SOLUTION

In the initial stage of the oil pool dumped in the ocean, the characteristic horizontal velocity, vertical distance and horizontal distance can be defined as $(g'H)^{1/2}$, H and a, respectively, where H and a are the characteristic thickness and the characteristic radius of the oil pool, respectively. The time scale is defined as $L/(g'H)^{1/2}$. Scaling of equation (1) yields

$$\partial u/\partial t + \frac{1}{2}\partial u^2/\partial r = \partial h/\partial r + R_h^{-1}\nabla_h^2 u + R_v^{-1}\partial^2 u/\partial z^2 \qquad (13)$$

where all the dependent and independent variables are non-dimensional and R_h and R_v are the horizontal and vertical Reynolds numbers defined by

$$R_h = L(g'H)^{1/2}/\nu \qquad (14)$$

$$R_v = R_h (H/L)^2 \tag{15}$$

If it is assumed that the volume of the oil pool is 1000 barrels ($1.19 \times 10^8 cm^3$) and the initial radius is 10 m, the mean depth is 19 cm. L and H can be taken as the initial radius and thickness of the pool. Therefore, when we take L = 10 m, H = 0.2 m, $\Delta\rho/\rho = 0.1$, $\nu = 0.1 \ cm^2/sec$, then $R_h = 4.5 \times 10^5$ and $R_v = 1.8 \times 10^2$. Hence, the effect of the viscosity can be neglected except near the boundaries of the oil pool. The first approximation of (13) is obtained by neglecting the viscous term. Since the vertical shear of the velocity u is small except near the interface, the second term of the l.h.s. of equation (11) is approximately equal to

$$\frac{1}{2} h^{-1} \int_0^h \partial u^2/\partial r \, dz \simeq \frac{1}{2} \, \partial \bar{u}^2/\partial r \tag{16}$$

Equation (11) becomes equivalent to (13) without the viscous terms if the viscosity terms and stress terms are neglected in the former equation.

Scaling of equation (10) by use of the characteristic values described above yield the same form. The scaled equations of motion without viscous terms and continuity are thus given by

$$\partial u/\partial t + \frac{1}{2}\partial u^2/\partial r = -\partial h/\partial r \tag{17}$$

$$r^{-1}\partial(rhu)/\partial r + \partial h/\partial t = o \tag{18}$$

where the bar over the velocity is dropped.

The system of equations (17) and (18) is similar to the system for the compressible gas dynamics (Courant, 1963). When the non-dimensional velocity

$$c = h^{1/2} \tag{19}$$

is introduced, equations (17) and (18) are changed into

$$\partial u/\partial t + u\partial u/\partial r + 2c\ 2c/\partial r = o \tag{20}$$

$$\partial c/\partial t + c\partial u/\partial r + 2u\ \partial c/\partial r = -r^{-1}cu \tag{21}$$

The system of equations (20) and (21) forms the hyperbolic equation in the (t, r) space. It becomes the ordinary differential equation on the characteristic curves α and β which satisfy the equations

$$\phi(r,\ t) = \alpha \tag{22}$$

$$\psi(r,\ t) = \beta \tag{23}$$

and α and β are called characteristic parameters.

The system of equations (17) and (18) can be written with the matrix notation as

$$\frac{\partial}{\partial t}u^{(i)} + A\frac{\partial}{\partial r}u^{(i)} = a^{(i)} \tag{24}$$

where $u^{(i)}$ and $a^{(i)}$ are column vectors defined by

$$u^{(i)} = \begin{pmatrix} u \\ h \end{pmatrix} \qquad\qquad a^{(i)} = \begin{pmatrix} o \\ -hur^{-1} \end{pmatrix} \tag{25}$$

and A is the matrix

$$A = \begin{pmatrix} u & 1 \\ h & u \end{pmatrix} \tag{26}$$

If we can find some row vector $\lambda_{(i)}$ satisfying

$$\lambda_{(i)}(A - \tau I) = o \qquad (27)$$

where τ is the eigenvalue corresponding to $\lambda_{(i)}$, the vector product of $\lambda_{(i)}$ with (24) yields

$$\lambda_{(i)}\frac{\partial}{\partial t}u^{(i)} + \tau\lambda_{i}\frac{\partial}{\partial r}u^{(i)} = \lambda_{(i)}a^{(i)} \qquad (28)$$

because of relation (27). In terms of u and h this equations becomes

$$\lambda_{(i)}\left(\frac{\partial}{\partial t}u + \tau\frac{\partial}{\partial r}u\right) + \lambda_{(2)}\left(\frac{\partial}{\partial t}h + \tau\frac{\partial}{\partial r}h\right) = - \lambda_{(2)}hur^{-1} \qquad (29)$$

The curvilinear coordinates α and β are introduced and the directional differentation along each of the coordinates is taken as proportional to $(\partial/\partial t + \tau\partial/\partial r)$ or

$$\partial/\partial\alpha = (\partial t/\partial\alpha)(\partial/\partial t + \tau^{(1)}\partial/\partial r) \qquad (30)$$

$$\partial/\partial\beta = (\partial t/\partial\beta)(\partial/\partial t + \tau^{(2)}\partial/\partial r) \qquad (31)$$

where $\tau^{(1)}$ and $\tau^{(2)}$ are different eigenvalues of equation (27). Then equation (29) can be expressed in the directional differentiation along α or β only for each eigenvalue instead of the partial differential equations about r and t variables.

The eigenvalue equation (27) can be written by the determinant as

$$\begin{vmatrix} u-\tau & 1 \\ h & u-\tau \end{vmatrix} = o \qquad (32)$$

The root of this equation (or eigenvalue) is

$$\tau_{(1)} = u + c \; ; \quad \tau_{(2)} = u - c \qquad (33a)\ (33b)$$

where c is defined by equation (19). If the characteristic parameters α and β are defined corresponding to the eigenvalues $\tau_{(1)}$ and $\tau_{(2)}$, respectively,

$$-\psi_t/\psi_r = r_\alpha/t_\alpha = \tau_{(1)} \qquad (34)$$

$$-\phi_t/\phi_r = r_\beta/t_\beta = \tau_{(2)} \qquad (35)$$

The row vectors $\lambda_{(i)}$ corresponding to $\tau_{(1)}$ and $\tau_{(2)}$ are respectively given by $\lambda_{(1)}/\lambda_{(2)} = c$ and $\lambda_{(1)}/\lambda_{(2)} = -c$. Substitution of these values into (20) yields

$$cu_\alpha + h_\alpha = -r^{-1}hut_\alpha \qquad (36)$$

$$cu_\beta - h_\beta = r^{-1}hut_\beta \qquad (37)$$

Equations (34) and (35) defining the characteristic curves can be written as

$$\chi_\alpha = (u+c)t_\alpha \qquad (38)$$

$$\chi_\beta = (u-c)t_\beta \qquad (39)$$

The system of equations (36) to (39) forms the characteristic system of the hyperbolic equations (17) and (18).

In order to determine change of the oil pool in its developing stage, the system of equations (36) to (39) is solved by a numerical method. For this purpose, the initial shape of the oil pool is given by

$$h = \exp\{-\frac{1}{2}(r/b)^2\} \qquad (40)$$

and $u = o$

Professor R. O. Reid calculated velocity u and thickness h numerically by use of his program based on characteristic method. The results of u and h are checked against the total volume

$$V = 2\pi \int_o^\infty h r dr = 2\pi b^2 \qquad (41)$$

and the initial potential energy

$$E = \pi \int_o^\infty h^2 r dr \qquad (42)$$

Both V and E must be conserved during the spreading, since no dissipation and diffusion processes are included. In the calculation, b is taken as 0.9 thus leading to V = 5.08 and E = 1.27.

The results of the calculation are shown in Figures C-1 to C-8 as u and h are plotted against r with a computer for every half unit of t from t - 0 to t = 3 and for t = 4. The values of V and E are approximately conserved up to about t = 2.5. Until then, the oil pool becomes flatter and the outward speed u increases with time. The original shape of the oil pool changes into a flat top bore with u almost linearly increasing with r. After this initial time, the hydraulic jump at the edge of the pool is so steep that computer calculation does not conserve the values of V and E as seen in Figures C-7 and C-8.

