

ABATEMENT OF BLOWING SALT CONDITIONS INLAND
FROM LAGUNA MADRE, TEXAS

BY

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REPORT TO COASTAL BEND REGIONAL PLANNING COMMISSION
UNDER URBAN PLANNING CONTRACT OF JUNE 7, 1967

CORPUS CHRISTI, TEXAS

1968

Preparation of this report was financially aided through a federal grant from the Urban Renewal Administration of the Department of Housing and Urban Development under the Urban Planning Assistance Program authorized by Section 701 of the Housing Act of 1954.

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- 1 -- Letter from Dr. B. J. Copeland, Marine Science Institute,
University of Texas at Port Aransas, 1968.
- 2 -- Preliminary survey of wind erosion and salt damage on the Kenedy Ranch,
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- 3 -- Engineering Report by James P. Naismith, 1967.

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TU 4-4716 OFF.
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July 7, 1968

1213 OCEAN DRIVE

Coastal Bend Regional Planning Commission,
Corpus Christi, Texas.

Gentlemen:

I enclose herewith my report on my investigation of the blowing salt and sand condition in the area of the Central Flats of Laguna Madre, Texas, pursuant to my contract with you of June 7, 1967.

Very truly yours,

W. Armstrong Price
W. Armstrong Price

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INTRODUCTION: THE REPORT AND AREA

Damages and Undesirable Conditions to be Investigated

The undesirable conditions are the intensification after 1949 of the blowing of salt, salty dust and sand into lands along the Laguna Madre from the shorelines of Kleberg and Kenedy counties inland, Figs. 1, 2 and 5.

This subject is discussed more fully in Part II under the heading "Initiation of the Present Investigation".

Directives of the contract may be summarized as follows:

1. Review of previous reports on the specific problem.
2. Assembly of additional pertinent information from recorded sources and previous observers and investigators.
3. Making of ground and air observations, with surveys.
4. Securing advice of specialists.
5. Evaluation of solutions for the abatement of the blowing salt condition.
6. Suggestions for possible sources of financing for remedial operations.

Directive No. 3, making of field surveys, has been accomplished in sufficient detail for present purposes in spite of the constantly flooded condition of the mainland and much of the flats from Hurricane Beulah of September, 1967, to the time of writing.

The writer's previous field studies with experience gained while conducting a survey for Humble Oil and Refining Company 1947-1949, with other information from the part of that survey directed by H. N. Fisk, have simplified and shortened the field surveys. A series of vertical aerial photo-mosaics of the 1930s, 1950s and 1960s has supplied information on the development of the present conditions. This development was intensified in scope and rate by the occurrence of two major hurricanes -- Carla of 1961 and Beulah of 1967 -- which flooded the flats, and also by two droughts of record lengths.

The Directive No. 3, to make field surveys, is found not to require a detailed resurvey of the flats at present because of the rate and extent to which changes are likely to occur. Detailed surveys should, however, be made during the planning stage for any remedial operations attempted. Such a survey would include pertinent phases of the entire environment of the Laguna Madre and Baffin and Redfish Bays.

Accessibility of the Central Mud Flats of Laguna Madre

The Central Mud Flats of Laguna Madre are accessible at their borders from the Intracoastal Waterway and from roads of the Kenedy Ranch. The nearest airports are the Kingsville, Mansfield and King Ranch fields.

From September 1967 through May, 1968, the Flats has been accessible from the mainland side only by marsh buggy, due to the sand of the mainland being soaked with water to the surface, with lakes in all closed depressions. Marsh buggies from Padre Island would have a delay in preparing to cross the Waterway.

The highway from Kingsville through Sarita to Raymondville passes within about 20 miles of the Flats and in normally dry years access to the flats can be had at several points, especially with 4-wheel-drive cars.

Trafficability of the Mud Flats

The only vehicles that can safely travel the mud flats in all its parts at all times are the marsh buggies or swamp buggies in use in the area by geophysical survey teams.

Because the flats are smooth, it is not necessary to use vehicles with very high and broad roller-type wheels, there being none of the narrow, deep, partly hidden tidal or other channels as in marshes of strongly tidal coasts.

When the margins of the flats are dry enough for jeep travel, experience shows the need to travel in twos, one jeep having a winch and long cable. The latter should carry a deadman log.

SUMMARY

A. GENERAL SITUATION

1. Natural and Artificial Changes in Laguna Madre 1949-1967.

Affecting the problems of this investigation since 1949 have been changes in the hydrography (tides and currents) caused by operations of man and also intensification of the normal variability of the rainfall regime.

2. Harmful and Undesirable Effects of the Changes; Integration.

The harmful and undesirable effects of these changes can be understood only when the factors of both natural and artificial changes are integrated.

3. Development of the Region.

The artificial changes have been made in response to the growing need of the region for transportation by water and on land: in part for commerce and in part for recreation.

4. Attack on Undesirable Conditions.

Some of the undesirable conditions can now be checked or lessened by artificial works, others could be remedied in future by draining irrigated areas into selected parts of the tidewater area, while others are uncontrollable effects of the regional climate.

5. Flooding has Obstructed the Investigation.

Flooding of the mainland and parts of the Mud Flats has restricted field investigation largely to observation from the air and from the edge of the Intracoastal Waterway.

6. Need for Comprehensive Study of Laguna Madre.

This investigation points to the need for a comprehensive plan for the development of Laguna Madre and its bordering lands. There are at present unknowns

in the hydrographic and hydrodynamic conditions of the lagoon which should become known in their integrations before further piecemeal changes in the environment are brought about and in order to develop the region to the best advantage for public use and enjoyment.

7. Most Readily Attacked Conditions.

Undesirable conditions most readily attacked at present are the intensification of the blowing of salt and salty dust from the northwestern Mud Flats of the Central Flats of Laguna Madre. This intensification was caused by the dredging of the Intracoastal Waterway by the United States Army Engineers. Checking of the drifting of sand across the Mud Flats in order to prevent its invasion of the Kenedy Ranch can be accomplished, but would be more expensive than to control of the blowing salt and dust. The identifiable damages and undesirable conditions have affected chiefly only the Kenedy Ranch. These conditions originate on flats owned by the State of Texas. Other undesirable conditions investigated are the result of regional climatic characteristics.

8. Sources for Financing of Remedial Operations.

The federal government, being the main offender, would seem to be the logical source of financial aid. Additional surveys would be required before the costs of remedial operations could be determined more fully and accurately than here estimated.

B. CLIMATIC VARIATION AND LOOSE SANDS

1. Semi-Arid Climate.

Laguna Madre is in the semi-arid zone where potential evaporation exceeds actual precipitation. This zone is characterized by variability which, on the basis of local records, has no readily recognizable periodicity besides the yearly seasonal changes. The variation ranges from fully arid (western desert type) to fully humid (Houston, Texas, type), but, in the main, is of semi-arid and dry sub-humid types, Corpus Christi lying on the border between these two types.

2. Recent Intensification of Droughts.

The usual droughts at Corpus Christi since 1880 have lasted only 3 years, but from 1949 to 1956 and from 1961 to 1965, the droughts were 7 and 5 years long, respectively. These droughts intensified the blowing of salt, salty dust and sand on the Central Flats.

3. Recent Periods of Excessive Rainfall.

Between droughts there have been periods of several years, each, in which rainfall exceeded the yearly average of 26.4 inches. Record peaks of yearly rainfall have been reached 6 times in the last 33 years.

4. Effects of Droughts.

The droughts of the 1950s and early 1960s caused large movements of blowing sand on Padre Island and the central flats, deadening of grass in the blowing sand areas, blowing of salt and salty dust from the Central Flats, and damage to live oak trees on the Kenedy Ranch.

5. Effects of Hurricanes of September 1961 and 1967.

Hurricane Carla of 1961 lowered the tides in Laguna Madre and the month's rainfall was only 3 inches. Hurricane Beulah of 1967 flooded Laguna Madre by 10 feet or more at the Central Flats and the month's rainfall was 20 inches.

6. Effects of Rainy Periods.

The seasons and years of heavy rainfall saw the recovery of the grass cover on most of the newly damaged mainland areas and lessening or cessation of blowing salt and dust on the Flats.

C. ARTIFICIAL CHANGES AND THEIR HYDROLOGIC EFFECTS

1. Earthen Fill of John F. Kennedy Causeway, 1950.

The fill of the causeway from Corpus Christi to the north end of Padre Island is a 4-mile dam closing the north end of Laguna Madre. Two narrow gaps at channel bridges are closed by swing barges. Even if the barges were replaced by pile bridges over these channels, the fill would still greatly decrease the mixing of bay and lagoon waters, shorten the fetch (distance over water) of the wind-blown sheets of water entering and developed in the lagoon, and also largely destroy the pre-causeway funneling effect when waters are driven southward into the lagoon from the wide areas of the bays to the north.

A result of the building of the causeway has been to lower the maximum heights and lateral extents to which wind-blown sheets of water have flooded the Central Flats, where the normal gravity tides are only 1 to 2 inches in range.

2. Dredging of Intracoastal Waterway and Mansfield Cut, 1949, 1962.

These waterways and the branch canals dug for development of oil and gas have rapidly drained off wind-blown sheets of water ("wind tides") before they could spread as widely over the Central Flats as they did previously. This has isolated from exchange with lagoon waters areas totaling about 5 square miles of the flats that lies in closed depressions.

D. EFFECT OF CHANGES ON SURFACE SEDIMENTS OF MUD FLATS

1. Sand Largely Replacing Clay and Destroying its Algal Mat.

The Middle Ridge separating the eastern Sand Flats from the western Mud Flats, and the Mud Flats themselves, were in 1949 surfaced by saline clay stabilized by a leathery mat of blue-green algae (pond slime) which was firmly bonded to the clay. The mat prevented wind erosion of the clay, except along its edges, which were of variable position.

Wind-blown sand, and possibly also sand carried by the lagoonal flood of Hurricane Beulah, has covered about two-thirds of the area of the Mud Flats and, in 1968, has developed a field of sand dunes.

2. Alteration of Microrelief of Flats Surface.

Wind erosion and the transfer of eroded sand and clay have changed the slight, but significant variations in flatness of the Central Flats. Hence, the 1949 topographic map of Humble Oil and Refining Company is no longer a completely adequate guide to the possible artificial flooding and drainage of the flats.

3. The Greatest Changes in Sediment Cover occurred during the hot months of the years of drought, but there has also been change during such months in years of normal or excess rainfall.

4. Uncertain Fate of Algal Mat on Remaining Clay Surfaces.

The closed depressions of the Mud Flats below about +2 feet msl seem, since Beulah, to be largely floored by clay and to have a dark, organic covering. Whether this dark cover is a live algal mat is not known. Because these depressions seem to have been continuously water-filled since Hurricane Beulah, the mat may be dead.

5. Hydraulic Fill and Spoil Dumps on Flats; Sand of Sand Flats.

Spoil and spoil dumps along the Intracoastal Waterway furnished much blowing sand in the westward migration of loose sand during the droughts of the 1950s and early 1960s.

The area of the sand flats of Padre Island, including the slightly high area of the Sand Bulge, was reported to be delivering more than the normal volumes of blowing sand to the wind.

6. Sand Invading Grassy Range Along Lagoonal Border of Kenedy Ranch.

During the droughts since 1949, the elevated grassy flats-island ridges known as potreros (pastures) north of the Mud Flats, including a row of smaller islands, the Calabazas, lost an appreciable acreage of range grass to invading sand. Much of the

grass grew back during the rainy years.

7. Salt-crystal grains and salty dust were blown inland, during the droughts, from the Mud Flats, where the algal mat had died and been removed by wind erosion. These materials blew inland in a zone 15 to 20 miles wide and extending northwestward from the Mud Flats. Many live oak trees on the Kenedy Ranch were killed and others suffered leaf-burns as far as Highway 77 at Sarita. Mesquite brush was defoliated in dry months but the foliage returned in wet periods.

E. FEASIBLE REMEDIAL MEASURES

1. Areas of Bare Sand Menacing Kenedy Ranch in 1968.

The chief menace to the Kenedy Ranch range is now from the 10 square miles of sand dune fields on the Mud Flats. Neither the elevations of the dunes nor the extent to which they have been moving into the western and northern margins of the Mud Flats are known. There was no dune invasion at the west during the droughts of the 1950s and early 1960s.

Padre Island Flats sands may or may not be a present menace.

A secondary menace is the sand of the spoil dumps, but this may be strongly active only during droughts or in dry months following additions of fresh spoil from dredging in the Waterway.

2. Remedial Measures.

There are no feasible means of stabilizing the very extensive sand flats of Padre Island. Application of the diked-lake method seems infeasible because of the great size of these flats.

The spoil dumps could be stabilized by treatment with an oil sludge or a resinous sludge applied after each dredging.

The sand dunes on the Mud Flats may require a combination of the following

two methods. For sandy areas above flooding levels, the 1940-1955 cane-hedge method of the Armstrong Ranch is applicable, but no costs can be given at present. For the lower lying areas, flooding during the hot, dry months should stabilize their sands, giving grass a chance to be seeded on them from the higher, re-grassed areas.

3. Diked-Lake Method of Flooding the Mud Flats.

By enclosing the 15 square miles of the main source area of blowing salt and dust, the area could be kept wet during the hot, dry months and drained afterward to reduce the salinity and prevent total evaporation.

In time, flooding the lower parts of the sand dunes and the sandy flats between them would permit a thin layer of clay to be deposited. Very thin layers were laid down each year in 1947-1950, their thicknesses varying from about 1/4 to 1/3 inch a year. After a layer a few inches thick had been laid down, an algal mat would begin to develop on it, if a suitable regime of alternate flooding and draining with lagonal water were carried out.