The numerical result up to t = 4 can be corrected by use of

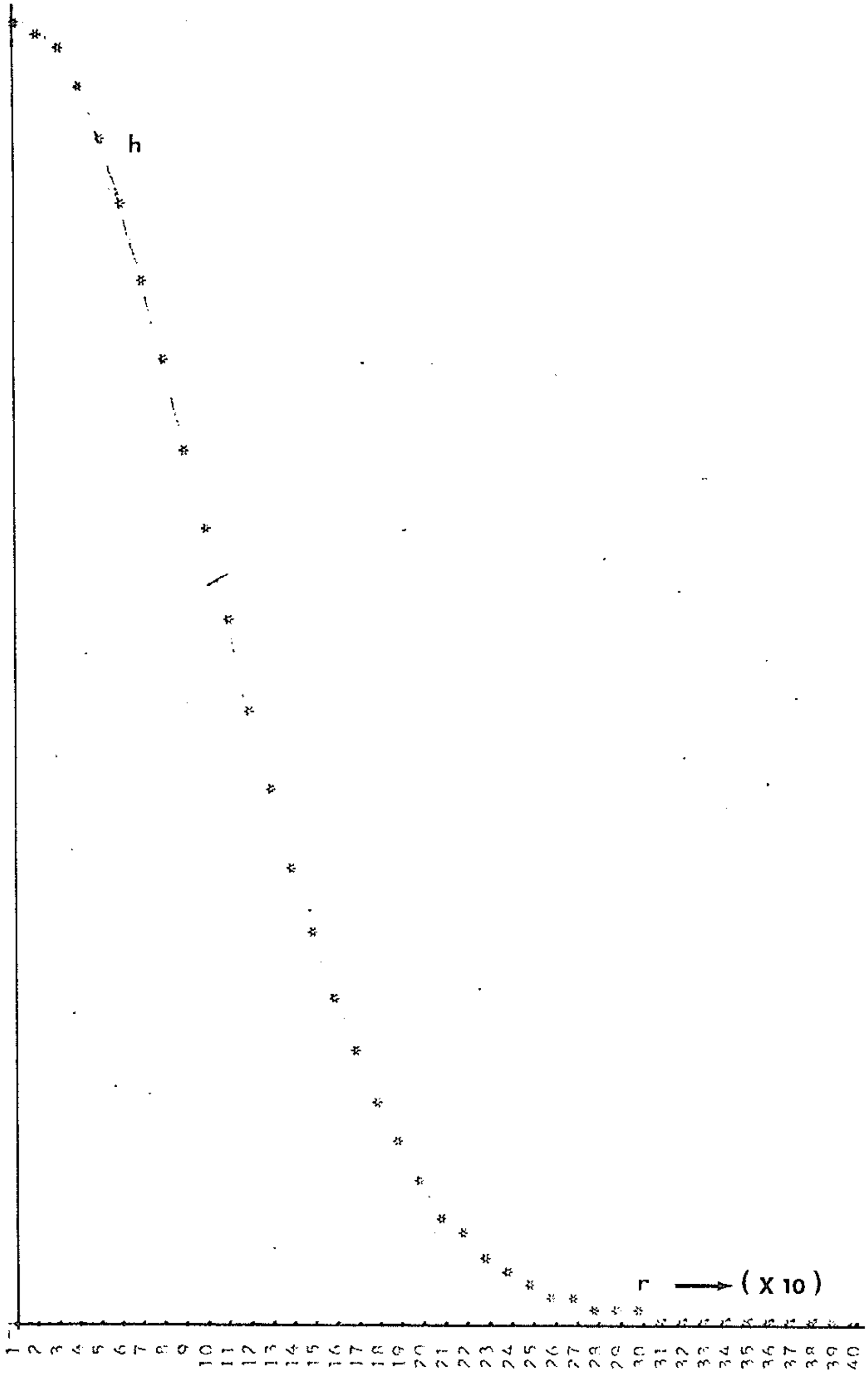

Figure C-1. Oil Spreading t = 0, V = 5.084, E = 1.270

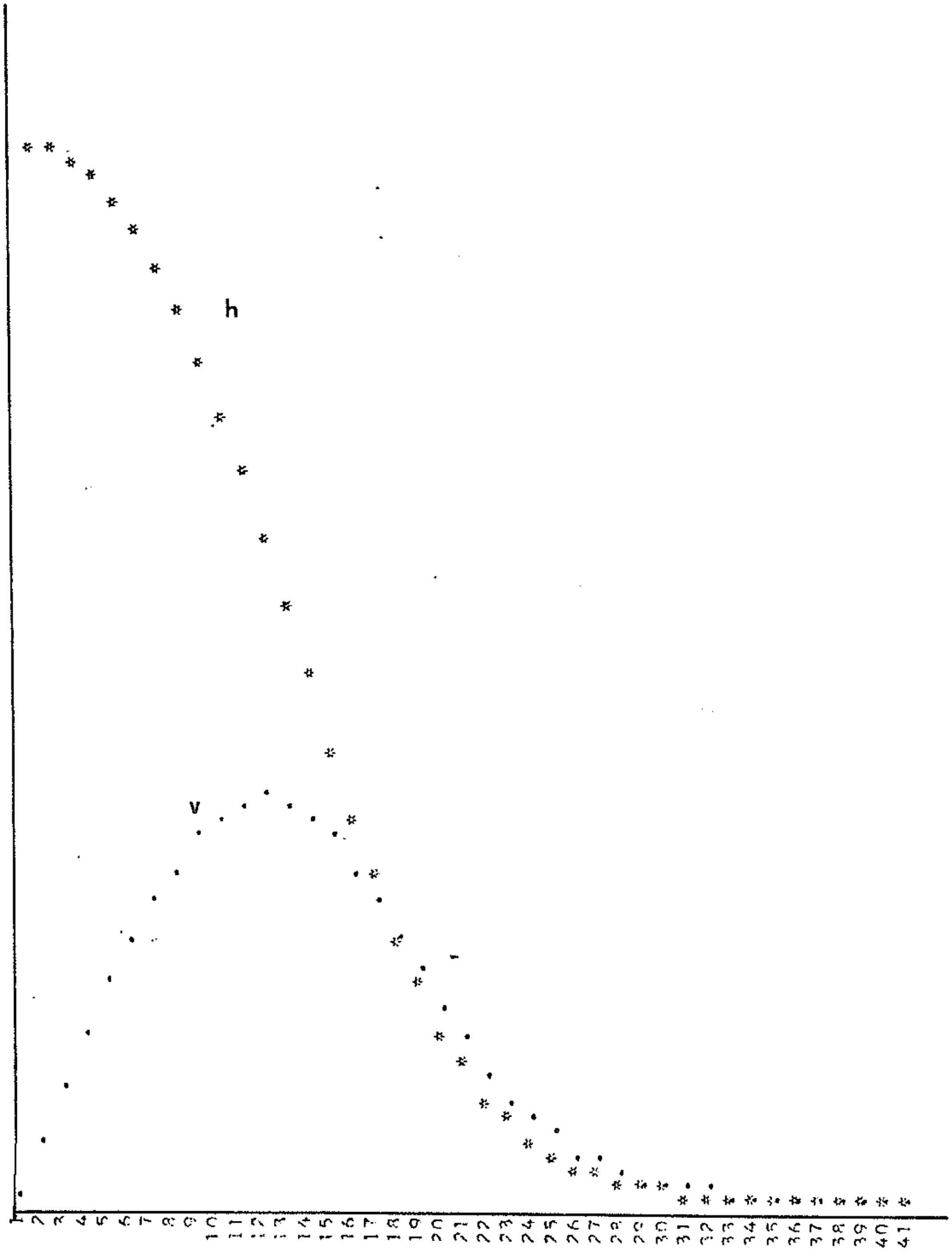

Figure C-2. Oil Spreading t = 0.5, V = 5.063, E = 1.248

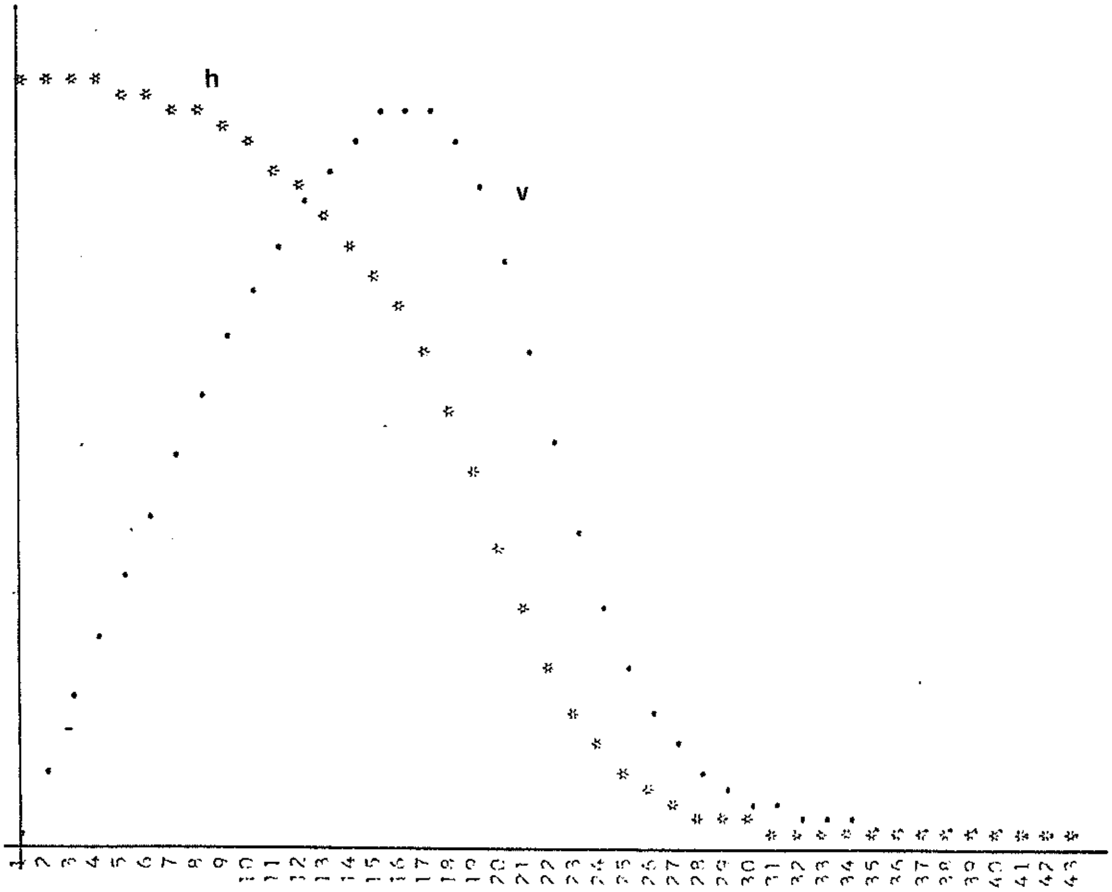

Figure C-3. Oil Spreading t = 1.0, V = 5.057, E = 1.239

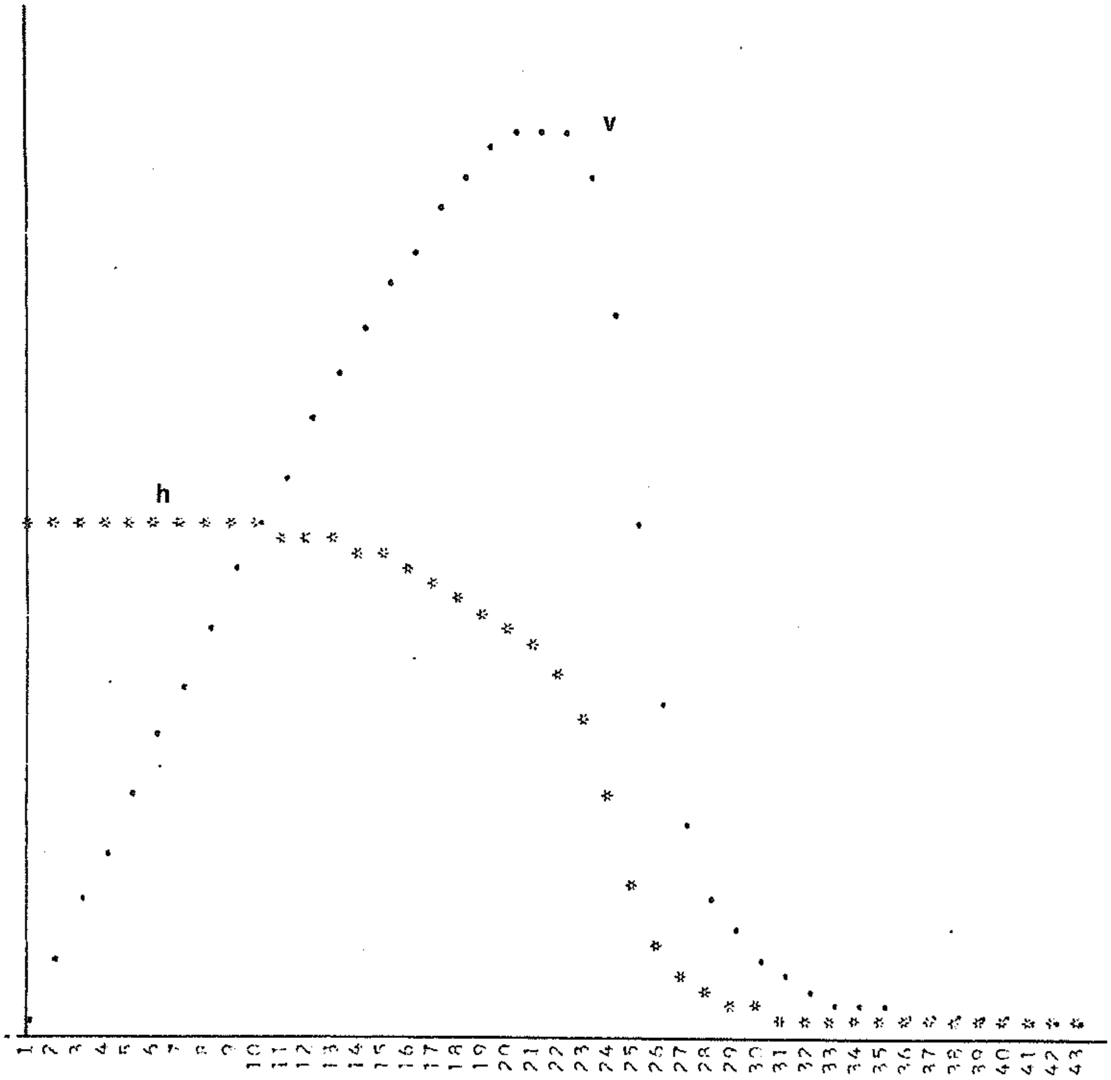

Figure C-4. Oil Spreading , t = 1.5, V = 5.061, E = 1.234

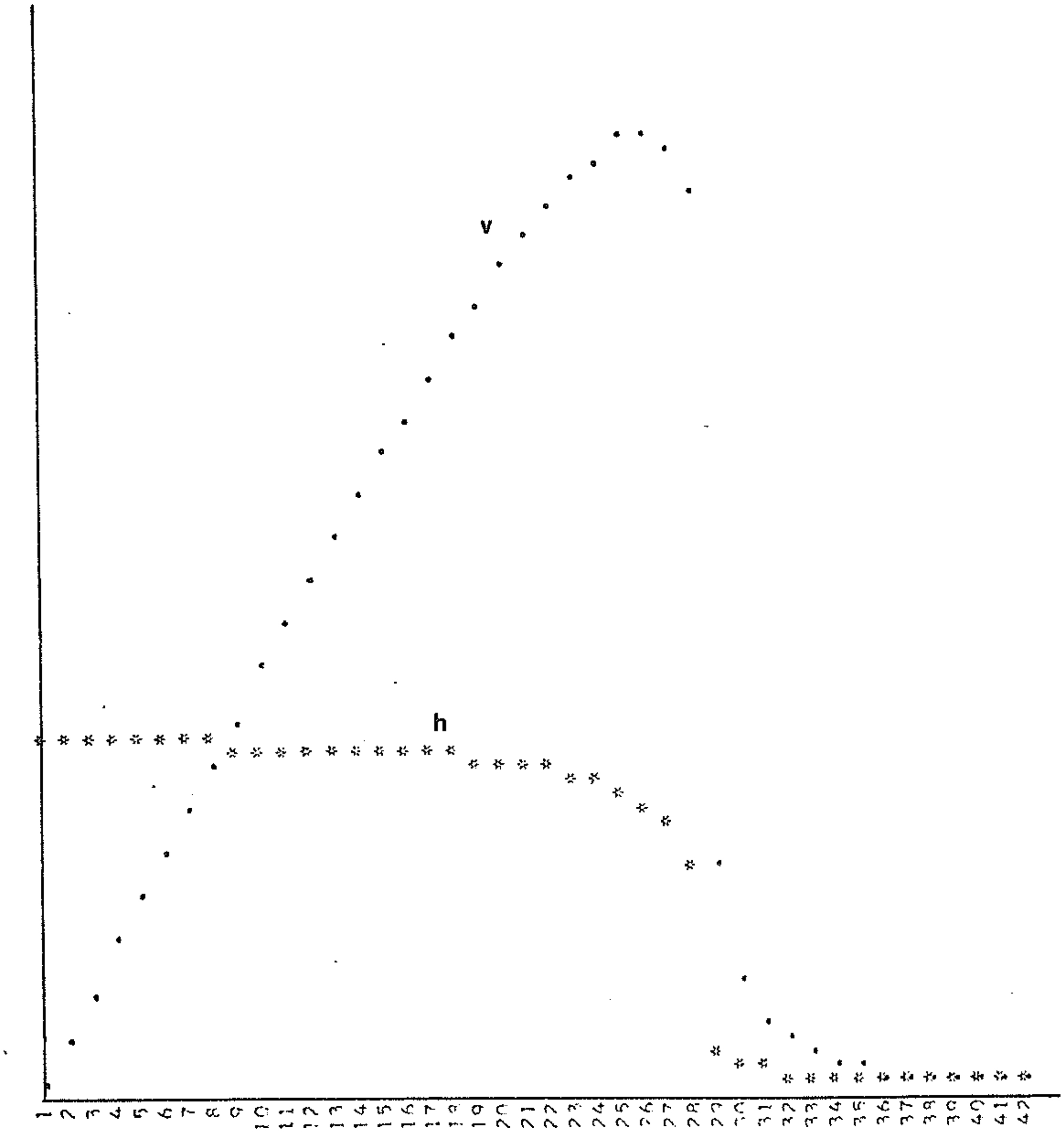

Figure C-5. Oil Spreading t = 2.0, V = 5.128, E = 1.248

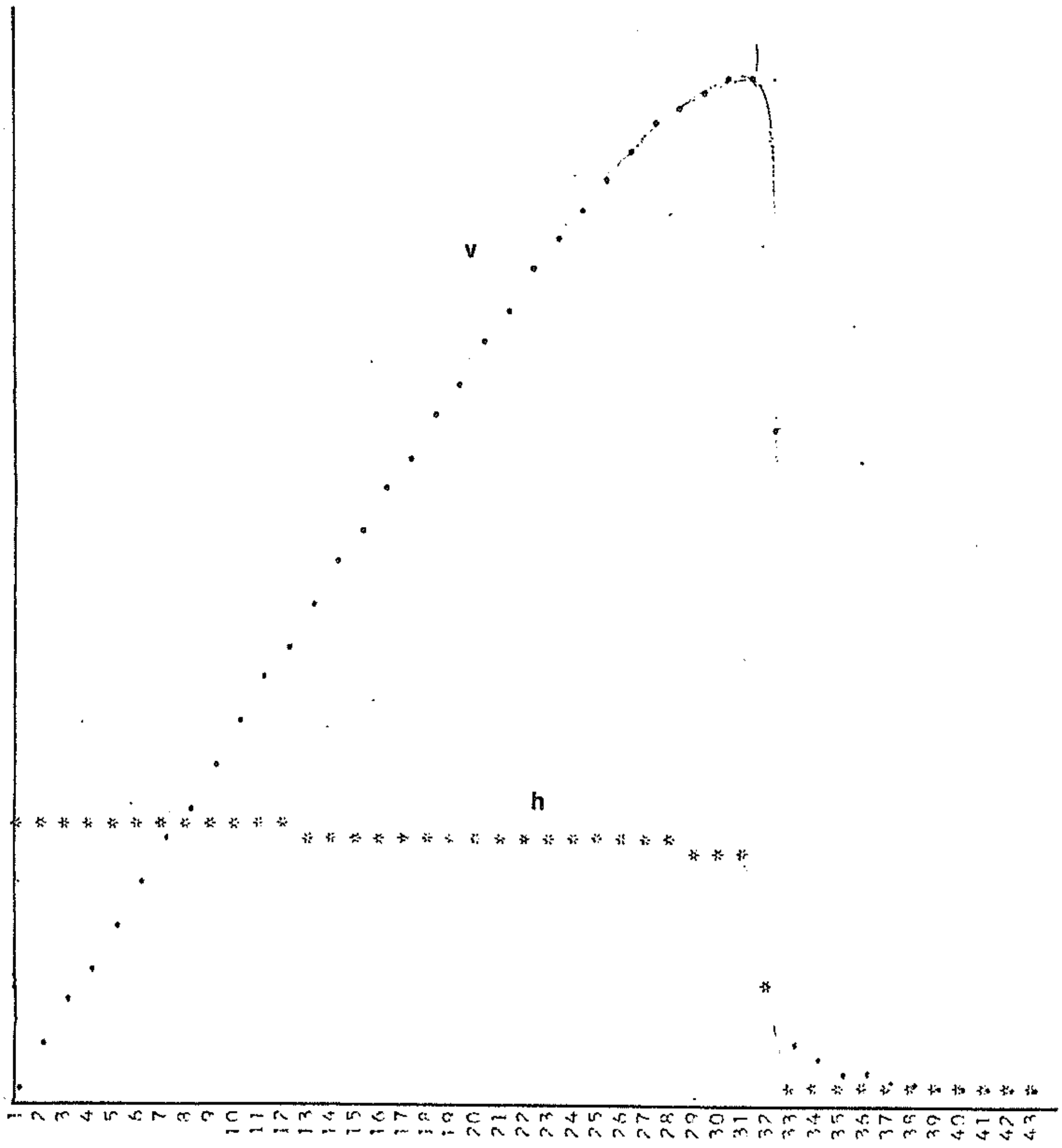

Figure C-6. Oil Spreading t = 2.5, V = 5.120, E = 1.173

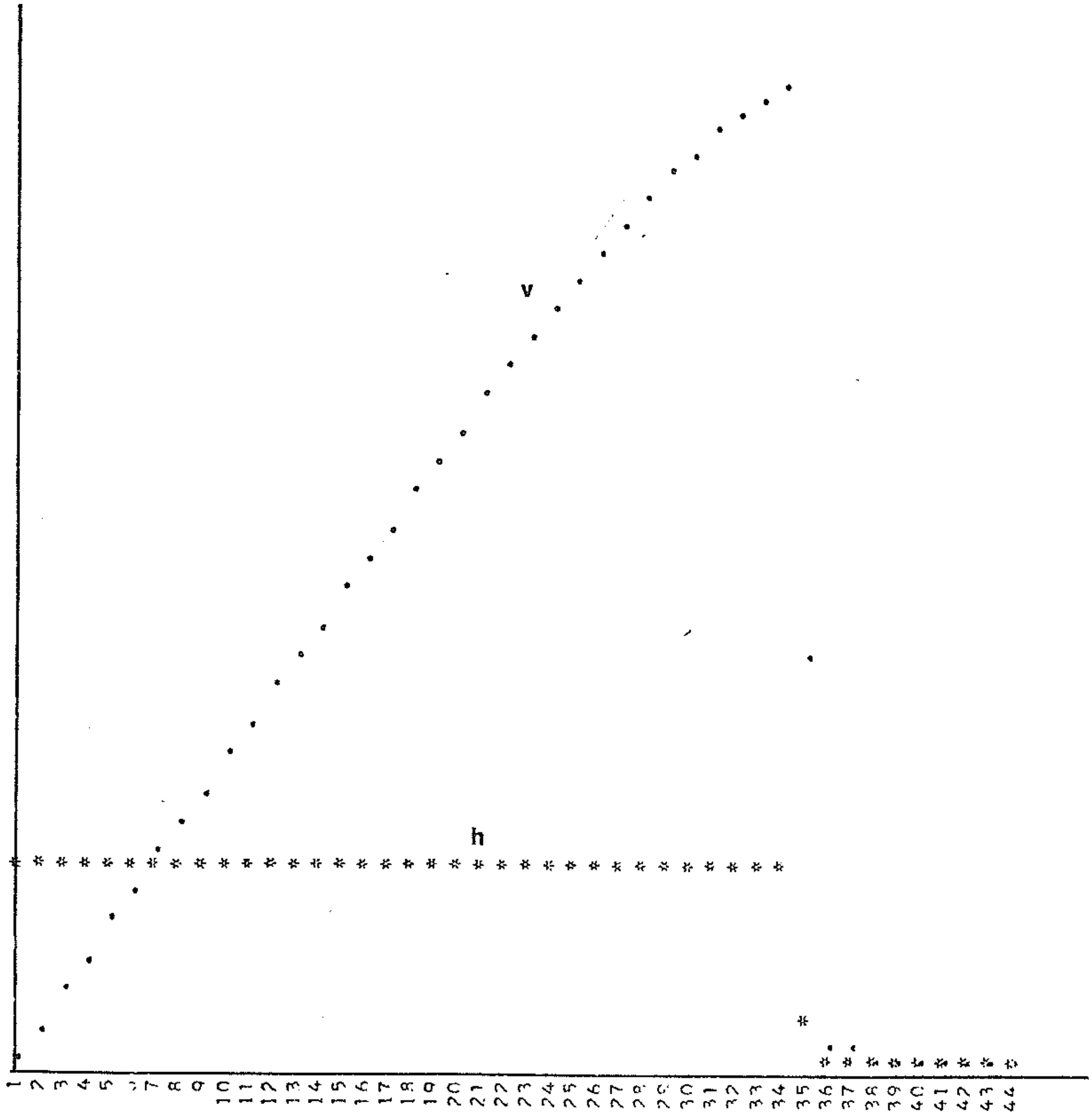

Figure C-7. Oil Spreading t = 3.0, V = 4.891, E = 1.034

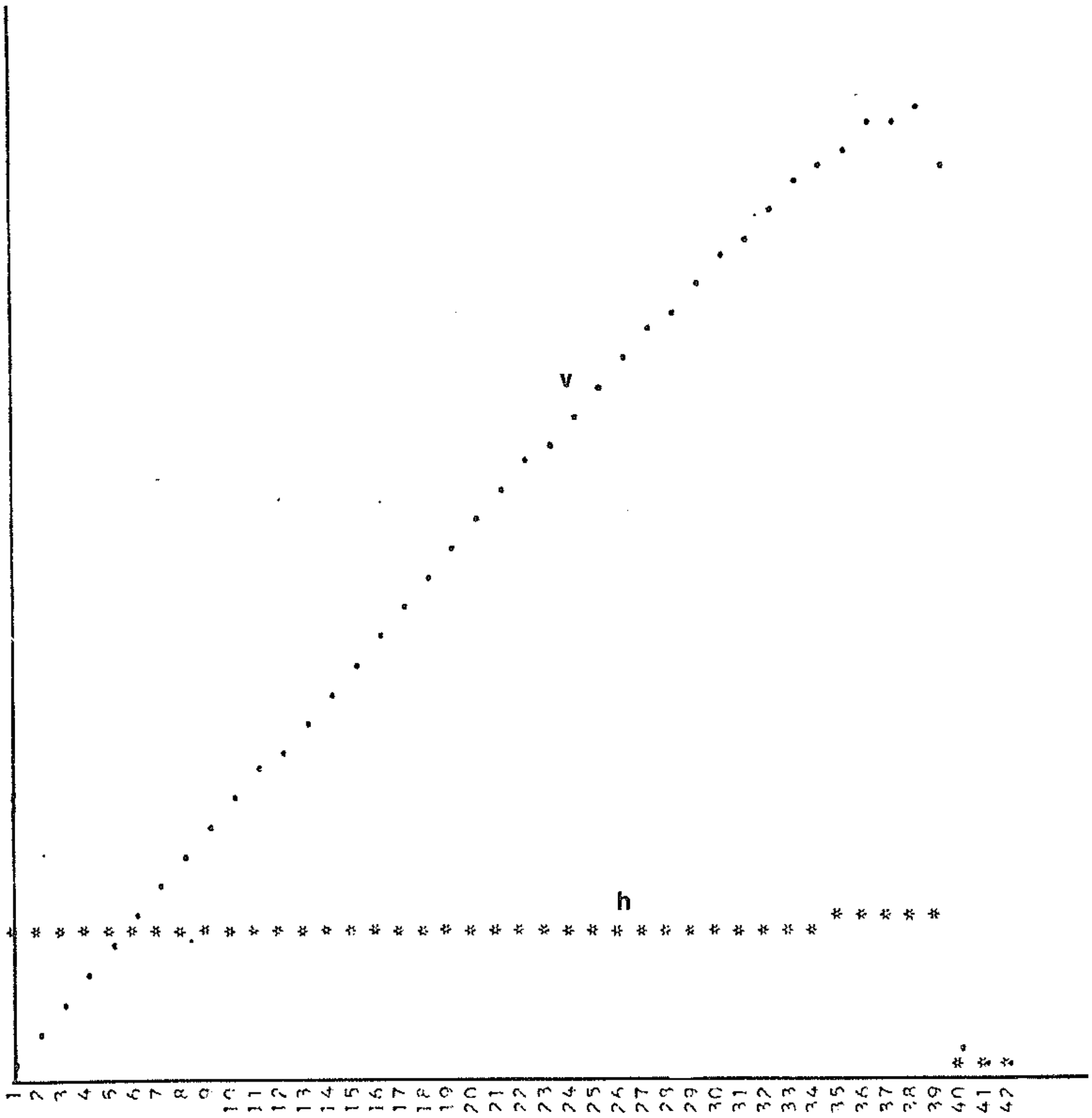

Figure C-8. Oil Spreading t = 4.0, V = 4.307, E = 0.749

the conservation of V and E. Then at t = 4, distributions of velocity and thickness are expressed by

$$u = \alpha_o r \text{ (for } o<r<R_f); \; u = o \text{ (for } r>R_f)$$

$$h = h_o \text{ (for } o<r<R_f); \; h = o \text{ (for } r>R_f) \qquad (44)$$

The numerical value of α_o is determined by a slope of the curve of Figure 8 and values of R_t and h_o are obtained with the correction based on conservation of E and V. The results are

$$h_o = 0.087; \; \alpha = 0.194 \text{ and } R_f = 4.3 \qquad (45)$$

SPREADING OF BORE

Analytical solution of velocity and thickness h can be obtained by substituting (43) and (44) into (17) and (18) with assumption that α_o and h_o are dependent on t. Equations (17) and (18) are now expressed by

$$\frac{d\alpha_o}{dt} + \alpha_o^2 = o \qquad (46)$$

$$\frac{dh_o}{dt} + \alpha_o h_o = o$$

Solutions of (46) and (47) are easily obtained and expressed as

$$\alpha_o = (\alpha_i^{-1}+t)^{-1} = (c+t)^{-1} \qquad (48)$$

$$h_o = h_{oi}(1+\alpha_i t)^{-2} = A(C+t)^{-2} \qquad (49)$$

where α_i and h_{oi} are initial values of α_o and h_o respectively and the origin of t is taken as zero. The last terms of (48) and (49) are expressed by A and C equally $\alpha_i^{-2}h_{oi}$ and α_i^{-1} respectively.

The radius of the oil pool R_f is determined from the conservation of the total volume V and is given by

$$R_f = R_{fi}(1+\alpha_i t) = B(C+t) \qquad (50)$$

where R_{fi} is the initial value of t and $B = R_{fi}\alpha_i$. From the numerical results of Figures 1 to 8, the initial values of the base are taken as given by (45).

The area of the pool is given by

$$A = \pi R_f^2 = 1.88(5.15+t)^2 \qquad (51)$$

by substituting numerical values B = 0.774 and C = 5.15 from (45).

In order to apply these results to actual situation, an oil pool of volume of 10^4 m^3 (or about 10^4 metric tons) is considered. Since the results of numerical calculations of the last section and analytical solutions of this section are expressed in non-dimensional terms, dimensional quantities are restored with adequate characteristic horizontal and vertical distances L and H. Then the time scale P is given by $L/(g'H)^{1/2}$. The vertical scale H is chosen as the maximum initial thickness (at r = o) since the non-dimensional thickness h is unity at r = o. Thus the horizontal distance L can be determined from the total volume V_d in dimensional form as

$$V_d = 2\pi b^2 HL = (10^4). \qquad (52)$$

With $\Delta\rho/\rho = 0.1$, L and P are determined for two values of H as follows:

	$H = 10^2$cm	10 cm	10^3cm
L(m)	44.4m	140.7	14.1
T(sec)	44.4	444.	4.44

The increase of the area of the pool for two sets of the maximum initial thickness 10cm and 10^2cm is plotted against time after starting of the bore in Figure 9. For $H = 10^2$cm, and 10cm the bore starts at 3 min. and 29.5 min., after the initial damping, respectively, corresponding to $t = 4$. Curve I (for H = 100cm) is almost proportional to t^2 after 10 min. of start of the bore, whereas curve II (for H = 10cm) shows the effect of the initial value of the area until about 2 hours after start of the bore. Curve I and II reach 100km^2 at about 2 and 5 hours after the start of the bore from this theory. However, when the area increases, thickness of the pool becomes smaller and thus the effect of viscosity becomes important. Therefore the results shown in Figure 9 should be modified.

EFFECTS OF VISCOSITY

Viscosity may change the process of bore formation shown in Figures 1 to 8. However, its effects become more important after formation of the bore, because, the thickness becomes smaller and the bore front has a sharp velocity gradient.

The vertical Reynolds number defined by (15) becomes 2.25 and 2.25×10^3 for H = 10cm and 10^2cm, respectively with $\nu = 0.1$ cm^2/sec. for the initial volume of 10^4m^3. Therefore the bore formation for the first case is not correctly described with Figures 1 to 8, which are obtained without viscosity. In addition, the initial thickness of 10cm of sudden dumping seems unrealistic. However, the curves of Figure 9 illustrate that an oil pool dumped initially with larger thickness spreads more rapidly.

Since the horizontal Reynolds number is smaller by a factor $(H/L)^2$ then the vertical Reynolds number, as seen from (14) and (15), the horizontal viscosity term is neglected. Further, within the bore the velocity u is uniform and thus $\nabla_h^2 u$ vanishes. The horizontal viscosity term is important only at the bore front but the vertical viscosity term is effective all over the interface of water and oil.

The vertical viscosity term in equation (17) is given by

$$\frac{1}{h} R_v^{-1} \int_o^h \frac{\partial^2 u}{\partial z^2}\, dz = R_v^{-1} \left(\frac{\partial u}{\partial z}\Big|_h - \frac{\partial u}{\partial z}\Big|_o \right) h^{-1}$$

$$= -(R_v h)^{-1} \frac{\partial u}{\partial z}\Big|_o \qquad (53)$$