4. Cost of Diked-Lake Method.

The Naismith report (Exhibit 3) estimates \$1,250,000.00 as the cost of installation. The costs of operation have not been estimated.

5. Draining Closed Flats Depressions by a Canal.

By draining only the present enclosed depressions (5 sq. mi.) by a canal through a gate, and alternately flooding and draining, an algal mat, if not now present, could be restored, but only on clay surfaces. Dune movement, however, would menace the canal.

6. Cost of Cane-Hedge Method of Sand Satabilization.

The cost of this method depends on such factors as availability of part-time labor and the cost of fencing areas to be planted. Fencing against cattle would probably be needed for 3 to 5 years of adequate rainfall. Where wire rusts too rapidly, plastic-covered fence-wire is available in Europe and could be tried out here.

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PART I -- DESCRIPTION OF STUDY REGION

Regional Climate

Table 1 summarizes the climate of the Laguna Madre and Baffin Bay with geographic and hydrographic data (Rusnak 1960, p. 162). Figure 1 is a map of the region, showing the location of the critical area known as the Central Mud Flats.

TABLE I. SUMMARY OF CLIMATIC, GEOGRAPHIC, AND HYDROGRAPHIC DATA

Areal extent

Entire basin (water and shoals) . . .	609 sq. mi.
Entire basin (water excluding shoals)	475 sq. mi.
Northern Laguna Madre (water and shoals)	124 sq. mi.
Northern Laguna (water excluding shoals)	120 sq. mi.
Average width	2.5 mi.
Length	50 mi.
Average depth (approximate at M.L.W.)	2.5 ft.
Baffin Bay (plus tributaries)	85 sq. mi.
Average width Baffin Bay	3 mi.
Length Baffin Bay	15 mi.
Average depth (approximate at M.L.W.)	5 ft.
Southern Laguna Madre (water and shoals)	400 sq. mi.
Southern Laguna Madre (water excluding shoals)	270 sq. mi.
Average width	5 mi.
Length	55 mi.
Average depth (approximate at M.L.W.)	2.5 ft.

Climate

Area classification (after Thornthwaite, 1948)	Semi-arid
Average normal annual rainfall (50 yr. record)	27 inches/year
Evaporation in excess of rainfall . .	21 inches/year
Average annual temperature (50 yr. record)	22°C.
Absolute maximum (50 yr. record)	40°C.
Absolute minimum (50 yr. record)	-11°C.
Hurricane frequency (after Price, 1956)	40/century
Hurricane floods crossing Padre Island (after Price, 1956)	18/century

Rivers

No major rivers flow into the area. Very slight fresh water inflow from ephemeral streams during local rainfall.

*

Tides**Laguna Madre**

There is no periodic tide. Rise and fall of water at any particular locality is dependent upon wind condition. Extreme wind can cause a tidal range of three to four feet.

Outer coast (referred to mean low water)

Mean sea level	0.5 feet
Mean high water	1.0 feet
Lowest expected	-3.0 feet

*Rio Grande discharged into Laguna Madre near Port Isabel in the 1870s.

Figure 2 is a topographic map of the Central Flats.

Table 1 was prepared in 1959 to represent the average condition along Laguna Madre. Climatic data for Corpus Christi differ only slightly from those of the table.

Corpus Christi lies on the boundary between Thornthwaite's (1948) semi-arid and dry sub-humid climatic zones. His maps of yearly weather (Thornthwaite 1941) show the succession of different climatic types which here characterizes the variable semi-arid zone as summarized in Table 2. Aridity increases here slightly toward the south. Corpus Christi and the Laguna Madre are slightly more humid than the country a few miles inland.

TABLE 2 -- CLIMATIC YEARS PER CENTURY AT CORPUS CHRISTI

<u>Fully Arid</u> <u>(Desert)</u>	<u>Semi-Arid</u>	<u>Dry</u> <u>Sub-Humid</u>	<u>Moist</u> <u>Sub-Humid</u>	<u>Fully</u> <u>Humid</u>
5	41	41	11	2

The rainfall is quite variable but averages 26.4 inches at Corpus Christi, Figure 3. Runoff characteristics differ greatly between the clay-floored areas of the mainland north of Baffin Bay and south of Kenedy County and the deep sands of the mainland sand plain between these areas. The region is subject to droughts upwards of 1 to 3 years long, and has had two longer droughts since 1930, Figure 4.

Storms include hurricanes of large-to-regional sizes and lesser tropical cyclonic storms, wind-storms accompanying cold fronts from the north, and the relatively small tornadoes with a larger number of water spouts confined to the bays and lagoons. Tornadoes occur with hurricanes and cold fronts ("northers").

The winds are monsoonal, coming from the north about 1/3 of the time in fall, winter and spring, and from easterly to southerly directions in spring, summer and fall.

The semi-arid coasts are the windiest of the temperate flatlands. Calms are infrequent except in summer mornings and in August.

Bordering Lands of Laguna Madre

Padre island is bordered along the Gulf beach east of the Central Flats by a chain of grassy foredunes elongated parallel with the shoreline. There is a mid-island belt of grassy plain with scattered, low, grassy sand dunes. On sections of Padre Island there are, facing Laguna Madre, long narrow fields of bare and slowly migrating sand dunes of the longitudinal (seif) type. These bare ridges trend east-west and migrate toward the west, with sand streaming off them onto the marginal sand flats and into the waters of Laguna Madre.

Sand from Padre Island has narrowed Laguna Madre in recent historical time. At the north end, the narrowing has been 1/2 mile in a century, and in some places that much in 30 years.

Bathymetry

The Laguna Madre is very shallow. It has a smooth, sloping floor on the east side shallowed by sediment coming from Padre Island. There are a few slightly deeper basins and troughs on the west side (Rusnak 1960, figures 3-5). Baffin Bay has the largest area of relatively "deep" water south of Corpus Christi Bay. Baffin Bay is nearly closed at its mouth by a zone of shallow platforms or pinnacles of carbonate-cemented coquina reef covered by extensive layers of serpulid worm tubes and barnacles.

The Laguna Madre section of the Intracoastal Waterway was opened in June, 1949, and is maintained by the U. S. Army Engineers with a width of 125 feet and a depth of 12 feet. It runs near the west bank of Laguna Madre from Baffin Bay southward and through the Land Cut and central flats on that alignment. Oil and gas companies

have cut various short and long canals from the Waterway to drilling sites in the water. The Mansfield Cut is also maintained at a depth of 12 feet by the U. S. Engineers. It crosses the Waterway from Port Mansfield through Padre Island to the Gulf. It is located 36 miles north of Brazos Santiago, the tidal inlet of Port Isabel.

Salinity and Hydrography

Because of constrictions of the outlets, the waters of Laguna Madre, north and south, are chemically more like those of lakes than of estuaries. However, high windiness prevents vertical temperature stratification, the upper and lower waters mixing readily. Baffin Bay may have very low salinities in years and seasons of prolonged rain and after flash floods from its creeks, but also has the record for high salinity, reaching 45 parts per thousand chlorine (sea water has 27 parts per 1000). The southern Laguna Madre is normally less salty because of its inlets, but the opening of the Intracoastal Waterway has tended to lower the contrasts between north and south. Both water bodies are affected by the high evaporation rate.

Currents in Laguna Madre are those of wind tides except near inlet mouths. The current pattern reverses alternately north and south with the monsoonal winds' reversals. Away from inlets and canals, currents as fast as 30 cm/sec (0.7 mi/hr) have been measured.

Besides the lunar tides of 1 or 2 inches near the Central Flats, seasonal tides with a range of 1.0 to 1.5 feet produce high waters twice a year. Wind tides reaching heights of 0.5 foot are common and reach 3 to 4 feet in terminal areas and on the Central Flats under strong, sustained winds. High salinities occur at times in small coves of the lagoon and in shallow closed depressions on the flats and crusts of evaporite salts form at times in such places and on the upper reaches of flats, especially on the Central

Mud Flats. The salts readily blow away or are redissolved, only the gypsum and iron compounds remaining within the sediments as separate bodies. The gypsum crystallizes in the sand to form rosettes of inter-locking crystals of selenite. These are numerous in the sand at shallow depth and have been dredged up on spoil dumps. Iron-bearing organic compounds are widely distributed in the lagoonal sands.

South Texas Sand Plain (Erg).

From Baffin Bay southward to the clay plain of the Rio Grande delta, the coastal part of the mainland is covered by wind-blown sand. Most of this South Texas Sand Plain is almost flat, being well stabilized by grass, or oak groves ("mottes"), or thorny brush (mostly mesquite). Most of the plain has only low, stable, degraded sand dunes.

Brooks-Kenedy Dune-Sand Lobe

The northeastern part of the South Texas Sand Plain is here called the Brooks-Kenedy Lobe, Figure 1. It has somewhat looser, or more loosely stabilized, sand than the rest of the sand plain. It also has numerous scattered areas of bare blowing sand, with dunes. These bare areas take a standard form produced on a grassy plain by the pattern of the on-shore winds of the warm and hot months. This form has been called a "banner dune complex" (Price 1958).

The banner is a sheet of sand originating in an area of damaged grass in which a blowout pit has formed. The excavated sand fans out downwind with a median axis trending N 45° W, or nearly so. The fan has a spread ranging from about 15° to 35°. Along the edges of the fan, sand is held by vegetation so as to form a pair of diverging ridges. As the banner elongates, dune ridges form across the bare fan. They vary from initially NE-SW transverse ridges to ridges that finally extend E-W and are of longitudinal (seif) type.

As the blow continues, the initial blowout spot or area is sunk to the water-table and may release no more sand. Meanwhile the sand of the fan slowly travels downwind into the vegetation where it is held and the dunes disappear, leaving, however, the interdune swales etched erosionally into a marly soil bed where they are preserved.

The banners are normally about 1 to 1-1/2 miles long and about 1/2 mile wide. The extinction of a banner by natural processes requires many years. Secondary blowouts may start in the area of a first banner, developing long compound forms.

The areas of the Brooks-Kenedy Lobe between bare banners are complexly ridged by the lag ridges of former banners which have now interferred to form patterns of Vs and Ws (Price 1958, Figure 7). The total area of grassland with stable ridges in Vs and Ws exceeds the total area of the bare banners.

Cane-Hedge Method of Stabilizing Blowing Sand

On the 55,000-acre Armstrong Ranch in the Brooks-Kenedy Lobe, 5,000 acres of blowing sand were stabilized from 1940 to 1955 by native grasses voluntarily growing in the protection of cane hedges and wire fencing. Only ranch crews were used.

Areas of active blowouts (areas in which banners start) were covered by cut-brush. Hedges of Georgia Cane (Arundo donax) were planted across the paths of migrating dunes and on the less active parts of banners. Planting areas were fenced.

This method was followed, with variations, in the developmental stage of the Cameron County Park at Brazos Santiago Pass east of Port Isabel and has been used by the writer and L. E. Rawalt in a test plot on northern Padre Island, both projects being successful. This cane has unique structural and growth features which make it the best hedge plant found for the purpose in this climate. It grows better where sand blows into it than elsewhere in sandy land.

The Kenedy Ranch has traditionally been content with the existing range and had not, by 1949, instituted a general sand-stabilization. Some unsuccessful efforts were made in the early 1960s to hold the grass on the damaged areas along the flats border north of the Mud Flats.

Formation of Central Flats of Laguna Madre

A central area across Laguna Madre had by 1947 been shoaled up to a minimum of 2.4 feet above msl by strata of lagoonal sand-and-clay with wind-blown sand in the eastern half. The deposits were formed because the lagoonal gravity tides were reduced here to 1 to 2 inches in the zone half-way between two tidal inlets 112 miles apart. Wind tides blowing alternately from opposite directions were stilled or evaporated on the flats and dropped their sediment. Sand blown and washed over from Padre Island also added to the deposits. Similar half-way sediment plugs are known in other long lagoons that lack in-flowing rivers. The Central Flats slope up landward to the west and eastward toward Padre Island with slopes as high as 1 foot per mile to levels of 4 to 6 feet msl.

Currents moving southward have built a line of grassy sand spits known as "potreros" along the western shore of Laguna Madre from the neighborhood of Baffin Bay southward. A low bare extension of this spit line forms the Middle Ridge ("The Swell" of Fisk 1959) of the Central Flats. Along the eastern flank of this ridge the Intracoastal Waterway has been dredged. This median spit now rises to about 2.7 feet above sea level (between 1968 dunes) in one area and seems to be still slightly more than 2.0 feet msl along its whole length from Potrero Lop  no to Avoca Island. North of the Central Flats, wind-blown sand from Padre Island has accumulated in vegetation against and on this line of spits where it has formed a series of well grassed ridges separated by narrow shallow swales. These potrero ridges, Figure 2, rise to elevations of 10 to 15 feet or more.

Central Mud Flats and Algal Mat of 1949

The western indentation of the lagoon shoreline, Figure 2, occupied by the Mud Flats is about 6 by 11 miles in size, or 66 square miles. Fisk's borings (Fisk 1959) show that this was once a depression formed by the branches of two creek that flowed off-shore when the sea level was much lower than today. This area will here be called the Mud Flats, although 2/3 of it is now covered by sand.

Several flats islands composed of grassy remnants of the Brooks-Kenedy Lobe and its stabilized dune ridges rise from the Mud Flats. The largest of these ridges are the Mesquite Rincon group, Avoca Island and El Toro Island. The clay-floored Mud Flats were bordered at the east by the Middle Ridge (Fisk's Swell) now rising to from 2.4 to 2.7 feet above msl between dunes. The clay was strongly stabilized at the surface in 1949 by a tough, leathery algal mat composed of blue-green algae with their filaments penetrating downward through successions of thin layers of clay, sandy clay and dead, peaty mat material impregnated by hydrogen sulphide gas with its rotten-egg odor.

Along the border of the mainland at the west and northwest in 1949, the mat died out landward and salty clay particles had blown up to form a wide scattering of clay dunes. This border zone is perhaps 9 square miles in area, Figure 5. The clay surface of the flats sloped up to the northwest at a maximum of about 1 foot per mile until the steeper marginal zone was reached. Several closed, shallow depressions lay on the Mud Flats between flats island ridges and out on the flats west of El Toro. The largest of these depressions enclosed about 2 square miles at +2.4 feet msl and extended to about 0 msl. Areas on the Mud Flats in 1949 are shown in Table 3.

TABLE 3 -- AREAS OF MUD FLATS (approximate) EXCLUSIVE
OF SAND "ISLANDS"

<u>Mud Flats</u>	<u>Length N-S Feet</u>	<u>Width E-W Feet</u>	<u>Sq. Mi.</u>
NW section below +2.4 ft. msl	28,000	15,000	15
Areas S & W of Mesquite Rincon			7
Higher Borders above Closed Depressions			<u>9</u>
Total Area of Central Mud Flats			31

The algal mat was kept alive by being wetted by wind-blown sheets of lagoonal waters which were usually highly saline. In 1948 it was flooded 80 per cent of the year. Between wettings, the mat dried and cracked but protected the clay from wind erosion except along the margins where the mat was irregular in occurrence or absent.

When wetted again, the mat wrinkled into ropes, bumps and domes. Hydrogen sulphide and nitrogenous gases in the peaty layers were strong enough in the lee of flats islands to threaten to asphyxiate travellers who might mire down.

Grassy Islands and Ridges Standing Above the Mud Flats

A series of large and small grassy sand-ridge "islands" 5 to 10 feet high rises from the Mud Flats with NW-SE elongations, Figure 2. As noted, these are remnants of the ridged topography of the South Texas Sand Plain which became divide ridges between ancient creek valleys now filled with flats sediments. The largest group of these ridges is the Avoca-Mesquite Rincon assembly in the southeastern half of the Mud Flats. North of Avoca "Island" lies El Toro, an oval "island" about 1.5 by 0.7 miles

in size. As the Central Shoals built up, these former true islands became drowned by the sheet of mud.

Along the mainland shoreline from near Baffin Bay southward, an alignment of southward pointed sand spits once formed a low ridge the extension of which crosses the mid-length of the Central Flats from Lopëña past El Toro to Avoca. Sand drifting across the Flats from Padre Island in small amounts at a time has built beach plains against the east sides of these spits and islands except for the bare Middle Ridge previously described. The spit line is now covered with the grassy beach plains, which are from 1,000 to 4,000 feet wide and upwards of 15 feet high. The beach plains are composed of parallel N-S beach ridges separated by narrow linear swales, all heavily grassed in the normal condition. One of these ridges was built during 6 weeks of strong droughty winds in 1948 (Price 1958).

The elevated beach plain belts are slightly separated from the ridges of the sand plain north of the Central Flats and are cut transversely into the quadrangular segments known as "potreros" or pastures. Potrero Lopëño, the widest of these, lies at the northeast corner of the Mud Flats.

Some of the sand blown from Padre Island across the sand flats passed over the Middle Ridge onto the algal mat, but before 1949, did not kill it or accumulate into dunes, being merely held in the irregularities of the surface.

Clay Dunes of the Mud Flats and the Blowing Salt and Dust

Margins of the Mud Flats above the reach of frequent wind-blown waters and facing toward the easterly and southerly winds are dotted with clay dune ridges (Price 1958, 1963) elongated either along a local shoreline irregularity or parallel with the contours of the sloping margin of the flats. These ridges rise to from 2 to 15 feet above the surface and are grassed on their summits and their gentle rear slopes, but facing the

flats are steep and may be gullied.

Clay dunes are known only in the dry climates and are numerous in South Texas along the borders of clayey flats and dry lakes. When a clay flat dries out it develops a thin, brittle, salty crust which cracks into polygonal cakes. These roll up at the edges and are blown off by the wind, breaking down in part into sand-sized pellets of tough clay and in part into salty dust. In some cases, instead of cracking, the crust is made fluffy by the growth in it of saline crystals. The crystal grains and fluffy clay particles then blow away. There may be various amounts of fine sand in the blown materials.

Rough calculations show that $1/4$ of the crust fragments blown off a flat accumulate against a shore rise, in vegetation along the flats margin, or against trash lines on the flat to form clay dunes. The remaining $3/4$ of the materials blow over as dust, some rising into the general atmospheric circulation and some being caught by vegetation back of the dune.

The algal mat and the clay to which it is bonded crack on drying but do not provide large quantities of blowing materials. However, from wide, deep cracks cut through the mat, some dry particles blow away. These do not seem to contribute materially to the marginal clay dunes, which develop primarily from the bare flats beyond and higher than the mat.

Sand Flats and Sand Bulge of Padre Island

The gently sloping western flank of Padre Island has a broad zone of bare sandy flats over which wind "tides" move back and forth. This is commonly made somewhat stable against wind erosion by the blowing away of the finer sands leaving the coarser grains behind on the surface as a thin and rather weak crust of closely spaced grains. When dry this surface is probably slightly strengthened by salts. Near the

water, the sand flats tend to be moist much of the time. All these conditions reduce the amount of sand blown from these flats. Thus, sand dunes do not seem to form from the sand of these flats east of the middle ridge.

Blocked Ends of Northern and Southern Laguna Madre

The trough known as the "The Hole" which is the shallow southern end of the northern Laguna Madre lies eastward toward Padre Island and ends against the "Sand Bulge" east of El Toro, Figure 2. The northern end of the southern Laguna Madre, known as Redfish Bay, lies against the mainland and terminates with a westward hook south of Mesquite Rincon. The King Ranch Shoreline runs south from this terminal hook.

Life Forms on the Flats in 1947-1949

Exclusive of the grassy islands, the life forms seen on the flats were transient or of low types.

Wind-blown sheets of water brought in great schools of fish, with flocks of gulls feeding on them in the shallow water. At times, many fish were trapped on the flats and died either because evaporation was producing a lethal brine or where the returning waters left the fish in closed depressions. Here they were eaten by gulls or died as the water evaporated. Coyotes were probably prevented by the mud from feeding on the trapped fish as they do on firm bottoms.

The blue-green algae of the mat were accompanied by various other micro-organisms. The only animal observed feeding on exposed areas of the mat was a small brown-and-black wasp. If birds other than gulls ever landed on the mat, it was not noticed by the writer.

Animals from the mainland at times travelled the edges of the flats, but found no food there except on flats islands.

Ecological Value of an Algal Mat

In Exhibit 1, Dr. B. J. Copeland, Assistant Professor at the University of Texas Marine Science Institute, Port Aransas, states that algal mats return nutrient solutions to the lagoon when water drains off them, and that these nutrients are valuable for marine life. No monetary value can be put on this nutrient return without a research project on the specific mat and its environment.

Because the flats act as evaporating pans, increasing the area and times of their inundation would increase the salinity of the lagoonal waters, tending to offset the value of mat restoration, if high salinity is regarded as detrimental to the environment.

PART II -- HISTORY OF RAINFALL, DROUGHT, AND BLOWING SALT CONDITIONS

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PART II -- HISTORY OF RAINFALL, DROUGHT AND
BLOWING SALT CONDITIONS
Initiation of the Present Investigation

This investigation was made in response to widespread public concern over the increase in the amount and distance of travel of salt and salty dust blown inland from parts of Laguna Madre in the 1950s and again in the early 1960s. The most widely noted effect was the browning of leaves on the eastern sides of live oak trees in the Kenedy Ranch and along Highway 77 from Sarita southward to Armstrong.

At the same time, sand began to blow from the spoil dumps along the Intracoastal Waterway and accumulate on the potrero ridges and adjacent flats inlands, including the Calabazas island chain extending west of the southern end of Potrero Lopéño.

Salt and salty dust accumulating on electrical installations west of Baffin Bay and from there westward to Falfurrias and Alice, with dust on crops, were thought by many people to have come from flats drained by the Waterway.

All these conditions were widely blamed on the opening of the Intracoastal Waterway in June 1949 and on the naturally high salinity of the Laguna Madre and Baffin Bay.

Several steps have been taken to investigate the blowing salt and sand condition and to seek remedies for it, the latest of which is the present investigation under the Coastal Bend Regional Planning Commission, with the writer as consultant investigator. The possibility of keeping the waters of the coastal bays and lagoons at normal oceanic salinities is not a part of this investigation.

Investigations by Gulf Coast Salt-Erosion Committee and
U.S. Soil Conservation Service

Citizens of twelve counties along the coast and inland from the northern Laguna Madre formed a Gulf Coast Salt Erosion Committee with E.L. Turcotte, Jr., then manager of the Kenedy Ranch, as chairman. After gathering information, this committee

secured the aid of the United States Soil Conservation Service of the Department of Agriculture. A journalistic account of the committee's findings appeared in the Corpus Christi Caller-Times of Sunday, April 4, 1965, page B1, and two unpublished reports, including Exhibit 2, herewith, were made by the Soil Conservation Service. The other is the Coover and Rechenthin report (1965).

Exhibit 2 used an unpublished report to the Humble Oil and Refining Company as a basis for its investigation, incorporating two maps from it.

Survey of the Central Mud Flats by Humble Oil & Refining Company
1947-1949

In the Humble's study, Price was assigned the surface geology and geomorphology of South Texas, including the general nature and origin of the Mud Flats. Lewis E. Rawalt was Price's foreman. In 1948, H.N. Fisk organized and directed a coring survey of the Central Flats and the adjacent parts of Padre Island. His large report has not been released by Humble, but access to it was granted the Soil Conservation Service for their study and much of the substance of the Humble surveys of Fisk and Price have been published (Fisk 1959, Price 1958). The Humble topographic map Figure 2, is used as the basis of the present study, with data from their core records. Rawalt was Fisk's foreman in the coring operations and in some other phases of Fisk's investigation.

Events Affecting the Environment of the Northern
Laguna Madre and Central Flats 1949-1968

The natural environment of the Laguna Madre in both its northern and southern (Redfish Bay) halves has been affected by three major engineering operations:

1. 1951. Closing of the north end of Laguna Madre by an earthen causeway fill, leaving only the openings of the Intracoastal Waterway and the Humble Channel, both of which have been obstructed by swing-barge gates.
2. June, 1949. Opening of Intracoastal Waterway from Corpus Christi Bay to Brazos Santiago inlet, a distance of 112 miles along Laguna Madre, the canal being 125 feet wide and maintained at a depth of 12 feet.
3. May 1962. Opening of the Mansfield Cut through Padre Island with a transverse channel from the mainland at Port Mansfield.

Hurricane Flooding

Flooding by hurricanes and lesser tropical cyclonic storms, with some current erosion, has affected Laguna Madre and the Central Flats. The large and intensive Hurricane Beulah of September 22, 1967, which travelled from Brownsville to Hebbronville before turning southwest, was expected to flood the southern end of Laguna Madre from the Gulf, raising it to 10 feet above sea or higher, but official figures have not been seen. The tide was at 7 feet in Corpus Christi Bay before the after-storm river-flood arrived. Photographs and bottom-channeling patterns show that the Mud Flats was flooded, but the height is not yet known.

Hurricane Carla of 1961 caused low tides at the mouth of Baffin Bay and did not flood the Mud Flats. However, some of the lesser tropical cyclonic storms may since 1949 have done so. Hurricane floods channel and erode some areas and leave deposits of sand and clay on others.

Rainfall and Drought

The mean annual rainfall for Corpus Christi for 1931-1967 was 26.42 inches and the monthly mean 2.2 inches. For the 11 months of August-June, 1967-1968, the rainfall was 53.66 inches, or more than twice the mean of 24.2 inches for the period. This rainy period has kept the watertable in the South Texas Sand Plain at the level of the plain and seriously interfered with land travel. It has also reduced the salinity of Laguna Madre and Baffin Bay, as well as of pools on the Mud Flats. There is an unusually heavy growth of vegetation in the region. However, sand dunes had, by July, 1968, formed on the sand flats west of the waterway canal.

The annual rainfall mean has been appreciably exceeded for 15 calendar years since 1931, Figure 3. Only 5 years had essentially normal rainfall with precipitation within the range 26-27 inches. Only two of these years were successive.

Annual and periodical deficiencies, indicating drought, are indicated on Figure 3 and the droughts (deficiencies) that have occurred since 1888 are shown in Figure 4 by the number of months that they lasted. The normal drought-length of 3 years has been exceeded twice -- in the 1950s and early 1960s -- but droughts followed each other so rapidly from 1890 to 1902 that the period attained a record for its length of general drought conditions, totaling 121 months out of 150. The term "drought" is defined differently for different conditions, but deficiency below the annual rainfall volume, the definition here used, is the simplest criterion and seems to apply well to the problem in hand. Rainfall at the different observation stations throughout the region along Laguna Madre seems, in general, to be sufficiently similar for the Corpus Christi record to be representative.

bottom on Mud Flats are smaller than in older photographs but yellow color of water is confusing.

6. Air Observations of Price, October and November, 1967

Dark-to-black surfaces seen in and west of depressions of Mud Flats. Areas of sand dune pattern on western part of Flats, but not accurately located. Sand along Middle Ridge and in zone along marginal slope south of the Calabazas. Strong, ridged channeling-pattern along western zone of Mud Flats.