since equation (17) is the vertically averaged form of (13) and the surface shear $\alpha u/\alpha 2|_u$ vanishes because of no stress at the surface. The profile of velocity u is sketched in Figure C-9.

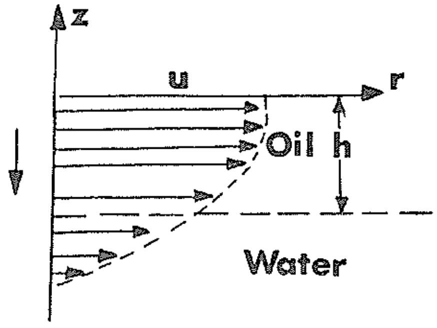

Figure C-9. Velocity Profile.

Since the water just below the oil also is dragged by the oil, the bottom shear $\alpha u/\alpha 2|_o$ is of the order of uh^{-1} and the viscosity ν in R_v may be taken as average of the viscosity of the water and oil. Then the viscosity term can be expressed by

$$-(R_v h^2)^{-1}\ \delta u \tag{54}$$

where δ is the scale factor defined by

$$\left.\frac{\partial u}{\partial z}\right|_o = \delta u h^{-1} \tag{55}$$

Equation (17) is changed into

$$\frac{\partial u}{\partial t} + \frac{1}{2}\frac{\partial u^2}{\partial r} = -\frac{\partial h}{\partial r} - K\frac{u}{h^2} \tag{56}$$

Equation (18) is the same. Then the equation of motion for the bore is

$$\frac{\partial \alpha_o}{\partial t} + \alpha_o^2 = -\frac{K\alpha}{h_o^2} \tag{57}$$

instead of (46). Equations (47) and (57) are system of non-linear equations and analytical solutions are impossible. However, if we assume that

$$\eta = K(\overline{h}_o)^{-2} \simeq K(h_o)^{-2} \tag{58}$$

where $\overline{h}_o$ is the adequate average of h_o, u is constant. Equation (57) can be analytically solved and its solution is

$$\alpha_o = \eta e^{-Kt}(1+\eta\alpha_i^{-1}-e^{-\eta t})^{-1} \tag{59}$$

and

$$h/h_{oi} = \eta^2\{\alpha_i(1-e^{-\eta t}) + \eta\}^{-2} \qquad (60)$$

It is easily seen that (59) becomes (48) when $u \to o$. The important difference of (60) from (49) is that h_o has a limited value when $t \to \infty$ in equation (60). This is because, from the continuity equation (47), h_o is given by

$$\log \frac{h_o}{h_{oi}} = -\int_o^t \alpha dt \qquad (61)$$

and thus if the r.h.s. has a limit for $t \to \infty$, then h_o/h_{oi} also has the limit. Without viscosity, α_o decreases only as t^{-1} for large values of t and thus the r.h.s. of (61) becomes infinite as does log t for $t \to \infty$. This leads to (49) which shows that h_o decreases to zero as $t \to \infty$.

The problem to determine a value of η remains. Since n depends on the adequate average of h_o, it is simply assumed that

$$\eta = (h_{oi} + h_m)/2 \qquad (62)$$

where h_m is the minimum value of h_o corresponding to take $t \to \infty$ in the r.h.s. of (60). Of course the assumption (62) is crude but the viscosity term (54) itself is approximate and thus (62) is not far from truth. Then h_m can be approached by substituting (62) into the equation which is obtained by taking $t \to \infty$ in (60). The result is

$$M = (4K)^2\{\alpha_i h_{oi}^2 (M+1)^2 + 4K\}^{-2} \qquad (63)$$

where

$$M = h_o/h_{oi}$$

The value of M can be determined from a root of (63) with a condition that $M < 1$.