7. Air Observation of Price, June 12, 1968

Out of the 15 square miles of bare flats previously estimated as the area of algal mat north and northwest of Mesquite Rincon in 1949, air flights of 1967-1968, including one of June 12, 1968, showed about two-thirds now covered by bare sand and sand dunes and that only about 5 square miles now has a dark bottom, as seen through the standing water. Such dark surfaces outline flooded areas west of the Middle Ridge. Dark color may represent an algal mat of the 1949-type, but except after Hurricane Beulah, these waters seem to have been mainly from rain and fresh land runoff. Scattered small bunches of a yellowish algal scum were seen on flooded areas along the Waterway.

The remaining areas of the Mud Flats were sandy and covered by dunes, supposedly low. The 9 square miles of the marginal zone seemed to be stable and with no dunes except the stable clay dunes.

The Intracoastal Waterway since 1949 has drained the Central Flats, preventing the sheets of wind-blown waters from reaching their former heights and lateral extents.

Since the Humble topographic map was made in 1949, two hurricanes have flooded the flats and wind-blown sand has moved across it. The core-log cross-section, Figure 6, as correlated by the indirect means described, indicates that the passage of the sand

was accompanied by lowering of the N-S Middle Ridge between Potrero Lopeño and El Toro by from 1 to 3 feet and deposition of sand on the eroded surface so as to raise it to levels of +0.6 to +2.7 feet msl. This change was found along a distance of 6,000 feet between core holes Nos. 6, 1 and 2. Also, there has been a net lowering to +1.7 feet at Core Hole No. 4.

During the highs of the seasonal tide, which generally occur in May and November, the level of Laguna Madre would normally be at about +0.5 feet msl. At that time a wind set-up or "tide" of 0.75 to 0.9 feet might now spill over the Middle Ridge through the relatively narrow gap at +0.6 feet msl except for the draining action of the Intra-coastal Waterway. What other lowering of the Middle Ridge may have occurred would have to be determined by a leveling survey.

Closed depressions in the Mud Flats held water from Hurricane Beulah and subsequent rains at least until June 12, 1968, without drying up.

Sediments Under the Flats and Lowering of Middle Ridge

The cross-section, Figure 6, shows the logs of 7 core holes dug by Rawalt along the N-S Middle Ridge (Fisk's Swell) for this investigation. Fisk (1959, Figure 7 D, 8F and 9 C) also shows the alternations of bedding and thin lamellae (layers) under the flats. Not shown is the layer of beach rock about 9 feet thick, according to a boring by E.W. Behrens, Geologist of the University of Texas' Marine Science Institute at Port Aransas, Texas, which was topped at 8 to 10 feet below the surface under the Middle Ridge in the Humble Survey. Rosettes of selenite (gypsum) crystals were dredged above the rock. The latter had encrustations of the parallel tubes of calcium carbonate, which form a worm-reef.

In the cross section, Figure 6, the tight packed sand topped from 1.0 to 2.5 feet below sea level allows a length of only about 0.5 foot of it to be cored by hand without

the use of a cutter inside the tube. The elevations of the top of this packed sand, taken from the Humble survey of 1947-1949, permit the rough (± 0.5 foot) assignment of elevations to the ground surface at the bore holes, Figure 6.

According to the Humble survey (Fisk 1959, p. 116) an estimated $1/4$ to $1/3$ inch of clay was settling out on the flats a year from the lagoonal waters.

PART III -- CHANGES IN ENVIRONMENT OF CENTRAL FLATS REGION

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PART III -- CHANGES IN ENVIRONMENT OF CENTRAL FLATS REGION
Recapitulation of Events That Changed the Environment

The engineering operations which have altered some aspects of the environment of Laguna Madre and the Central Flats were listed in Part II as: (1) closing the north end of Laguna Madre with an earthen causeway fill, 1951; (2) dredging of the Intracoastal Waterway, 1949; and (3) dredging of Mansfield Cut, 1958 and 1963. The areas of land and wind-tide flats affected are now to be discussed.

Effects of Change on Baffin Bay

Baffin Bay is partly isolated from Laguna Madre by the narrowness of its mouth, the NNE - SSW axis of the entrance and the rocks and reefs that obstruct it. Thus, Baffin Bay may be affected relatively little by changes in water levels caused by dredging the canals and the damming the north end of Laguna Madre.

Reduction of the areas of flooding on the Central Flats should have reduced the amount of evaporative concentration of the lagoonal waters. Baffin Bay is reported by biologists to have been fresher after 1949 than normal for the preceding periods of study, partly because of flash floods feeding into it and possibly in part by the lowering of wind-blown sheets on flats in general.

Salt is said to get into the atmospheric circulation from the evaporation in air of water from spray of white caps, from surf and from drying flats. Probably as much, or more, salt in the air comes from the Gulf of Mexico in South Texas as from Baffin Bay and Laguna Madre.

Some of the dust seen crossing Baffin Bay from the south in former years is reported to have come from a dirt road through the Kenedy Ranch used in oil company operations. The mainland west of the arms of Baffin Bay is too remote (about 20 miles) from the Intracoastal Waterway for sand from the Waterway spoil to have travelled that far. While

one or two blowing sand areas have appeared since 1949 on the sandy ridge (a Pleistocene barrier like Padre Island) just west of Laguna Madre and north of the mouth of Baffin Bay, these blowouts have not grown since 1965 and seem to have gotten smaller.

There have at times been 2 tidal inlets through Padre Island opposite the mouth of Baffin Bay -- Boggy Sloughs -- but these seem not to have remained operative for more than short periods after being opened by flood waters. The inflow from Olmos, Santa Gertrudis and Agua Dulce creeks, that empties into Baffin Bay, has not been large or steady enough to keep the inlets from being closed by the strong longshore drift of sand characteristic of Padre Island beach.

If an artificial cut were to be maintained through Boggy Slough, it is possible that the salinity of the bay would be lowered enough to improve fishing in it, but the high rate of evaporation and low inflow from creeks does not make the prospect bright for such improvement.

Changes Caused By Damming Laguna Madre by
John F. Kennedy Causeway, Corpus Christi, 1951

The damming of the north end of Laguna Madre in 1951 reduced the fetch (length of open water) for that lagoon, thus lowering the maximum elevation of the wind-tide waters that bathed the flats. The dam raised the salinity of Laguna Madre by shutting its waters off from Corpus Christi Bay.

A part of the reduction in heights of wind-blown waters was by obstructing the funneling of wind-driven water from the bays north of the causeway into Laguna Madre.

Changes Caused By Dredging Intracoastal Waterway, 1949

This waterway has lowered the maximum elevations of wind-blown sheets of water and the extent of flooding of the flats in general. The effect was especially marked on the Central Flats where the water formerly spread widely and, in 1948, for 80 percent of the time.

In addition, the spoil dumps of this waterway were necessarily placed on land along the "Land Cut" through the flats. From Baffin Bay southward through the Central Flats, these dumps are close to the mainland and their heights allowed sand to be blown across the 125 - foot width of the canal during droughts and under winds of high speeds, as reported for the 1950s and 1960s.

Changes Caused by Dredging Mansfield Cut, 1958 and 1962

It has been claimed that the opening of this cut in May, 1962, lowered the salinity of the southern Laguna Madre progressively for several years until it was only 1/3 of the 1962 salinity. However, all of this salinity change may be attributed to the similarly large rainfall increase from 14.1 inches in 1963 to 38.2 inches in 1967.

The opening of this cut should have increased the rate and volume of drainage of the wind-blown sheets of water caused by the Intracoastal Waterway.

Effects on Kenedy Ranch North of Central Mud Flats

On the mainland north of the Mud Flats and within a 4 or 5 - mile zone along the west side of the irregular line of the potreros and lesser shore islands, no new blowouts -- as marked by banners -- seem to have formed since the 1930 photography. On the southern potrero ridges, some areas were bare of grass for a while but had been covered by June 12, 1968. The restored areas have lost their ridging, however. Potrero Farias still had a long, narrow zone of bare sands (with dunes) running parallel with the beach ridges. This bare zone has lasted since 1952, the grass between it and the flats on the east having been restored by 1960 on new grass-

covered ridges built along the east side of the potrero. Potrero Canales, on June 12, 1968, had a narrow zone of bare sand along its eastern edge, but vegetation scattered on it may stabilize it.

Effects on Coastal Area of Kenedy Ranch West of Mud Flats

The blowing sand and other blowing materials that have been in motion on the Central Mud Flats had not, on the dates of the available aerial photographs and when flown over by the writer, invaded the range or at least not in sufficient quantity to destroy the grass and form banners.

Effects on Kenedy Ranch NW from Mud Flats to Sarita

Leaves of live oak trees in a zone along Highway 77 have, since the early 1950s, been browned on the sides of the trees facing east and southeast. Such leaves seen in 1967-8 cannot be those that were dead in the 1950s. Thus, leaf growth has not been prevented there, although the fully formed leaves have been deadened or browned after growth. From the air a number of groves ("mottes") of live oak are seen to be completely bare of leaves and many mottes are said to be dead. In Exhibit 3, p. 23, Coover and Rechenlthin, 1965, such dead trees located 10 miles inland from the Laguna Madre flats, are illustrated.

Because no banners, active or recently stabilized, have been seen in the ranch within a coastal zone about 4 or 5 miles wide, it must be concluded that any new blowouts formed inland, or the spreading of old ones since 1949, must have been caused by drought combined with the grazing of cattle, not by invasion of blowing materials from Laguna Madre or its flats.

The widespread deadening of live oaks deprives cattle of shade said to be valuable to them and exposes grass to wind erosion for which the trees formed wind breaks.

Changes Along Middle Ridge ("Swell") of Central Flats

The low, bare ridge that runs south from Potrero Lopeno along the fronts of El Toro and Avoca Island had a thin cover of clay with an algal mat in 1949. The mat was absent in 1967 and 1968 when visited by boat by Rawalt and Price and the surface was sandy and moist. In June, 1967, the ridge was covered by fields of sand dunes. Cores taken along this Middle Ridge, described in Part II and Figure 6, by variable amounts up to 3 feet show that a layer of "tan" wind-blown sand from a few inches to a foot thick had by May 14, 1968, been deposited on the eroded surface.

Areas covered by sand will not support an algal mat, remaining unstabilized until otherwise vegetated.

The detail of the Humble topographic map, shown reduced as Figure 2, no longer accurately depicts the details of the surface configuration, although the general relationships between flats, depressions, and islands are unaffected.

Alteration of Surface of Mud Flats

The area formerly known as the Mud Flats is now largely covered by sand and sand dune fields, as was seen from the air on June 12, 1968. Out of the 15 square miles estimated as the area of the Mud Flats north of Mesquite Rincon and Avoca, 10 square miles seems now to be covered by bare sand including some bare clay.

Depressions west of the Middle Ridge have remained filled with water since Hurrican Beulah of September, 1967. Their water level has approximated +2.0 feet msl. The saline waters of the hurricane flood, which probably reached 9 or 10 feet, remained in these depressions but have been diluted by the heavy rains, presumably without further addition of lagoonal waters.

As seen through the water, the bottoms of the flats lakes are dark to black. This color is presumed to be from organic matter present ever since the Waterway

was opened, but the present nature of the bottom in these closed depressions and of the organic coloring matter are not known. Whatever type of organic material covers these bottoms would help to support or restore a blue-green algal mat, if the former regime of alternate flooding and drying were restored.

The bare sand-covered areas of the Mud Flats have bare migratory sand dunes. These menace the mainland grass; up to June 12, 1968, no noticeable invasion had occurred. The western margin of the flats with its clay dunes looks much as it did in 1949, with scattered areas of dark bottom, possibly in small water-filled depressions. The margins seem not to have been overrun by sand dunes.

Landward Margins of Mud Flats

From the air, the 9 square miles of the marginal area seems stable, with its clay dunes, as before 1950, having caught much of the blown salty clay, and the escaping dust not having changed the land vegetation.

Future of the Sand-Covered Parts of the Mud Flats

Until remedial methods are taken, the dune fields of the Mud Flats should continue their slow northwestward migration during hot, dry months, and should eventually cover the clay-dune zone of the flats margin and enter the mainland of the Brooks - Kenedy Lobe, killing grass.

If the sand invasion takes place along a wide front, the form of the blowing sands may not be restricted to banners, but could develop continuous bare dune fields like those of the western part of Padre Island and a strip on Potrero Farias.

If severe droughts like those of the 1950s and early 1960s should not come again, sand invasion of the mainland might be slow enough to be confined to isolated banners, like those of the present bare sand areas of the Kenedy Ranch.

Advance of dunes across the Mud Flats should be slowed down to some extent by the up-rise of capillary water from the flats and occasionally by rain water draining from the mainland. Sand movement would be faster during droughts, and additional sand might then enter the flats from spoil dumps.

PART IV -- FEASIBLE MEANS OF ABATING THE BLOWING SALT CONDITION

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PART IV -- FEASIBLE MEANS OF ABATING THE BLOWING SALT CONDITION

Objectives

Objectives which have been advocated by the public of the region have been primarily to:

1. Stabilize the sand; (a) of the spoil dumps of the Waterway; (b) of bare sand areas on and near the flats.
2. Restore the algal mat on the Central Mud Flats.
3. Lower the salinity of Laguna Madre; (a) by cutting inlets in Padre Island, or (b) by irrigation.

Some of these objectives are centered on one and some on another phase of the undesirable conditions supposedly originating in the Laguna Madre as a result of artificial changes that have been made in its environment. To attempt to ameliorate all the undesirable features of this semi-arid region, at one time, would require more than one project.