Now K must be determined in order to solve (63). Since δ is unknown but less than unity, we take $R_v^{-1}\delta = 4.44 \times 10^{-4}$. This corresponds to take $\nu = 0.01\ cm^2/sec$ if $\delta = 1$. For evaluation of R_v, ν should be taken as the mean of water and oil viscosity and $\delta < 1$, thus the above value of ν is reasonable. After some time oil and water form an emulsion near the interface and thus further decrease the effective viscosity. With δ_i and h_{oi} the same as in the previous section, the root of equation (63) is given by $M = 0.01$. Thus $h_m = 8.7 \times 10^{-4}$ or 0.087 cm in dimensional terms. The effective dissipation coefficient = 0.023. The maximum area A_m for $h = h_m$ is given by

$$A_m = 5.08\ h_m^{-1} \qquad (65)$$

or in dimensional term $(10^5/h_m)\ m^3$ with non-dimensional h_m and thus $11^5 km^2$. The change of the area can be determined by dividing the total voluem 5.8 with h_o expressed by (60), since η is now known. The result of the computation is plotted in Figure C-10 with the limiting value A_m. The curve shows that the effect of viscosity is very remarkable in slowing down the rate of spreading.

When viscosity ν is taken as $0.1\ cm^2/sec$ as the one for crude oil only, the limiting area A_m is further decreased. In this case the root of equation (63) $M = 0.105$ and $\eta = 0.163$. The limiting

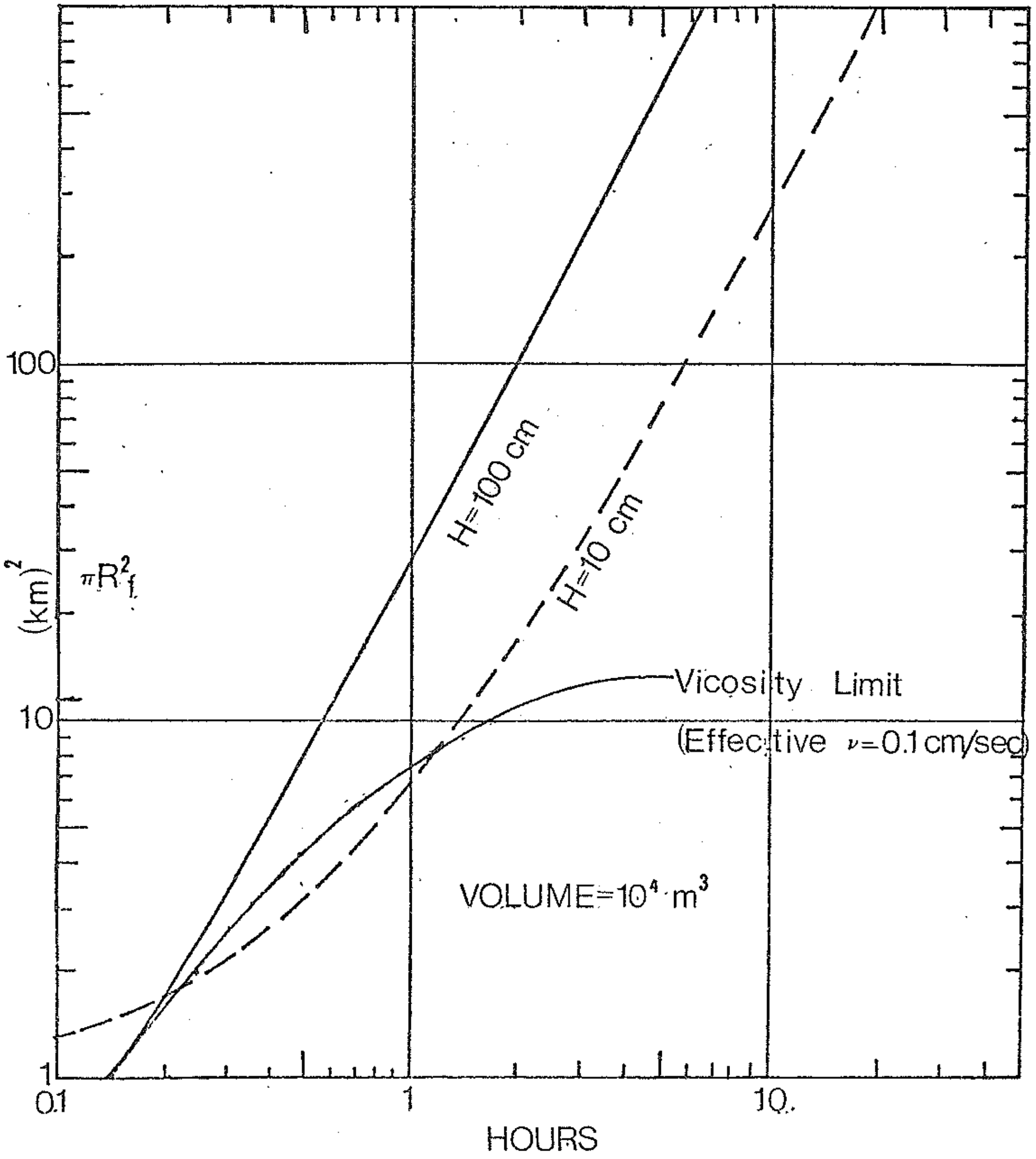

Figure C-10. Viscosity vs Time For Gravity Flow.

value $h_m = 8.8 \times 10^{-3}$ (0.88cm) and A_m = 11 km. However, this limiting area does not remain the same, since emulsion effect may cause the pool to disperse by horizontal diffusion as discussed in next section.

EFFECTS OF HORIZONTAL DIFFUSION

As indicated by observations for the Torrey Canyon incident, an oil pool forms emulsion with water after some time and the density of oil increases. In this event gravity effects are no longer active. In such a condition, the pool does not spread as a bore nor by gravitational force but is transported as a passive mass by surface currents. These currents consist of the mean flows which are caused by tides, stationary wind stresses, surface slope and density gradient and are modified by the Coriolis' force (Neumann, 1968) and the fluctuating flows or turbulences. The mean flows should be determined in each location only by actual measurements but the turbulence effect on dispersing passive oil has some general features and thus will be discussed here.

The diffusion of dye patches in the ocean has been studied for some years by several authors (for instance, Ichiye, 1965; Okubo, 1968). This process may be similar to dispersion of an oil pool after emulsion with water and patch-breakup occur. When a dye patch or oil pool becomes sufficiently large, the Reynolds number of the water which transports it also becomes large and energy transfer from larger eddies to smaller eddies are carried out by inertial forces. This condition is called by inertial subrange and the area of the patch increases proportional to t^3 (Okubo, 1968) (See Figure C-11). Okubo confirmed this rule by use of dye patch diffusion data in the ocean up to 1967. He determined from various experiments that the variance of dye concentration σ_{rc}^{2} is

$$_{tc}^{2} = \int_{o}^{2\pi}\int_{o}^{\infty} S(t,r,\theta)r^{3}drd\theta / \int_{o}^{2\pi}\int_{o}^{\infty} S(t,r,\theta)rdrd\theta \qquad (68)$$

where S(t,r) is dye concentration and r is the distance from the center of dye to a reference point in the dye. The result is shown in Figure 11, which indicates that the t^3 - rule is valid for σ_{rc}^{2} of almost 10^{6}km. Since σ_{rc}^{2} is proportional to the visible area of a dye patch, it is considered as representative of size of the patch.

In order to apply this rule, it is necessary to decide the initial size of the oil pool at the beginning of spread due to horizontal diffusion. This initial area may be taken as the limiting area A_m. This area is due to the effect of viscosity and may remain the same if there is no dispersive action of turbulence. However, emulsion effect may increase the density of the oil pool and, although gravity effect does not spread the pool any more, the horizontal turbulence may take over. Thus, this area can be considered as the initial area for t^3 - rule.

In Figure C-12, the change of an oil pool area of volume $10^4 m^3$ and the initial maximum thickness lm is schematically plotted against time. In the first several minutes the pool spreads by its initial

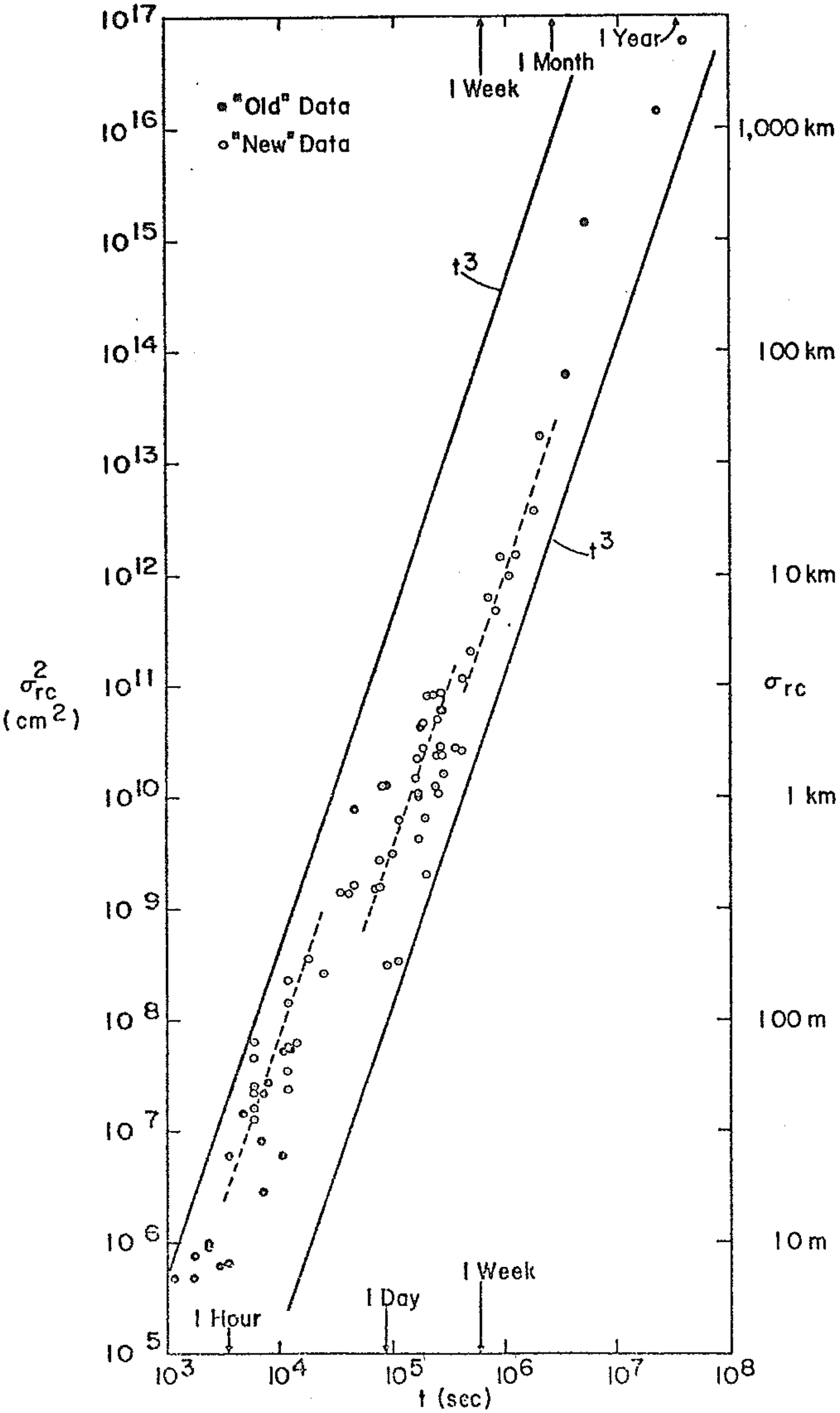

Figure C-11. Variance vs. Diffusion Time.