Sand Stabilization - Spoil Dumps of Waterway

To stabilize these dumps where they are largely of sand would require restabilization after each addition of new spoil. Choice between several possible methods would have to be made on the basis of a research study. Because of the cost of transporting a supply of shell or gravel for a quick stabilization, this method would probably not be economically feasible. Application of an asphaltic or resinous sludge would probably be the most feasible method and might be used with grass seeding.

Among the plants which, in this region, are used for sand cover, the native grasses have proved to be the best. They can be obtained near the Laguna Madre flats from the western ranges, especially from the potreros.

Sand Stabilization - Potrero Farias

To stabilize the long, narrow belt of loose, blowing sand on Potrero Farias, the Armstrong Ranch method described below would seem to be the most feasible.

Sand Stabilization - Mainland Range - Armstrong Ranch Method

This method employed cane hedges, cover of cut brush, fencing-out cattle, and final cover by the native grasses.

The cane hedges (Arundo donax or georgia cane) have the following advantages over salt cedar, sun flowers, growing live oak brush, and other growing wind-break plants: (a) the cane has long-lived roots from which stalks grow up year after year; (b) cane is jointed and is able to "walk up on the sand" by putting out roots from each joint as it is shallowly covered by new sand; (c) the hedges become very thick with successive years; and (d) the hedge may become a partial wind-break in one good season (6 months), and should be an adequate wind-break in 3 years, and improve for several years more until fully developed.

The cane would have to be raised in nurseries at nearby fresh water lakes or at ponds fed by wells. It must be planted in a mature state, with hard stalks but live buds. The canes must be kept moist between cutting and planting. They are planted fastest horizontally in 6 - inch to 1 - foot plow furrows with cover sand tamped down. The cane will not grow in sour land, but will stand salt water for some time.

Fencing is the most expensive item in the use of cane hedges. Ranch crews can provide the labor. If the wire lasts only 3 years, the cane may be coarse enough by then

Blowing of Sand and Salt Excessive During Recent Droughts

Dunes on northern Padre Island that were fully stabilized by grass and contained Spanish coins of the middle part of the 1540s blew away during the early 1950s. Wind erosion was unusually high throughout the sandy parts of the region during this drought and the blowing salt conditions were reported to be excessive on the Mud Flats.

In the most recent drought, 1960-1965, the blowing salt conditions were again strong on the Mud Flats.

Action of Salt of Blowing Materials

The salt content in the blowing clay particles takes up moisture from the air and the clay becomes sticky. It sticks to surfaces on which it comes to rest and the salty moisture corrodes metallic and painted surfaces. On electrical equipment, the salty solutions conduct electricity and cause shorts.

History of Movement of Sand in Region in Recent Droughts

The following account of changes in sand accumulations is taken from the writer's experience, the Humble survey, the Soil Conservation Service Report, and from successive aerial photographs of the 1930s, 1952, 1960, and 1967.

1. Tobin Photography of 1930s and Humble Survey 1947-1949

No bare sand on mainland border within 2 to 5 miles of western margin of Mud Flats. Flats islands and potreros fully grassed. Clay and algal mat on Middle Ridge.

2. Ammann Photography, February 27, 1952, and Fisk Report 1959

Field of bare barchan dunes between Waterway and potreros. East border of Potrero Lop  o and Potrero Farias, bare sand zone 800-1200 feet wide. On Mud Flats, sand filled "The Lake" lobe of "The Basin" depression. Sand spread somewhat widely on Mud Flats. No change on border of mainland.

3. Tobin Photography, February, March, April, 1960

Barchan dunes along west border of Waterway, as in 1952. On Potrero Lop  o grass fully covered the 1952 bare zone. Potrero Farias had an eastern bare zone 500 to 1800 feet wide, but a new low grassed ridge had formed along its east flank. The Calabazas islands had bare shore zones on east and southeast. Sand covered Middle Ridge and much of Mud Flats.

4. Soil Conservation Service Reports, 1963, 1965

Drifting sand on Sand Bulge, but no dunes reported there. Calabazas islands and small islands north of them bare. All of Mud Flats and a 1-mile zone along mainland margin mapped as "scoured or covered by wind action."

Areas among Mesquite Rincon had bare sand. Denuding of areas on flats islands and potreros seems to have been caused by overgrazing, possibly when flats crusted over after mainland range had deteriorated and cattle migrated to these ordinarily difficultly accessible islands.

5. U.S. Geological Survey Photography, September 30, 1967

Flats widely covered by yellow waters of Hurricane Beulah flood. No dune areas seen on sand flats or sand Bulge. No bare sand bordering the potreros. Calabazas grassed except for about 2/3 of the smaller ones. Small islands to north bare or covered by yellow water. No new areas of bare sand along mainland borders. Areas of black

to resist the feeding of cattle in normal years. Where exposed metallic wire rusts out too soon, the new long-lived plastic-covered wire being used in western Europe might be suitable for use in salty air.

The cane-hedge method must be used under expert direction or a high percentage of plantings will be lost.

Cut-brush may be used to cover new sand blowouts and the more active areas of old blowouts while the cane is getting established. To expedite coverage, the native grasses may be sprigged-in by hand, using a light caterpillar planter.

The georgia cane of the Texas Coast is acclimated to this region. Many hedge and cover plants of other coasts are not suitable because they do not tolerate a semi-arid climate.

The cane hedge method was successfully used in planting a test plot on northern Padre Island in 1965-7 by Lewis Rawalt and the writer. The Cameron County Park on the south end of Padre Island was kept stable during construction in the 1950s by sprigging in native grasses with a caterpillar planter.

Sand Stabilization - Central Mud Flats

The extensive cover of sand that has blown onto the Mud Flats since 1949 is of unknown thickness and elevation (relief). The flooding method here described (Exhibit 3, Scheme 2) for the restoration of an algal mat would help also to stabilize the sand dunes which would be surrounded by the water and sandy areas which may become covered by clay from the water. The flooding regime recommended would flood low-lying sand and clay on the flats for a part of the year, but leave them exposed during the remainder. No vegetative cover is known which would live on both sand and clay in these flats.

Salt-Water-Lake Method

Naismith (Exhibit 3) discusses two schemes that have been suggested for the treatment of the Mud Flats. Scheme 1 is discarded. It is the suggestion to dredge lateral canals into the Basin so that wind-blown waters may enter the flats. This, however, would affect only the areas now subject to flooding from the waterway and by rain water. Such canals would increase the rate of drainage of the flats now accomplished by the Intracoastal Waterway. This method, as Naismith shows, would not restore the algal mat over the higher clay-bottom areas. The lateral canals would have to be maintained, as they would be subject to filling with sand and clay. Canals that drain the closed depressions should let in seasonal tides and low wind "tides" and might sustain an algal mat on these low areas.

In Scheme 2 of Exhibit 3, a system of dikes would enclose the western flats north of Mesquite Rincon. Lagoonal water would then be pumped in from the Waterway to form a lake. To re-establish an algal mat on clay-covered surfaces and keep it alive, the lake would be alternately drained and refilled in a regime to be developed by experiment. The original mat was developed before 1947 under such alternate flooding and drying, the flood waters being usually much more salty than sea water or becoming so.

In the planning stage of an application of this method (Naismith, Scheme 2), topographic profiles would first be run and, at the same time, the areas of clay bottom mapped.

The lake would inundate the clay bottoms and also such areas of bare sand as are then below the level of flooding.

The sand inundated would be stabilized by wetting during the periods when the water was impounded. Still higher areas of bare sand, if then detrimental to the range, could be stabilized by grass planting.

During draining periods the flats would be subject to invasion by sand blown from low-lying areas. If such invasion were not in overwhelming amounts, it would be absorbed by the mat and the grass.

As long as no remedial action is taken, the present cover of tan wind-blown sand on the flats will continue to move northwestward uncovering the fine clayey sand which lies just below (Figure 6). This clayey sand would be more resistant to wind erosion than the present cover sand which accumulated there by wind transport. If, before the flooding is commenced, no additional sandy spoil is placed on the Waterway dumps, and no severe drought comes to make it move in large volume, the area of sand on the flats west of the Waterway should decrease. However, this sort of change is very slow.

As the flats were flooded, a layer of clay would be deposited on the flooded area. This would lie on the parts of sand dunes covered and also on low lying areas from which sand had just been blown off, whether still sandy or already clayey. The rate of clay deposition was estimated by Fisk in the Humble study (Fisk 1959) at $1/3$ to $1/2$ inch a year.

Canals of Oil and Gas Companies and the Proposed Diking of the Mud Flats

The lateral canals now used in oil and gas prospecting and production on the Mud Flats in the area of the proposed dike-enclosed lake would interfere with the operation of flushing and draining the lake area.

Increase in Salinity Versus Increase in Nutrients

Restoration of the flooding regime for the Mud Flats should cause two changes of opposed desirability: (a) restoration and maintenance of a mat would return to Laguna Madre nutrients valuable for marine life; and (b) increase in the spread of wind-blown waters over the shallow flats would increase the area of evaporation and increase salinity.

Irrigation of Mud Flats With Fresh Water For Crop Raising

If the proposed Inter-basin Canal brings enough fresh water for it to be used in reclaiming the Mud Flats, the preparation of the flats for crop raising would follow the Dutch procedure of draining off saline groundwaters and flushing salt out of the sediments to depths greater than that of capillary uplift. The applicability of this method to the Mud Flats has not been researched.

Irrigation of Mud Flats With Salt Water to Restore an Algal Mat

Overhead surface or subsurface irrigation of the Mud Flats by lagoonal waters would be far more expensive and difficult to operate than the dike-enclosed lake method, already described.

Canal Locks at Ends of "Land Cut"

If canal locks were installed at each end of the Land Cut through the Central Flats, it would be possible to close the down-current locks against an on-coming sheet of wind-blown water that might flood the northwestern Mud Flats basin. After maintaining the elevated water level for the required length of time, the level in the waterway might be lowered to permit drainage of the basin, if an outlet channel had been provided through the Middle Ridge.

This means of lessening the blowing salt condition would be far more expensive in installation, operation, and maintenance than the method of diking-in the northwestern basin of the Mud Flats.

Relocation of Intracoastal Waterway

In 1932, two other routes for the Intracoastal Waterway were surveyed through the Central Flats region west of the present location, Figure 2. One route would have run about 1 mile west of the present one, and the other would have run along the edge of the mainland. These were longer and less straight than the present route.

Relocation would be much more expensive than the other proposed remedial measures. The added mileage and the required bends would slow down water traffic. Purchasing rights of way through the Kenedy and King Ranches would be expensive and might require condemnation with the usual attendant lawsuits.

Lowering Salinity of Laguna Madre and Baffin Bay

Many people have advocated lowering the salinity of Laguna Madre and Baffin Bay as a supposed means of increasing the number and kinds of fish taken for sport and for sale. The details of the changes in the marine life which would be caused by reducing salinity to

that of the Gulf have never been sufficiently researched to show whether such a change would promote or damage fishing. Many empirical claims have been made that fishing increased greatly after this or that opening of artificial or natural passes, but these claims have not been accompanied by adequate data.

Methods advocated for the lowering of salinity have included: (a) removal of the earthen causeway fill across the north end of Laguna Madre, either wholly or partly, in connection with replacement of the swing-barge bridges with bridges on piling; (b) cutting of one or more passes through Padre Island in the northern Laguna Madre; (c) draining of used irrigation waters into the bay or lagoon when fresh water is brought to the South Texas coast from the more rainy East. These methods will now be discussed.

Removal of Earthen Fill Now Damming Laguna Madre

The northern Laguna Madre was said at the time the causeway from Flour Bluff to Padre Island (now called John F. Kennedy Causeway) was built to be furnishing 1/4 of the commercial fish for Texas. It was expected by conservationists that this fill would greatly reduce the fisheries of Laguna Madre. What effect it actually had seems not to have been described.

Removal of this fill in part or for any substantial percentage of its 4-mile length would freshen the lagoon by allowing water to be blown southward from Corpus Christi Bay, which is consistently less saline on the average than Laguna Madre.

Cutting of a Pass Opposite the Mouth of Baffin Bay

This widely desired tidal inlet would allow some tidal exchange between the inner waters and the Gulf. Unknowns are: (a) the rate of mixing of the lighter sea water sheet with the more saline and heavier lagoonal and bay waters; (b) the degree of further lowering

of the maximum level of wind-blown sheets of water passing down Laguna Madre; (c) to what extent the entrance of sea water would off-set the normally large rate of evaporation of Baffin Bay waters.

Drainage of Irrigation Water into the Coastal Waters

If an irrigation canal is constructed to bring fresh water from the northeast to South Texas, the desirability of draining used waters through the Central Mud Flats is questionable because the maintenance of an algal mat depends on wetting by highly saline waters.

Irrigation water returned to Baffin Bay would probably be less mineralized than the normal bay water and should, therefore, reduce its salinity.

Indeterminate Features of the Problem at the Present Time

Unknown values which would affect the planning of a project to ameliorate the blowing salt conditions are:

1. Area of clay bottom on Mud Flats at present, estimated in Figure 5.
2. Area and maximum elevation of sand dune cover on Mud Flats.
3. Rate of travel of blowing sand westward on the flats and rate of its replacement by clay from the proposed flooding.
4. Rate of replacement of sandy spoil along Waterway versus its being blown away in droughts unless stabilized.
5. Advantages of return of nutrients to Laguna Madre by lake waters drained off versus the disadvantage to marine life of the increase in salinity from evaporation on the flat during flooding.

6. Increase in heights of wind-blown sheets of water in Laguna Madre which would occur after a postulated removal of causeway dam at north end versus lowering of water by a cut through Padre Island opposite the mouth of Baffin Bay.
7. Value of the various remedial measures versus costs of installation and maintenance.
8. Nos. 5, 6, and 7, above, seem to involve the economy and ecology of the whole Laguna Madre and its shores as to transportation, fishing, recreation, and population development.

PART V -- SOURCES FOR FINANCING REMEDIAL OPERATIONS

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1	Responsibility of Federal Government
1	Lands Chiefly Damaged
1	Damage to Environment of Laguna Madre
2	Sources for the Financing of Remedial Operations

PART V -- SOURCES FOR FINANCING REMEDIAL OPERATIONS

Land Ownership

The title to the Mud Flats, or a large part of it, is held by the State of Texas.

The State established title in a lawsuit which began in 1949 at Corpus Christi. Land desired by Humble Oil and Refining Company, at least that portion around Potrero Lop  no and El Toro, was declared to belong to the State by reason of accretion to the State-owned islands.

Some persons have thought the ownership question might be re-opened on the basis of data from the cores taken by Humble.

Responsibility of Federal Government

The changes in the immediate environment of the Central Flats were caused in part by the federal government through the dredging of the Intracoastal Waterway and in part by drought.

Lands Chiefly Damaged

The chief damage found was to the range and live oak trees of the Kenedy Ranch, which is a part of Kenedy County. Damages in other areas resulting from artificial changes have been claimed but not demonstrated.

This report does not attempt to evaluate damages.

Damage to Environment of Laguna Madre

Loss of nutrients from the algal mat has been a loss to marine life, but decay of the mat was probably accompanied by a lesser return from it to Laguna Madre also of highly saline waters.

Sources for the Financing of Remedial Operations

1. The federal government seems to be the most likely source of revenue for remedial operations.
2. Unless some bureau or other federal organization has the authority to use funds for this purpose, Congress would be the ultimate source of aid.
3. If a good case is not made for remedial work centered on the Mud Flats, such work might be included in a general program for the improvement of the environment of the entire Laguna Madre, including Baffin Bay and the Mud Flats.
4. The Mud Flats, Baffin Bay and the entire Laguna Madre should be considered before any further dredging of passes or other major change in the environment of the Laguna Madre are begun.
5. In connection with the bringing of fresh water to South Texas by an Interbasin Canal, funds should be made available for a study of the return of water from the irrigated areas to Laguna Madre and its indentations -- bays and flats.

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Figure 1. - Map of South Texas Coastal Region.

Black arrows, net movement of winds of hot, dry periods.

Light arrows, directions of alternate along-shore movement of currents, wind "tides", and sediment.

Borders of deltas not shown.

Central Mud Flats lie west of Intracoastal Waterway with sand flats east of it.

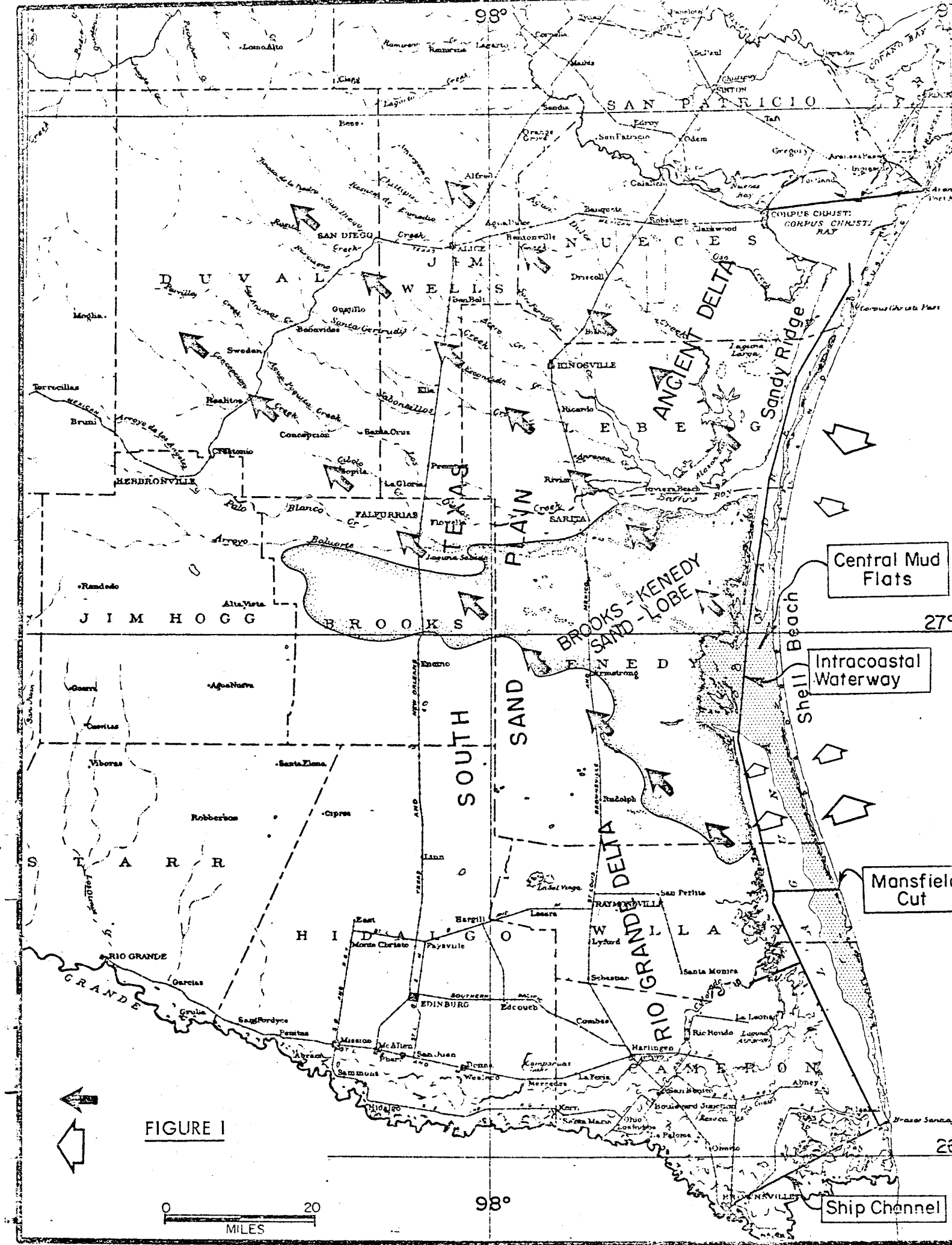


FIGURE 1

0 20
MILES

98°

28°

Figure 2. - Topographic Map of Central Flats of Laguna Madre.

Made by Humble Oil and Refining Company, 1949.

Heavy contours, 1 foot; light contours, 0.2 foot; contours of 2.4 feet, broken line.

LEGEND

CONTOUR INTERVAL 02 FOOT
HORIZONTAL AND VERTICAL
CONTROL BASED ON
U S C B G S DATUM

MILES

**GULF
OF
MEXICO**

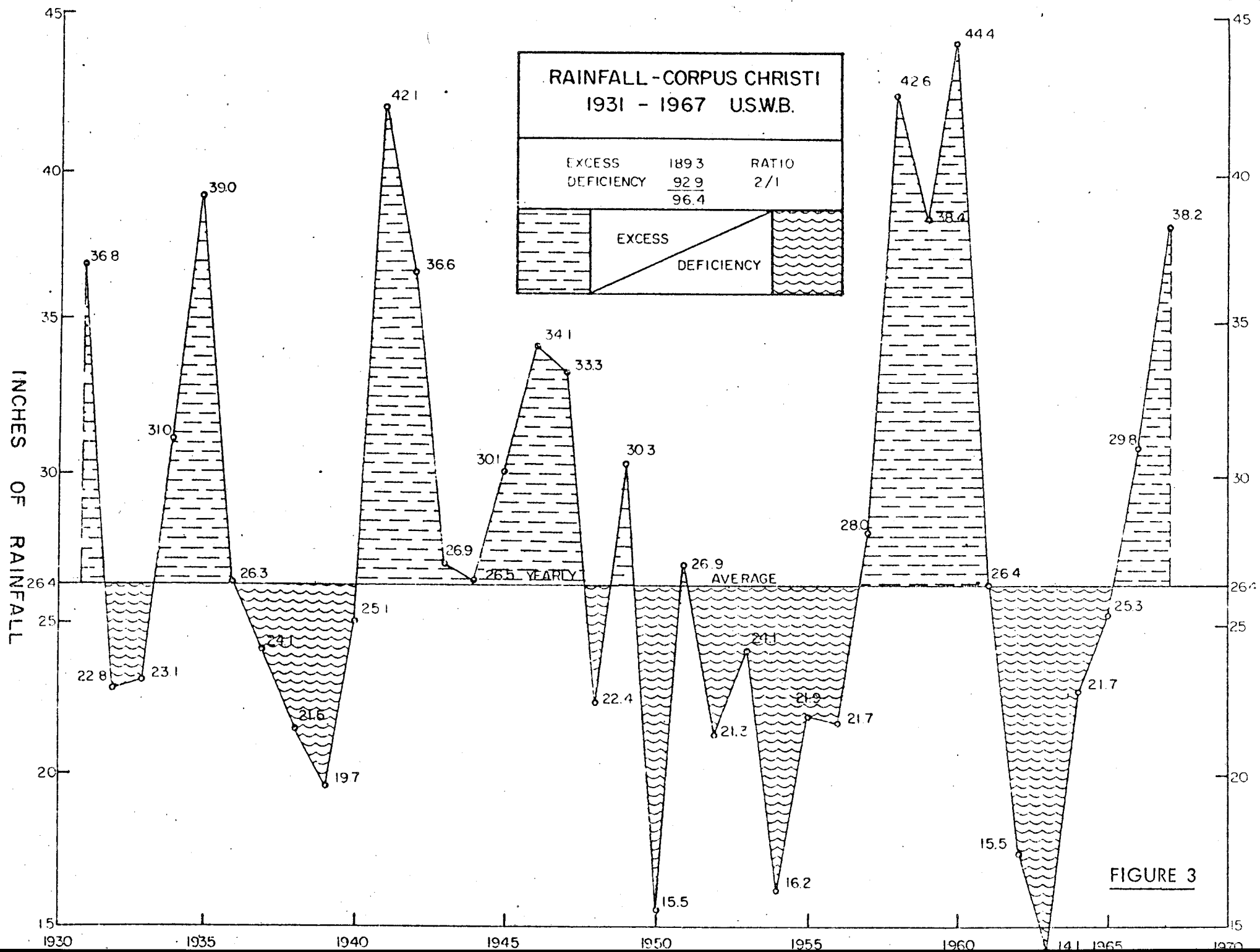


FIGURE 3

Figure 4. - Droughts at Corpus Christi, 1888-1967, defined as
deficiencies in annual rainfall for the indicated number of months
without significant breaks.

LENGTHS OF DROUGHTS - CORPUS CHRISTI, TEXAS 1888-1967 U.S. WEATHER BUREAU

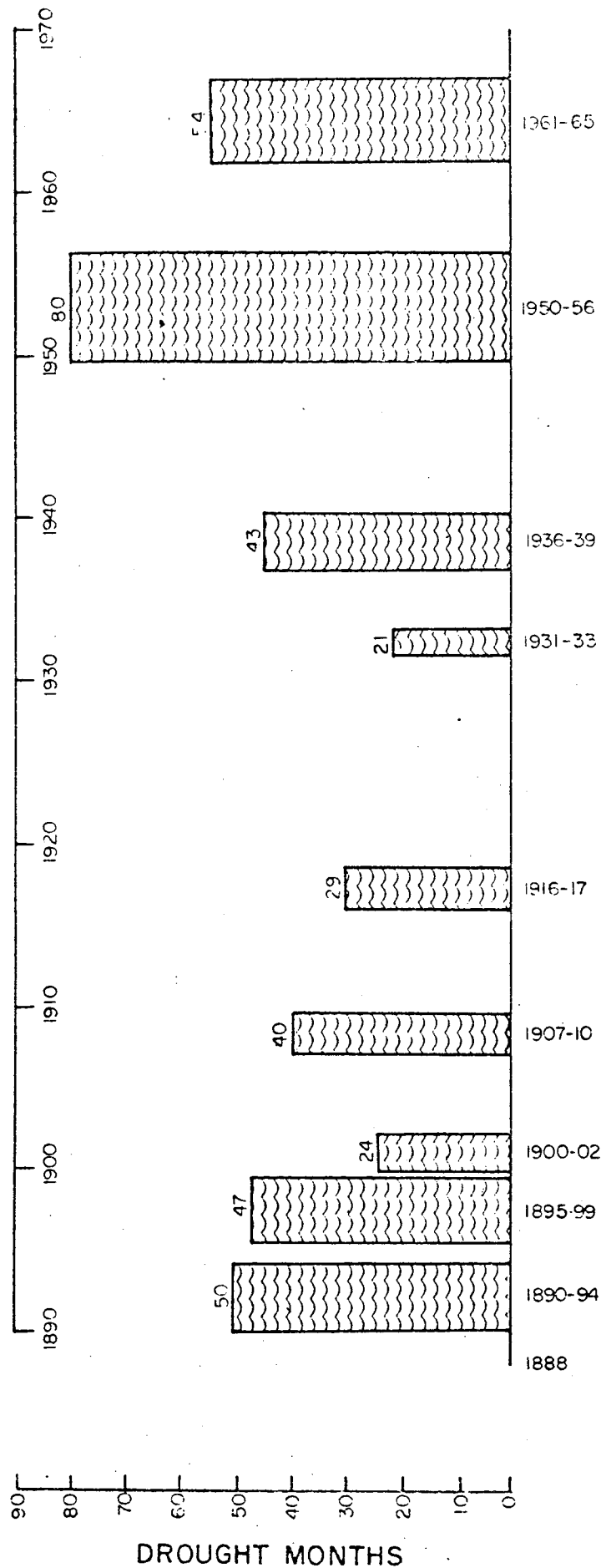


Figure 5. - Surface Conditions, Central Mud Flats of Laguna Madre.