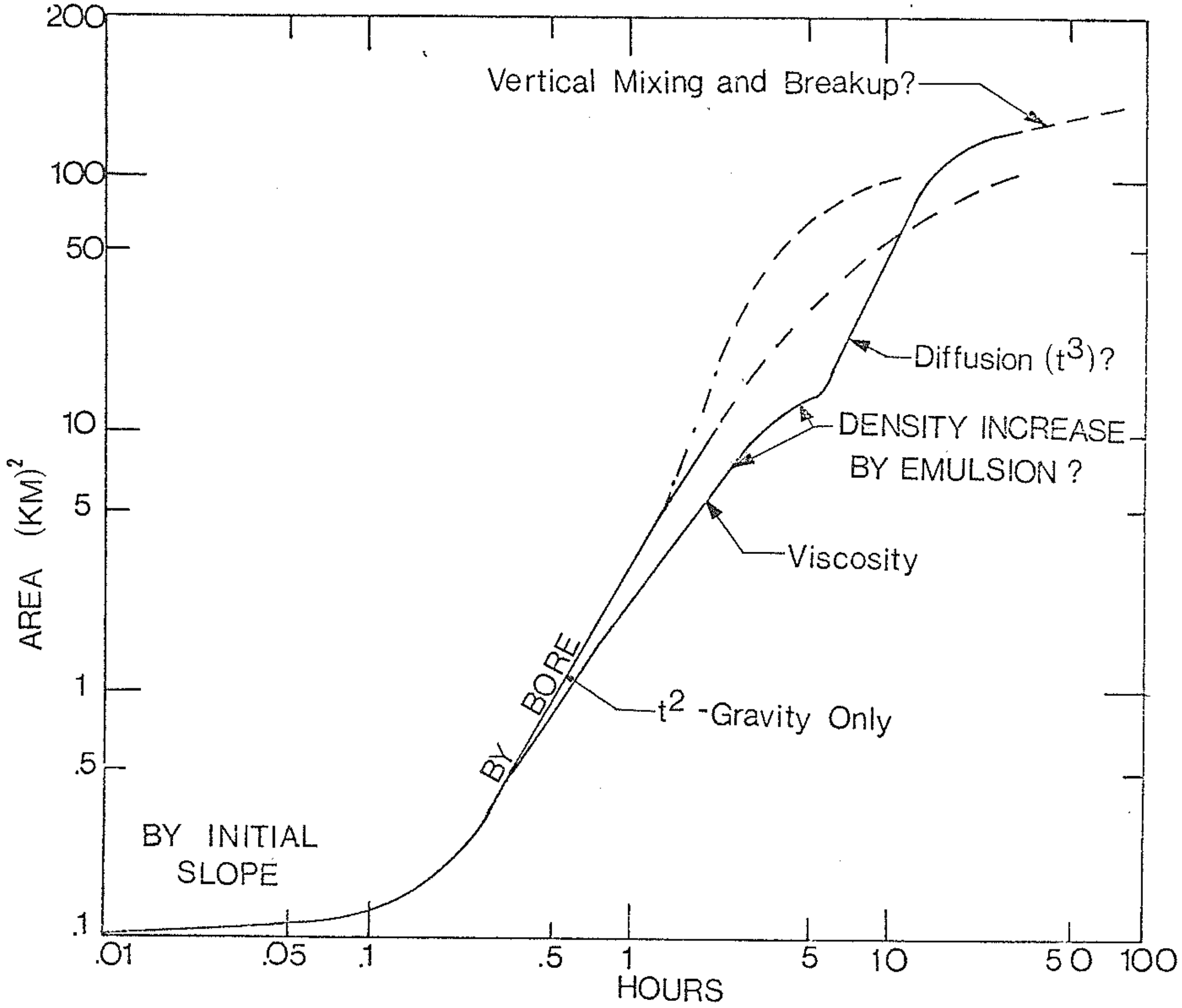

Figure C-12. Schematical Spreading of Oil Pool (Volume = 10,000m^3).

slope and then forms a bore. The bore spreads as a hydraulic jump as t^2 if there is no viscosity. However with viscosity of $\nu = 0.1$ cm^2/sec, the bore spreads more slowly and reaches its final size of about 10 km^2 after several hours. Then horizontal diffusion due to turbulence takes over dispersion processes and the area increases with t^3. However, after the area reaches 100 km^2, the thickness of the pool is only on the order of 1 cm even if increases by emulsion are considered. Increase of emulsion density stimulates vertical mixing and thus the t^3 rule becomes inadequate. Thus the increase of the area levels off.

In order to test this model with observed data, an oil patch observed by aerial reconnaissance during the Torrey Canyon incident was studied (Smith, 1968). This patch is a part of the initial spill which occurred after 0900h of March 18 when the ship was aground. The location and size of the pool are indicated in Figure C-13. The areas at successive stages were determined by planimeter from Figure C-14. Since the initial volume of the oil patch is unknown and the first observation of the area was considerably later than the spill, quantitative comparison with the theoretical model is impossible but qualitative comparison may be still worthwhile.

Since patch A (hereafter each stage is referred to as named in Figure C-13) was observed about 40 hours after the initial spill, it is hard to tell whether the level-off of spreading from patch A to D is due to the viscosity effect or vertical mixing effect. Sudden increase from D to E may be due to the t^3 - rule. Since turbulence becomes non-isotropic when the scale of a patch

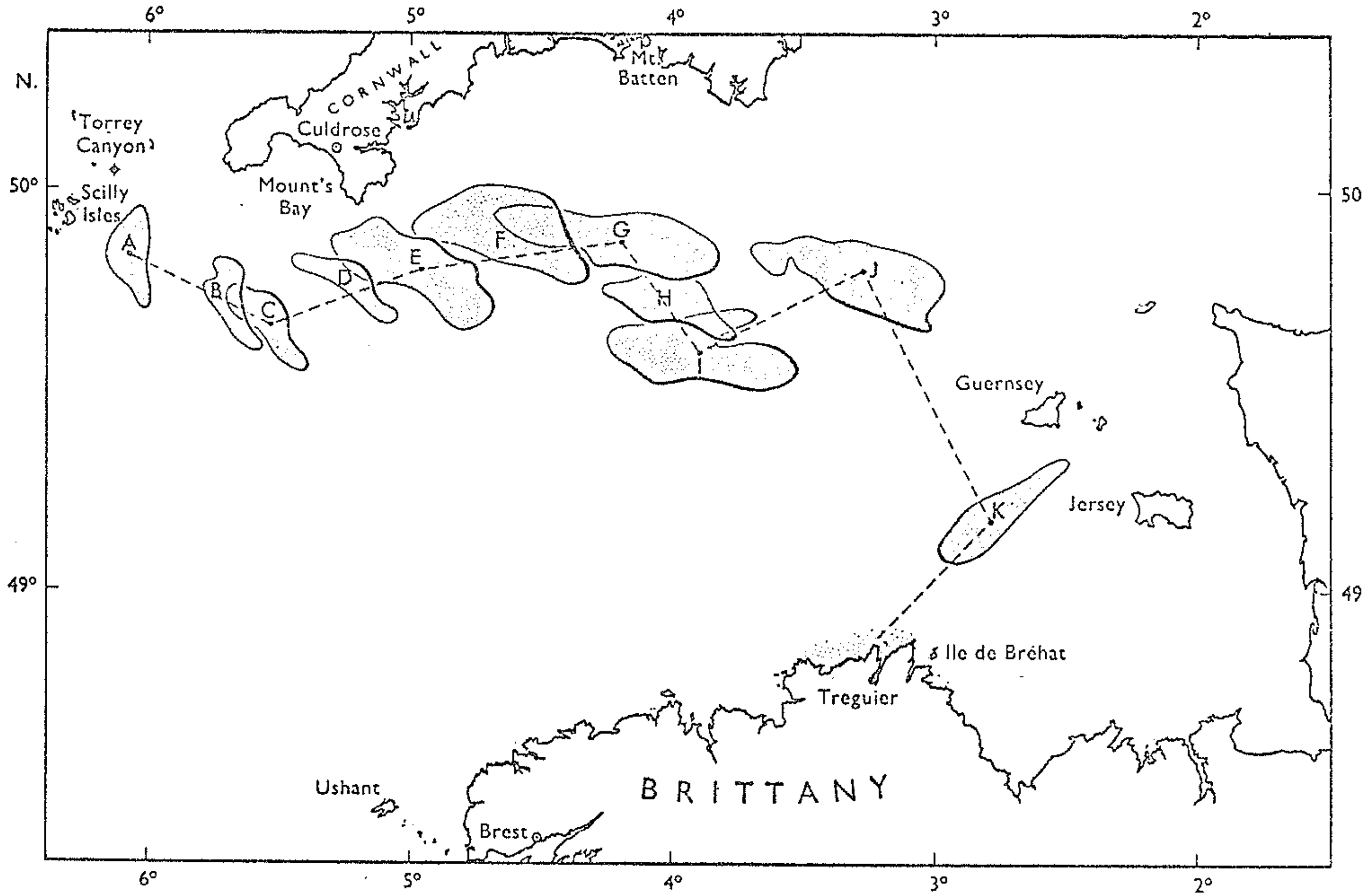

Figure C-13. Oil Drift March 20 to April 8.

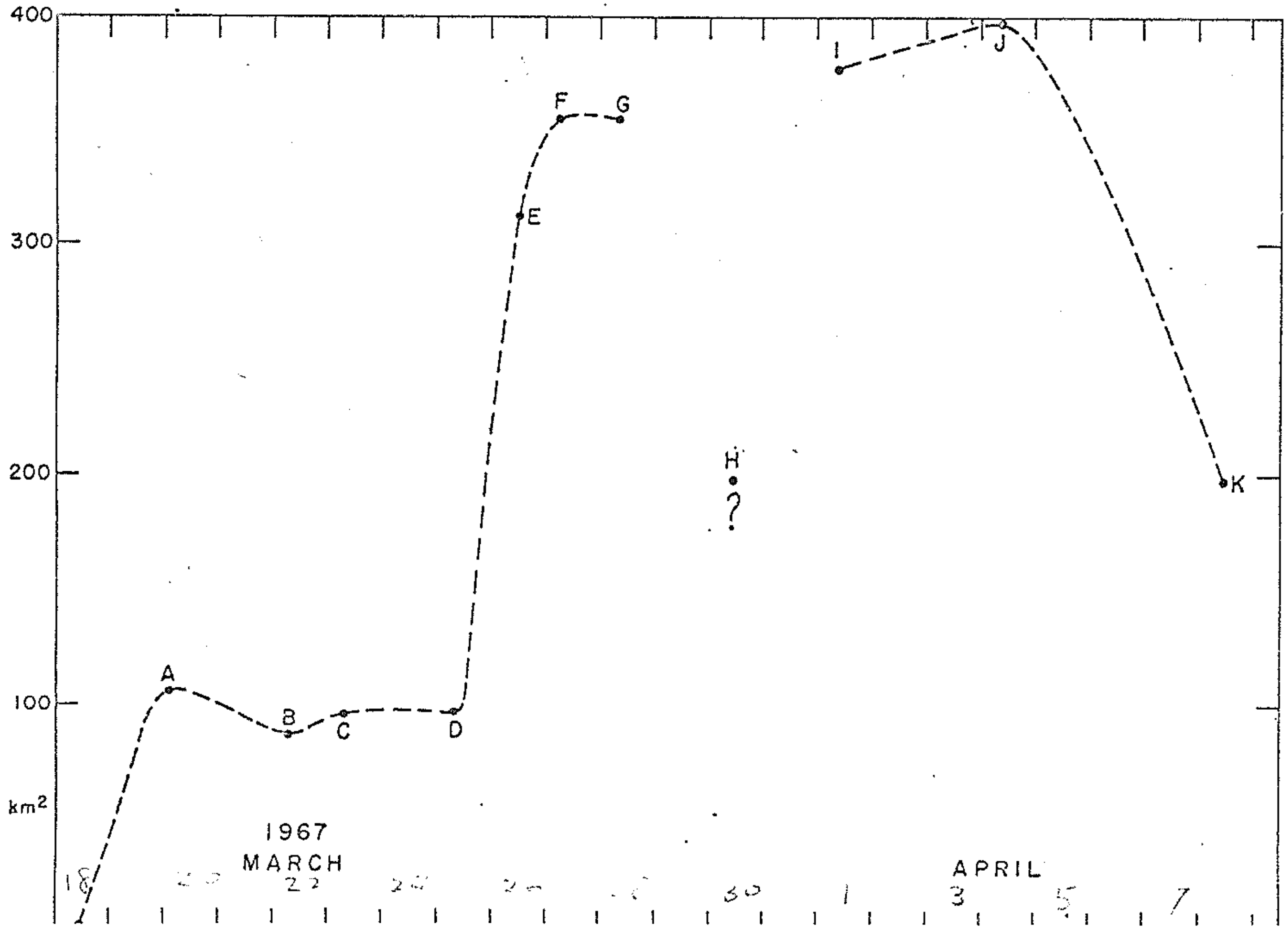

Figure C-14. Plot of Time vs. Oil Slick Size, Torrey Canyon.

increases, it is not surprising that the patch size suddenly increased from D to E. Actually the patch might have been caught by some eddies with scales on the order of 10^2km. Level-off and eventual decrease of size after F may be due to vertical mixing and probably sinking of a part of the patch. Patch H was observed inadequately and thus the area is doubtful.

By comparing Figure C-14 with Figure C-12, it can be concluded that an oil pool of about $10^4 m^3$ may spread to 100 km^2 within 10 to 20 hours and then it may reach 300 - 400 km^2 by effects of horizontal turbulence.

Recent measurements by Hollinger and Mennella with an airborne microwave sensor indicate that more than 90% of the oil was confined within a region of 1 mm thick whose area was less than 10% of the visible slick.

SUMMARY

The equation of the area of an oil pool is given in the following table after the initial hump is leveled out and becomes a hydraulic jump. In this calculation, viscosity is included and the time t is counted after the oil pool forms a hydraulic jump. In this equation η is a dissipation coefficient due to effective viscosity υ. P is the time scale, V_i, h_i and α_i are numerical constants which might be different for different initial shape (here it is assumed to be Gaussian in the radial direction). The effective viscosity is some average of the viscosity of water and oil, where the averaging constant depends on the boundary layer structure between the oil and the water. Since numerical values of η are smaller than α_i, the final area is proportional to $V(H_\eta^2)^{-1}$ or if other quantities are the same, to H^5.

In Figure C-12, spreading of oil with initial volume of $10^4 m^3$ (or about 10^4 tons) and with initial maximum thickness of 1m is schematically shown. For several minutes, the oil will spread due to the initial slope and form the hydraulic jump (or bore). The area then increases with t^2 if there is no viscosity. However, as the thickness approaches 1mm, the viscosity (effective viscosity) shows its effect and the area does not grow. At this point, however, the oil pool ceases to form a uniform patch but will be broken up into smaller patches, although from the air it may still look like a large patch. Then each patch may be dispersed according to irregular motion of the ocean surface as a dye patch spreads over the upper layer of the ocean. This process is called Kolmogorof diffusion and the area of the oil pool (actually envelope of broken up patches) will increase with t^3 as shown in Figure C-12. This process was definitely indicated by observation of the Torrey Canyon oil pool, which increased from 100 km to 300 km within a day or less in April 25, 1967, a week after the initial spill. Also, when the thickness becomes 1mm or less, larger patches actually consist of oil blobs of much smaller sizes and eventually these blobs are further disintegrated into oil particles (Forrester, 1971).

In order to determine the extent of impact of an oil spill of 30,000-tons, the area of the oil pool for the initial volume of 30,000 m^3 after the formation of the bore is shown in Table C-2 and Figure C-15. As the equation of Table C-2 indicates, the final area is almost proportional to m^5 where m is the maximum initial thickness (in m), and proportional to V^{-2} where r is the effective viscosity in cm^2 sec^{-1}. Therefore, if the initial thickness is 2m instead of 1m, the area increases rapidly with time and the final (viscosity limited) area also increases. However, if the thickness of the pool approaches 1mm, Kolmogorof diffusion becomes effective and degradation of the slick takes place. Thus the area does not grow indefinitely. However, if a tanker is broken up by explosion or similar accident, the initial maximum thickness of 2m is not unlikely and thus in a few hours the area of the pool may increase 20 to 30 km^2. Therefore, all devices so far developed for prevention of oil spill may be ineffective or at least prohibitively expensive.

Table C-1. 500-Ton Oil Spill.

$$\text{Area} = \frac{V}{h_i H \eta^2} \{\alpha_i (1 - e^{-\frac{\eta t}{T}}) + \eta\}^2$$

$$\eta = \frac{4}{h_i^2} \frac{\gamma T}{H^2}$$

$$T = (g \frac{\Delta\rho}{\rho\omega})^{-\frac{1}{2}} (V/V_i)^{\frac{1}{2}} H^{-1}$$

$V_i = 5.08$; $h_i = 0.087$; $\alpha_i = 0.194$

V = initial volume

γ = effective viscosity = $(\gamma o+\gamma\omega)/(2\delta) \simeq \frac{\gamma o+\gamma\omega}{3}$

H = initial maximum thickness

$\Delta\rho$ = density difference of water and oil

$\rho\omega$ = water tensity

g = gravity constant

t = time

Table C-2. 30,000-Ton Oil Spill.

$$\text{Area (km}^2) = \frac{0.448\ m\eta^5}{\gamma^2}\{4.75(1-e^{-\frac{1.9\gamma}{\eta^2}\tau}) + \frac{\gamma}{\sqrt{m}\ \eta^3}\}^2$$

m : $\frac{\Delta P}{w\delta}$ in 10^{-1}

η : initial maximum thickness in m

γ : effective viscosity in centi-stokes (10^{-2} cm^2/sec)

τ : time in hour

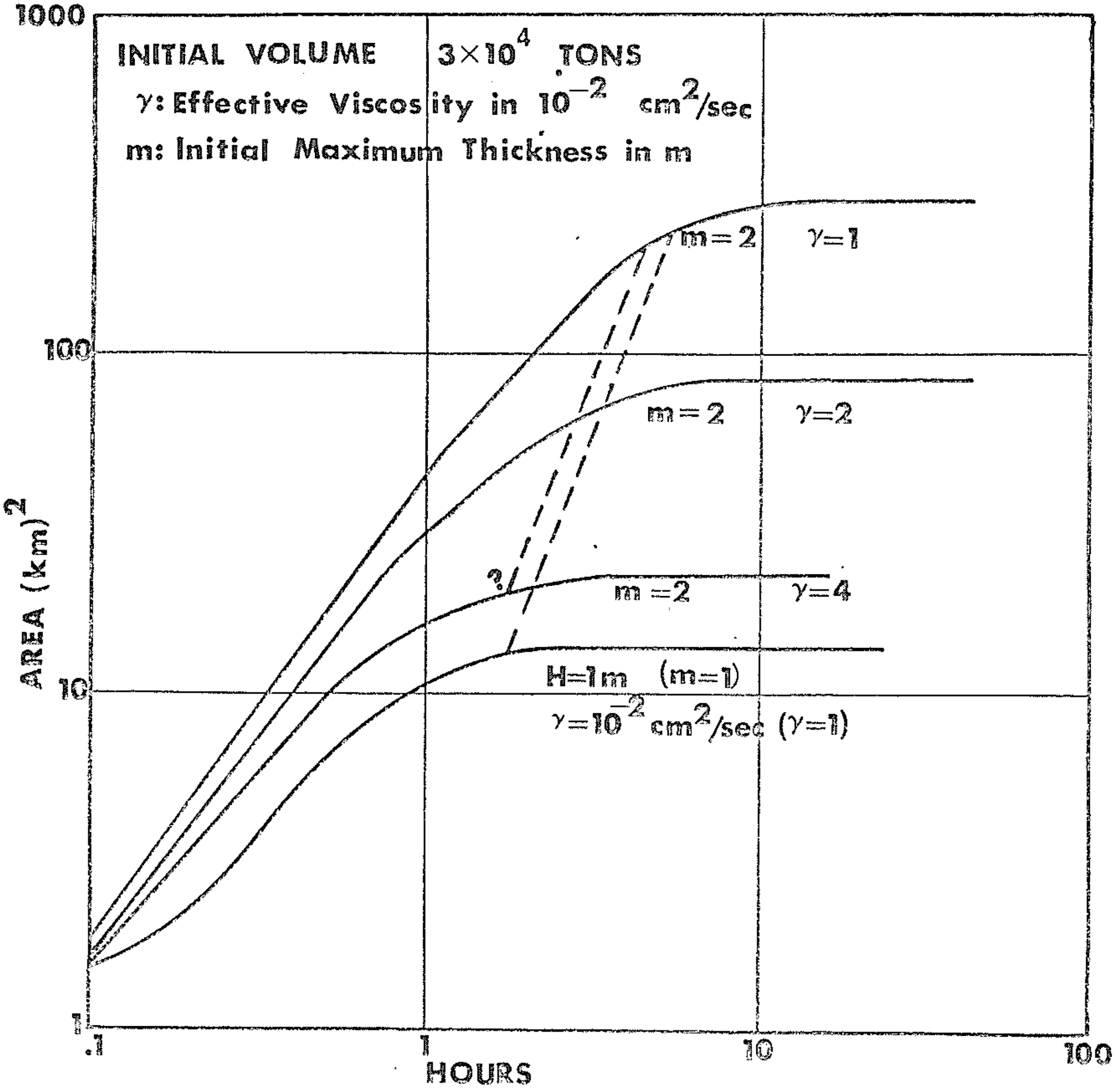

Figure C-15. Size of Oil Spill.

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APPENDIX D

COMPUTATION FOR ESTIMATING IMPACT OF CONSTRUCTION

A. Estimate of Dredged Volumes

B. Approximate Volumes for Island Construction

C. Turbidity Concentration Estimates

D. Settling Velocity

A. ESTIMATE OF DREDGED VOLUME REMOVED.

Dredged Volume

In Channel

$$1000' \times \frac{30' + 0'}{2} \times 7' \times 5280' = 555{,}000{,}000 \text{ cu ft}$$

In Dock Area

$$\left.\begin{array}{ll} & 2000' \times 4700' \times 30 = \\ + & 1/2(3000) \times (1000 + 3000)30' = \\ + & 2700' \times 1700' \times 30' = \end{array}\right\} + 600{,}000{,}000 \text{ cu ft}$$

TOTAL 1,155,000,000 cut

≈ 43,000,000 cu yds

Surface Area

In Channel

$$1000 \times 7 \times 5280 = 37{,}000{,}000 \text{ sq ft}$$

In Dock Area

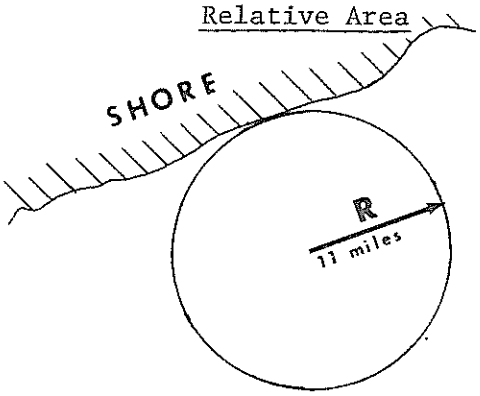
$$\left.\begin{array}{ll} & 2000 \times 4700 = \\ + & 1500 \times 4000 = \\ + & 2700 \times 1700 = \end{array}\right\} + 20{,}000{,}000 \text{ sq ft}$$

TOTAL 57,000,000 sq ft

≈ 1,300 acres

≈ 2.05 sq mi

Relative Area

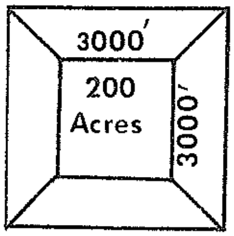


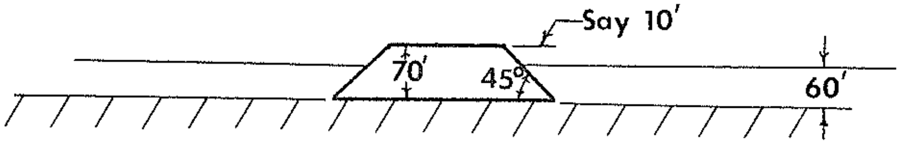
$A = (\Pi/4)D^2 = 380$ sq mi

Relative area = 2/380 ≈ 0.5%

B. APPROXIMATE VOLUME FOR ISLAND CONSTRUCTION.

The CEQ specification specified an island with area of 200 acres. Since there are 43,560 sq. feet per acre, a surface squsare 3000 ft x 3000 ft would be approximately equivalent in area. The sketch below was assumed for estimation purposes.