Laguna Madre waters at 1 foot above mean sea level, shaded areas in troughs at upper right and lower left-to-center.

Flats border zone, mostly bare, with clay dunes and scattered flats-islets; area lacking a continuous algal mat in 1949, shown by shaded area along left side.

Shaded oval areas on flats, water standing in closed depressions 1967-1968.

Numbered points, locations of core holes of Figure 6.

Figure 6. - Shallow Strata Along Middle Ridge of Central Flats, 1968.

Cross-section of core logs, west side of Intracoastal Waterway, May 14, 1968; approximate locations shown on Figure 5.

Vertical section of erosion and redeposition by wind and floods lies between surfaces for 1968 and for lowest position, 1950-1968.

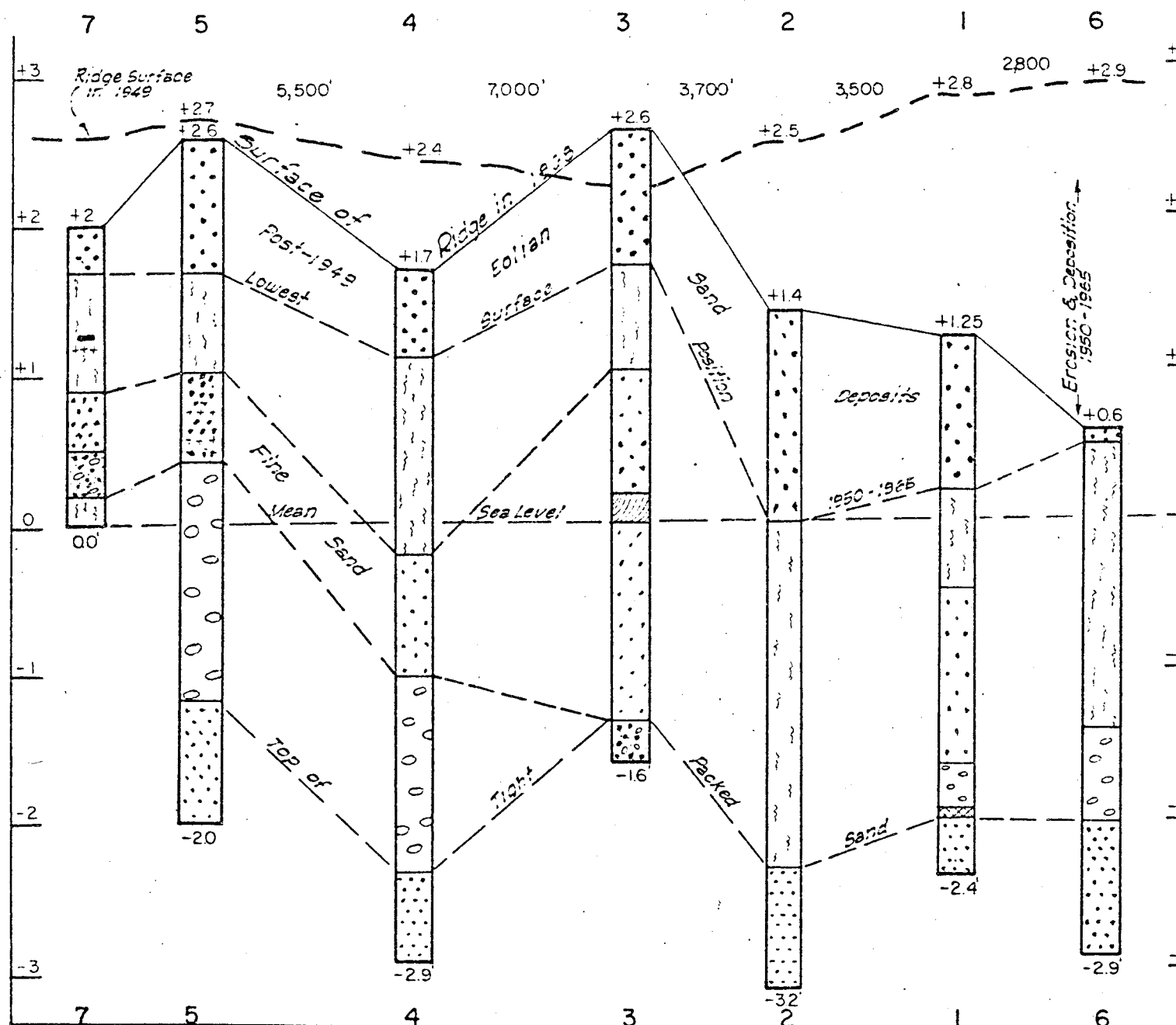
All measurements in feet, or feet and tenths.

Legend for types of sediments bored:

1. Sand, medium grained ("coarse" for the Flats), tan, wind-blown.
2. Clay, sandy, gray with thin brown-to-colorless grassroot channels.
3. Sand, clayey, gray, fine-grained, with black specks of organic iron-bearing minerals; water-soaked.
4. Sand, gray, fine-grained; black specks, fine lagoonal shells, one small fragment of bone; water-soaked.
5. Sand, fine grained, gray; packed, (tight), resistant to core barrel; little water; bottom not reached (9+feet of beach rock is topped in borings at about - 10 feet).
6. Clay, dark gray, peaty.
7. Peat, black.
8. Thin, brown, organic lamina (former algal mat).
9. Thin layers of white gypsum; microscopic rosettes of selenite seen under magnifier.

Elevations computed from 1949 Humble map of elevations of top of tight packed sand, No. 5; uncertainty possibly ± 0.5 foot.

FIGURE 6



EXHIBITS

No. 1 - Letter from Dr. B. J. Copeland, 1968.

No. 2 - Report of Isaacs and Franki, Soil Conservation Service, 1963.

No. 3 - Engineering Report by James P. Naismith, 1967.



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January 16, 1968

Dr. W. Armstrong Price
1213 Ocean Drive
Corpus Christi, Texas

Dear Dr. Price:

Sometime ago, when discussing with you the ecological significance of alternate flooding and draining of flats and pans in the Laguna Madre, I mentioned the possible ecological gain from artificially flooding and draining the Mesquite Rincon area that was inadvertently closed off by man's activities. I wish to re-iterate and clarify those points.

There is no question that the alternate flooding and draining of a mud-flat area is important in the regeneration of nutrient materials to its parent body of water such as lagoons and estuaries, especially to a lagoonal area such as the Texas Laguna Madre where there is no river input. Maynard Nichols states in a paper that the phosphorus level of water coming off a mud-flat in Estero Tastiota (central eastern shore of the Gulf of California) is 8 times higher than water coming onto the flat (1966; Publications Institute of Marine Science, Univ. Tex.; 159-167). His description of the lagoon reminds one of the Texas Laguna Madre, and I suspect that the behavior of nutrient transport is similar in both areas. Several other papers report the same sort of findings and have led to the establishment of a basic ecological principle that alternate flooding and draining of mud-flat areas are essential to the regeneration of nutrients in estuaries, bays and lagoons. The correlary of the above statements is that if the water is prevented from periodically covering the flat and receding back to the parent body, there is an effective stoppage of nutrient regeneration for a sizable part of the Laguna Madre; and hence a general lowering of fertility. There is, of course, the possibility of nutrient regeneration through the action of winds in the Laguna itself, although the process is at a slower rate and the amount is of less magnitude. I have mentioned phosphorous because more studies of that particular nutrient compound have been done, but other essential nutrients follow the same principle.

Whether this particular flat in the Texas Laguna Madre is of sufficient magnitude in providing essential nutrients to the Laguna to raise or lower the ecological harvest in the whole laguna is open to question. The only sure way to determine the relative worth of

one flat to the overall economy of the Laguna would be to conduct a study designed to provide the answers. One thing for sure would be that if all the flats connected to the Laguna were destroyed or rendered inaccessible the Laguna would surely decrease its productivity due to the lack of nutrient regeneration. So, one argument is that man should preserve or augment the role of nutrient regeneration to insure the natural productivity of the Laguna.

It is now an understood fact that organic detritus is a major food source in coastal bodies of water. In river-mouth estuaries, the river-borne detrital material makes up a very large percentage of the organic detritus utilized by estuarine organisms. In lagoonal systems, where there is little or no river input, the organic detritus is primarily derived from the draining of mud-flats where a tremendous amount of benthic photosynthesis has occurred. An argument for the maintenance of alternate flooding and draining mud-flats, then, would be the necessity of maintaining the important contribution of organic detritus from the very fertile mud-flat. References that might be of assistance are included in the recent volume on Estuaries resulting from the 1964 Conference on Estuaries at Jekyll Island, Georgia (cf. R. M. Darnell, p. 376; E. P. Odum and A. A. de la Cruz, p. 383; and G. C. Stephens, p. 367). The book is publication no. 83 of the American Association for the Advancement of Science, 1967.

To make estimates of the relative importance of the mud-flat that you are studying to the ecology of the Laguna Madre would be at this point speculative. Only through a definitive study could the real importance be estimated.

I hope that the above rambling will be of some help to you in your evaluation. If I can be of further assistance, please call on me.

Sincerely yours,


B. J. Copeland
Assistant Professor

BJC/ga

Preliminary Survey of Wind Erosion and Salt Damage on the Kenedy Ranch

Area of Survey

The general area of this damage survey was confined to the part of the Kenedy Ranch lying east of U. S. Highway 77. Most of the detailed observations were made along the coastal area within six miles of the bay. (Laguna Madre).

This was a preliminary study with the primary purpose of obtaining an estimate of the degree and extent of the wind erosion and the salt damage to vegetation.

Methods of Surveying

The survey of this area consisted of three parts. The first was an aerial reconnaissance of the general area. The second was an on-the-ground examination of selected areas. The third was to compare the appearance of the area on aerial photographs made in 1948 with photographs made in 1961.

Type and Extent of Damage

The areas of greatest damage are in a strip 18 miles long parallel to the coast. This strip lies in a northwesterly direction or downwind from an extensive salt and mud flat area consisting of approximately 110,000 acres. These flats 1 are primarily State of Texas land and lie between the mainland and Padre Island. Damage is greatest near the coast and gradually diminishes farther inland.

Loamy Sand Islands - Adjacent to Laguna Madre are large islands made up of a mixture of sand and clay which were apparently deposited by the wind from the salty mud flats over the centuries. These islands rise 5 to 10 feet above the mud flats. They are known as Potrero De Los Caballos, Potrero Grande, Potrero Cortailo, Potrero De Las Canelas, Potrero Farias, Potrero Lopeno, Calabazas Islands, El Toro Island, Tres Marias Island and the eastern edge of Mesquite Rincon. There is approximately 4,800 acres in these islands.

The greatest apparent damage is to Potrero Farias, which now has a shifting dune area of 320 acres that is not distinguishable on the 1948 photos.

Three of the Calabazas Islands totalling about 120 acres are at present 50 percent covered with an apparently recent deposit of about 2 feet of drifting salty sand from the adjacent flats.

Report prepared by Dean R. Isaacs, Range Conservationist, and Guido Franki, Soil Scientist, Soil Conservation Service, December, 1963.

Other islands are damaged to a lesser extent along their windward side. There is an estimated 900 acres on these islands where vegetation has been destroyed by being covered with drifting sand. These drifting sand areas do not appear on the 1948 photos.

Most of the area of these islands is covered with annual weeds mainly of *Tidestromia* and woolly sunflower. This weedy vegetation indicates a partially disturbed condition caused by some drifting of sand in the past few years. Remnants of alkali sacaton, hooded windmillgrass, pink pappusgrass and a few plants of bristlegrass indicate these islands have supported a good stand of grass in the past.

Small Clay Islands and Fringe Areas Around Salt Flats - A large part of Mesquite Rincon and a large area adjacent to the mainland consists of small islands and ridges that rise 20 inches to 48 inches above the mud flats. These are flat on top and range from less than two acres to more than ten acres in size. These are of clay soils and were apparently formed in place from the Beaumont Clay geologic material. The low islands and ridges are distributed over an area of about 14,000 acres. The islands and ridges themselves consist of approximately 5,000 acres. These areas apparently supported at one time a cover of Gulf cordgrass. Alkali sacaton, pink pappusgrass, shoregrass, seashore saltgrass and a few woody plants of huisache and wolfberry. These islands and ridges are now 20 percent to 100 percent denuded according to their exposure. The smaller islands are completely denuded. Much of this loss of vegetation has taken place during the last two years as indicated by dead stools of cordgrass, seashore saltgrass and woody stems of wolfberry which are still present. A few live plants of shoregrass and seashore saltgrass remain on some islands. This loss of vegetation is apparently due to a combination of sand blast from the salty flats, covering of plants by drifting salty sand and the toxic effect of a build up of salinity.

Damage to Trees - Liveoaks are a part of the climax (original) vegetation of this area. For an area extending approximately 6 miles inland from the coast there has been a tree top kill of greater than 50 percent on the liveoak. Some motts have as high as 80 percent defoliation with only a fringe of green leaves remaining on the protected leeward side. Trees 8 to 12 feet high appear to be dead to the ground. Low-growing or running liveoaks which are not as exposed to the wind sustain about a 60 percent top kill. This severely affected area consists of 80,000 acres of which 20,000 acres are dominantly liveoak.

For an area extending from 6 miles inland to 12 miles inland the liveoak has an average of 25 to 50 percent top kill. This ranges from 75 percent kill on the windward side of motts of trees to 15 percent kill on the protected leeward side. Low growing oak averaging 4 to 5 feet in height have the top two feet killed. This area of moderately affected liveoaks covers 80,000 acres of which 40,000 acres is liveoak.

For an area extending from 12 miles inland from the coast to U. S. Highway 77, the top kill ranges from 0 to 20 percent. Some motts completely exposed to the wind have a higher percent kill. Along U. S. Highway 77

the liveoaks suffer only a 5 to 10 percent dieback of the outer limbs on the windward side. This area of lightly affected trees covers about 52,000 acres of which 30,000 acres is dominantly liveoak.

Mesquite trees are also damaged to a lesser extent. However, there are very few mesquite trees in the area of severe damage.

Sand Dunes - There are approximately 40,000 acres of active sand dunes on the Kennedy Ranch east of U. S. Highway 77. Some are only a few acres in size. Others are as large as two sections. These dunes are constantly on the move. This movement of dunes has been a natural occurrence for centuries. In this survey no attempt was made to determine whether these dunes were more active during years of low rainfall. The only dune measured had travelled a distance of 600 feet in two years.

Effect on Soils - All of the affects on the soils lying in the path of the prevailing winds that blow across and pick up salt laden material from the dry Tidal Flats in the area surveyed cannot readily be seen. This can be determined only by laboratory analysis of soil samples selected at points that will provide data that can be used in finding out if there is a build up of toxic salts and whether or not it is a recent accumulation. Most of the soils in the affected area are deep fine sands. Some near the coast may be loamy fine sands and some possibly may be fine sandy loams.

The liveoak trees appear to be defoliated and with dead limbs mainly on the windward side. The green leaves and limbs on the down wind side indicate that most of these trees still have live trunks and roots. It therefore seems reasonable to assume that material that is carried by the prevailing south easterly winds is toxic to the above-ground parts of the trees on their southeast side. We have no data available as to what amount of salt in the soil can be tolerated by the roots and main trunks of liveoak trees.

It also can be assumed that salt-laden material on the trees and grass as well as what falls directly on the surface eventually will be carried into the soil by rain. The amount in the soil at the present time, the rate of build-up or the length of time required for a toxic amount to accumulate were not considered.

Causes of Damage

Damage to herbaceous vegetation, such as grasses and desirable forbs, is confined to the areas adjacent to the salty mud flats. Damage here is due to drifting salty sand covering the vegetation, sand blast damaging plants and salinity build up due to salt deposits on the vegetation. Damage to grass is very slight beyond a distance of 300 yards from the salt flats.

Damage to trees, primarily liveoak is apparently due to the deposit of air-borne salt-laden materials from the salt and mud flats on the leaves and stems. This salt-laden material is carried by the prevailing south-easterly winds. This is indicated by the heavy death loss and most severe

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1. PURPOSE AND SCOPE OF REPORT:

The purpose of this report is to delineate the engineering aspects of possible remedies to the wind erosion and salt problem at the land cut of the central mud flats of the Laguna Madre and to develop preliminary engineering data and estimates in connection with these remedies. The basic problem has been outlined to the writer of this report by W. Armstrong Price, Consultant to the Coastal Bend Regional Planning Commission. This report is the result of conferences with Dr. Price and independent calculations by the writer. It is not the intent of this report to propose any one scheme for alleviation of the problem but rather to comment on several suggestions and to outline advantages and disadvantages of each, together with supplying certain estimated cost data. Detailed engineering studies of two or more of the suggested schemes should follow as the project progresses.

2. THE PROBLEM:

The problem as outlined to the writer of this report is essentially one of restabilizing the mud flat area, either by the reconstruction of the former protective algal mat which was destroyed by the lowering of the maximum elevation of the lagunal water surface following construction of the Intracoastal Canal which passes through this area, or by other means.

Construction of the Intracoastal Canal in 1946-49 opened a channel with considerable carrying capacity through this central mud flat area. The flooding of the mud flat area has historically been dependent upon wind-generated tides as well as solar

and lunar tides. Tides on the flats are: about 0.1 foot daily, 1.0 foot seasonal and seasonal wind setup "tides". A large portion of the flats is above the elevation of seasonal high tides and has been flooded in the past only by unusual storm tides or more importantly by wind setup tides generated at times of the year when persistent northeast or southeast winds of considerable velocity were active. Due to the remoteness of the area and the lack of inhabitants around the study area there is no available long term record of water surface elevations on a day to day basis, although there is a record for one or two years in the files of Humble Oil & Refining Company. It appears however that the effect of cutting the Intracoastal Canal has been to reduce the maximum height of the storm and wind setup tides. This is because the additional head (potential energy) developed by winds blowing across the shallow waters which previously served to carry water up into the mud flat area is now in part used in developing large currents either northerly or southerly in the Intracoastal Canal. This means that for a given wind condition the water surface elevation will not now rise to the same height that it would have before construction of the canal. I have made no calculations of the magnitude of the tidal effect of the Intracoastal Canal for lack of both data on the particular area and observational data on winds and tides in similar areas. Research of available literature in this regard is continuing. The importance of the water surface elevation to this particular problem has been outlined by Dr. Price along the general lines following:

The surface of the central flats before the Intracoastal Canal was dug consisted of three types of terrain.

1. The eastern half was a bare sand plain stabilized only by evaporite salts.
2. The western half (west of the canal) was (a) a bare mud flat with (b) two large and several small "islands" of dune sand well stabilized by grass. The "mud" was clay and sandy clay stabilized by (a) algae forming a dense leathery mat which sun-cracked when dry and (b) hygroscopic salts in the clay. The algae and salts prevented more than small areas of the dry mat from being disintegrated and wind eroded. Blow sand, clay pellets and dust from the eroded areas collected locally into stable clay dunes and did not damage the ranches to the west. Since 1949, this algal mat has dried over a large area west of the canal and north of the Mesquite Rincon "Island". This is the area to be dealt with in this report.

At times since 1949 loose sand has been carried by wind from the Padre Island dunes toward the west generally and these dunes have covered certain areas of the flats. These elevated dunes are not a part of the problem of this report. The persistence of the algal mat from year to year depends upon it receiving a certain minimum duration of submergence by tidal waters. The flooding required in 1948-1950 was about 18% of the year. The present indication is that the construction of the Intracoastal Canal and the resulting lowering of the average tidal elevation

in the mud flat area has caused the algal mat to begin deterioration due to lack of adequate moisture. This in turn permits the sand and clay of the soils and the salts of the western part of the flats to be eroded by wind action and carried for considerable distances inland.

The detrimental effects of this action are mentioned in other reports. It would appear that rectification of this condition would require that water surface elevations in the area be returned to their previous pattern of height and duration to re-establish the algal mat and stabilize the clayey area. If this is not feasible, other methods of stabilization must be sought. This report suggests several schemes by which the problem might be reduced or removed, and mentions other schemes.

3. POSSIBLE SOLUTIONS:

- (a) Stabilization of the area by establishing vegetative cover. The difficulties associated with this scheme are mentioned in the report of the Soil Conservation Service, U. S. Department of Agriculture, Temple, Texas, "Report of a Preliminary Investigation of the Wind Erosion and Salt Problem on the Salt Flats of Laguna Madre," 1965, and is not covered in any detail here. It appears that the present problem (stabilization of clayey flats areas) was caused by the destruction of the naturally occurring vegetative cover, i.e. the algal mat. There has been no evidence that any other natural vegetation has been able to survive and propagate on the mud flats in

this area under the present conditions. The elevated dunes may be stabilized above the level of too frequent flooding using the well known vegetative methods.

- (b) Construction of sand fences or other devices on the downwind side of the flats to stabilizing the blowing material. This has been suggested and is certainly possible as a means of controlling wind erosion of areas of sand lacking a clay binder. This portion of the overall problem is not a part of this report. The mud flats proper are not subject to stabilization by sand fences. In fact it appears that there is no feasible downwind barrier which would be effective in controlling the materials of the mud flats once they have been suspended by wind.

- (c) Irrigation of the effected area with salt or fresh water.

It would certainly be possible to stabilize the area under concern, both sand and clay areas, if adequate volumes of fresh water were available to provide irrigation. However, there is no possibility of obtaining such quantities of fresh water for this use. Spray or subsurface irrigation with salt water could be expected to re-establish the protective algal mat. However, the facilities required would be so extensive and subject to such severe main-

tenance problems that I feel this method would not prove feasible.

- (d) Controlling currents in the Intracoastal Canal and thus permitting wind generated tides to reach their previous levels. This is certainly a possibility with regard to solution of the problem, however such a method would require two locks on the Intracoastal Canal at the northern and southern extremities of the problem area together with dikes and other structures from these locks to the land side and to Padre Island. The locks would be necessary for elimination of the currents in the canal at times when wind conditions were appropriate to develop tides in the mud flat area and would also be necessary for continuation of water traffic. However, at these times the locks and their accompanying dikes would block any flow along the Laguna Madre at the extremities of the area and would thus partly restrict the mechanism by which these higher tidal elevations have been reached in the past. Also, the cost and operation of such a project appears to be prohibitive considering the benefits to be derived at this time. For this reason no further detailed investigation has been made, aside from very rough preliminary figures which are included in the writer's files

but have not been included in this report.

- (e) Other means of influencing the water surface elevation in the problem area. It is felt that the two most feasible remedies for this problem lie in this general direction. These have been designated Scheme 1 and Scheme 2 for the purposes of future reference. Schemes 1 and 2 are delineated on the drawings accompanying this report and certain detailed information is included in the accompanying figures.

Scheme 1: The proposal of Scheme 1 is to influence the amount of flooding in the problem area by construction of channels from the Intracoastal Canal generally westward into the flats. At such time as conditions were proper these channels would provide carrying capacity for water above that which is naturally present and would thereby provide a mechanism for moving larger quantities of water into the flats. However, since these channels would represent extensions of the Intracoastal Canal the effect of that canal can be seen to be increased by their construction. That is, while these canals would provide flow capacity for water moving from the Intracoastal Canal into the flats they would also provide flow capacity for drainage of the flats, the

direction of the current being determined by water surface elevations. They would essentially provide greater flow rates toward the west at times of northeast or southeast winds but would not influence the surface elevation of the water except in the areas below sealevel but cut off from the Intracoastal Waterway. Otherwise the channels would be more efficient in moving the water under the head conditions available. It would appear that approximately 2300 acres of the flats could be flooded by such channels as the result of normal seasonal tides. These would be areas below elevation plus one on the 1949 topographic map of Humble Oil & Refining Co. The problem of maintaining channels in such an area is a separate question and a potential difficulty which might eliminate this scheme from consideration.

The channels proposed by this scheme are labeled a, b, and c on the attached drawing. For purposes of preliminary calculations the channel section was taken to be a 50 foot bottom width, side slopes of 1 vertical to 5 horizontal and depth varying, with the bottom elevation of the channels being at -1. The hydraulic characteristics

of these channels were assumed operable under an available water surface slope of .00005 (or one foot per 20,000 feet). The available slope would depend upon the water surface elevation at the Intracoastal Canal and the water surface elevation in the flats and would certainly decrease as flow continued toward the west because of the raising of the water surface elevation in the flats.

It should be noted however that these same channels might possibly serve as drains to the westerly area of the flats, preventing the buildup of wind tides which might otherwise increase the water depth to a greater level. The expected operation of these channels should be investigated in considerable detail before this scheme is undertaken since a draining of the flats under wind conditions would defeat the intended purpose.

In summary, channels such as proposed by this scheme would be adequate to provide intermittent flooding of the area of the flats below elevation 1.0 to 1.5. The effect of their presence with regards to other areas should be studied in detail to assure that they would not be detrimental. Also, some indication of the permanence of such channels should be obtained before this scheme is

given further serious consideration. The preliminary cost information developed for Scheme 1 does not include the cost of any erosion protection or other protective measures for maintaining of the channel.

Scheme 2: Construction of dikes and water lifting devices to maintain an artificially high water surface level in the area of the flats. This scheme would appear to have the greatest probability of solving the problem and possibly the least problems associated with it. It would consist of the constructing dikes along the easterly boundary of the mud flat area just west of the Intracoastal Canal and providing water lifting devices and inlet and outlet devices to artificially increase the water surface elevation in the mud flat area. For the purposes of preliminary cost estimates the alignment for the dikes was chosen as shown on the accompanying drawing. A crest elevation of +5.5 was used with side slopes of 1 vertical to 60 horizontal. It is felt that these slopes could be maintained assuming construction by dredged fill. The elevation of the dike would provide for covering most of the mud flat area with the exception of a narrow margin at the west. The suitability of the natural material

in the area for dredging and construction of such dikes is being further investigated at this time by Dr. Price. However, it is felt that the material will probably be adequate. Low dikes of this material were placed on the east side of the Intracoastal Waterway during its construction to hold back the spoil and water conveying the spoil. They lasted until Hurricane Carla of 1961 washed them away. The required volumes of dredging and estimated costs are shown on the accompanying figures. Also, other necessary costs such as inlet and outlet devices, spillway and drainage controls, provision for power access and anticipated yearly maintenance and operation costs are shown. The scheme has the following potential disadvantages:

1. It will require some operation which is relatively expensive because of the remote nature of the area.
2. The dikes will be subject to overtopping and erosion during storm tides. This potential overtopping can possibly be limited to specific areas of the dikes by constructing them at