Volume

Center	3000' x 3000' x 70'	= 630,000,000 cu ft
Sides	4 x 1/2 x 70 x 70 x 3100	= + 30,000,000 cu ft
TOTAL		660,000,000 cu ft
		24,000,000 cu yds

Bottom Area Covered

3150 x 3150 ≃ 10,000,000 sq ft.
≃ 230 acres
≃ 0.36 sq mi

Assume excess dredged material used for onshore construction. If sloped to sea it will result in an increased bottom area covered.

C. TURBIDITY CONCENTRATION ESTIMATES.

Given:
- Oil terminal location no. 2
- Construction of dredged channels and island
- Distance from shore (nearest) about 19 miles
- Water depth about 60 ft gradually shallower toward shore

Find: The expected maximum concentration near the shore (19 mi) downstream - instantaneous release.

Assumptions:

1. Amount of material continuously lost in the form of silt and clay sized particles which continuously drift away from the construction site.

   a. Consider as a continuous "point" source even though site is "large" on relative basis compared to Gulf, distance from shore, it can be considered as such for first approximations.

   b. From previous calculations the island volume is about 24 million cubic yards, hence assume 23,000,000 yd^3 involved in construction process.

   c. Assume a total of 70% (very conservative) lost during construction by suspension in effluent water and drift toward shore in natural currents. Therefore 2,300,000 yd^3 lost.

   d. Neglect settling as first approximation.

   e. Assume insitu specific gravity of dredged material is 1.94 say 2.0. Therefore:

$$2{,}300{,}000 \text{ yd}^3 \times 27 \frac{\text{ft}^3}{\text{yd}^3} = 62{,}000{,}000 \text{ cu ft}$$

The unit weight of mixture is about 130 lb/ft^3 hence, amount lost is 7,500,000,000 lbs or 3,750,000 tons.

f. Construction occurs over a considerable time period, i.e.

  1. assume construction can continue throughout entire year
  2. dredging and island construction require approximately 2 years total
  3. of this time assume 50% lost for various reasons such as only working in daylight, downtime, etc.
  4. hence

$$4 \text{ yr} \times 365 \text{ days/yr} \times 24 \text{ hr/day} \times 60 \times 60 - 3.15 \times 10^7 \text{ sec}$$

g. Material lost rate becomes

$$q = \frac{7.5 \times 10^9 \text{ lb}}{3.15 \times 10^7 \text{ sec}} = 240 \text{ lb/sec}$$

$\approx$ 2 cfs of "insitu" material is lost continuously in the water column.

This value seems high but will be used in 1st approximation.

2. Magnitude of current

a. Assume continuous current in shoreward direction

b. For wind driven current

  1. assume wind speed of 10 knots (approx. 50% of time at least this value)
  2. assume wind driven current is 3% of wind speed 0.3 knots.

c. Assume mean Gulf current at 1.0 knot

d. Total current is therefore 1.3 knots, or 1.5 mph or 2.2 ft/sec.

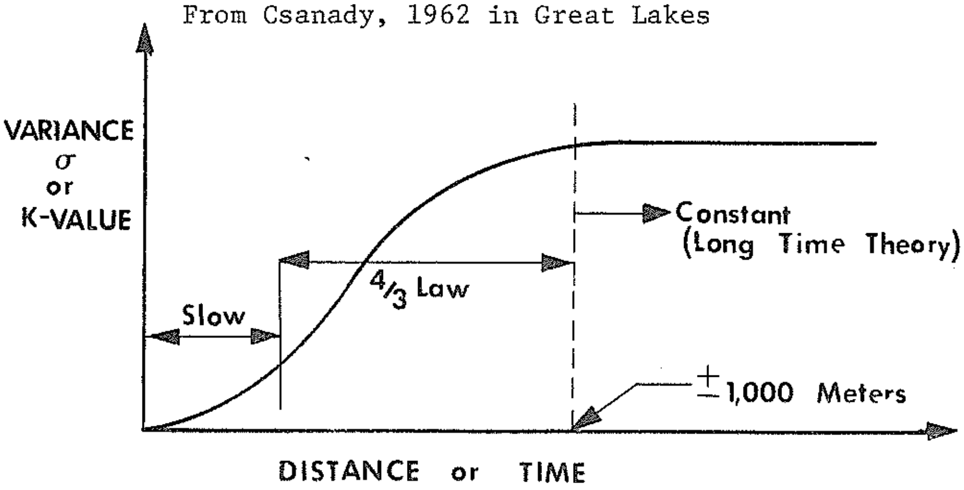
e. Assume continuous NW current of 2.2 ft/sec.

3. Distribution of concentration

   a. Assume a Gaussian distribution of concentration

   b. Assume a very long time for concentrations (i.e.) variance of concentration varies as Fickian theory of turbulent dispersion.

   From Csanady, 1962 in Great Lakes



   c. Hence, $\sigma_i^2 = 2\,K_i t$

   where σ_i = variance

   K_i = turbulent dispersion coefficient

   i = coordinate index

   t = time

   Therefore $\sigma_i = \sqrt{2\,K_i t}$

   d. Time involved in process, t

$$t = \frac{\text{distance}}{\text{velocity}} = \frac{19\text{ miles }(5280\text{ ft/mi})}{2.2\text{ ft/sec}}$$

t = 26,400 sec

= 0.3055 day

= 7.32 hours

   e. Relationships between longitudinal and lateral variance

   $\sigma_x \sim 2\sigma y$ from Csanady, 1962 Great Lakes Field Data.

4. Estimation of variances

From Csanady, 1962 the following range of turbulent dispersion coefficients were obtained

$K_y = 300 - 500 \text{ cm}^2/\text{sec} = 0.32 - 0.54 \text{ ft}^2/\text{sec}$

$K_x \doteq 4K_y = 1200 - 2000 \text{ cm}^2/\text{sec} = 1.32 - 2.15 \text{ ft}^2/\text{sec}$

$K_z = 1 - 5 \text{ cm}^2/\text{sec} = 0.001 - 0.005 \text{ ft}^2/\text{sec}$

Therefore

$\sigma_i = \sqrt{2K_i t} = \sqrt{2K_i} \cdot \sqrt{26,400}$

Hence

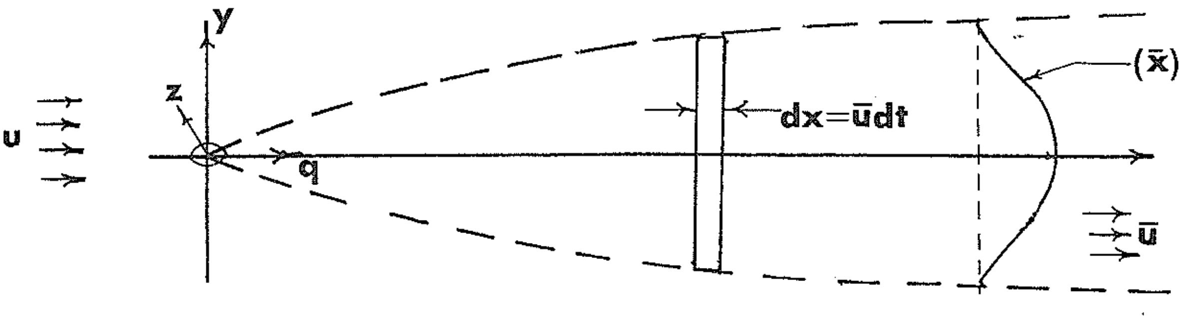
$\sigma_y = 130 - 170$ ft

$\sigma_x = 262 - 338$ ft (not applicable)

$\sigma_z = 7 - 16$ ft

Since connective transport by mean velocity is much greater than that by turbulent diffusion, σ_x was not used.

SOLUTIONS:



From Slade, 1968

$$\bar{x}\ (x,y,z) = \frac{q}{(2\Pi\sigma_y\sigma_z\sigma\bar{u})} \exp\left[-\left(\frac{y^2}{2\sigma_y^2} + \frac{z^2}{2\sigma_z^2}\right)\right]$$

Along the centerline y = 0 and at the surface z = 0 hence

$$(\bar{x})_{max} = \frac{q}{2\Pi\sigma_y\sigma_x\bar{u})}$$

1. Computation using low values of σ_i

$$(\bar{x})_{max} = \frac{240\ \text{lb/sec}}{(2\Pi \cdot 130\ \text{ft} \cdot 7\ \text{ft} \cdot 2.2\ \text{ft/sec})}$$

$$(\bar{x})_{max} = 0.019\ \text{lb/ sec}$$

2. Computation using high values of σ_i

$$(\bar{x})_{max} = \frac{240}{2\Pi \cdot 170 \cdot 16 \cdot 2.2}$$

$$(\bar{x})_{max} = 0.0064\ \text{lb/ft}^3$$

And since 1 lb/ft^3 = 0.01602 gm/cu, we can put this into another form

$(\bar{x})_{max}$ lb/ft^3	$(\bar{x})_{max}$ grams/cu cm	$(\bar{x})_{max}$ mg/1 = ppm
0.019	0.000304	304
0.0064	0.000102	102

Discussion:

The numbers obtained above are for an ideal, assumed "most conservative" case. The following factors should be remembered when considering the importance of these values.

1. They are for the maximum concentration at the centerline and decay is rapid to each side.

2. Steady 2.2 ft/sec current will probably vary in direction and time and magnitude.

3. Major assumptions of 10% dredged island volume lost and time involved resulted in a high value for the source.

4. No settling along the 11 mile path to shore!

5. Source considered as point, no thermocline effects.

D. SETTLING VELOCITY

Use 0.074 mm particle size for computation purposes since this is the Unified Soil Classification dividing size between silts and clays, and larger sands. The surface soil samples indicate large factions of silt-clay present.

In the stokian range where a Reynolds number based on particle diameter is less than 1.0, the settling velocity V_s can be found from

$$V_s = \frac{D^2(P_s - C_f)q}{18\ \mu}$$

$$V_s = 17.45 \times 10^{-3} \text{ ft/sec}$$

$$V_s = 0.0175 \text{ ft/sec} = \text{settling velocity}$$

This produces a Reynolds number of 0.0.004, well below the limit.

A particle moving at the surface at 2.2 ft/sec will take

$$t = \frac{\text{distance}}{\text{velocity}} = \frac{11 \text{ miles } (5280 \text{ ft/mi})}{2.2 \text{ ft/sec}}$$

$$= 26{,}400 \text{ sec}$$

$$= 0.3055 \text{ days}$$

$$= 7.32 \text{ hours}$$

to reach shore if no settling occurs.

Using a transport velocity of 2.2 ft/sec and a settling velocity of 0.0175 ft/sec a particle 0.074 mm (#200 sieve) will take 0.95 hours to settle out in 60 ft of water. By similar triangles, a partical located at the surface will settle to the bottom in a distance of 1.43 miles from the generation site. This neglects turbulence, flocculation, salinity and other factors.