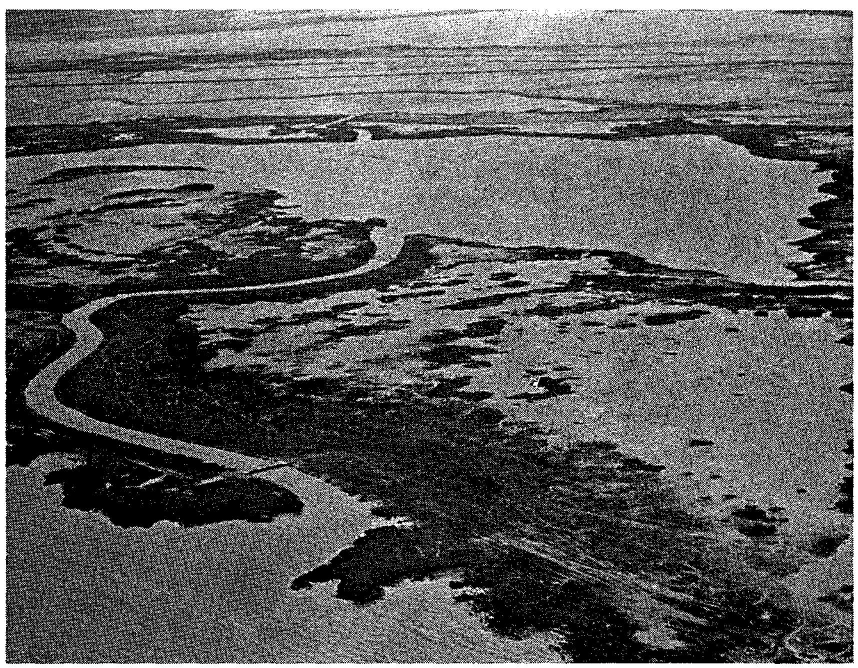
NUECES AND MISSION-ARANSAS ESTUARIES:

An Analysis of Bay Segment Boundaries, Physical Characteristics, and Nutrient Processes



TEXAS DEPARTMENT OF WATER RESOURCES
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April 1982

NUECES AND MISSION-ARANSAS ESTUARIES: AN ANALYSIS OF BAY SEGMENT BOUNDARIES, PHYSICAL CHARACTERISTICS, AND NUTRIENT PROCESSES

Prepared by the
Engineering and Environmental Systems Section
of the Planning and Development Division

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PREFACE

In 1976, the Section 208 Planning Program for nondesignated planning areas of Texas was initiated. Additional planning funds were subsequently made available by EPA to expand the scope of this planning effort and to consider other issues not previously addressed. These planning monies were available in early 1978 as a supplement to the EPA grant for Section 208 planning in nondesignated planning areas. A part of the funds were earmarked for development of analyses which could be used in future planning efforts for evaluation of the appropriateness of existing water quality standards in major Texas estuarine systems. Due to the short time frame of the supplemental grant funds, only three tasks were selected. Later these can be expanded upon throughout the continuing planning process. The three selected tasks are the subject of this report on the Nueces and Mission-Aransas estuaries:

1. Analysis of the appropriateness of existing bay segment boundaries;
2. Analysis of the physical characteristics of the selected estuarine systems including mixing, transport, current patterns, and salinity patterns; and
3. Definition of nutrient processes in Texas estuarine systems, especially the effects of inflows on nutrient cycling and contributions from deltaic marsh areas.

The above tasks are basic to any consideration of the adequacy of water quality standards for Texas estuarine systems. Future tasks, which are necessary to complete a comprehensive assessment of coastal water quality standards, include definition of the water quality requirements to meet various water use criteria for estuarine/river systems, and an assessment of the costs and benefits of various uses.

NUECES AND MISSION-ARANSAS ESTUARIES: AN ANALYSIS OF BAY SEGMENT BOUNDARIES, PHYSICAL CHARACTERISTICS, AND NUTRIENT PROCESSES

SUMMARY

This report is one in a series of reports on major Texas estuaries. The objective is to analyze existing data on the Nueces and Mission-Aransas estuaries for the purpose of water quality planning under Section 208 of P.L. 92-500. The report has three sections. The first presents an analysis of the appropriateness of existing bay segment boundaries for water quality planning purposes, and draws heavily upon the data analyses performed in the last two sections of the report. In the second section, the physical characteristics of the Nueces and Mission-Aransas estuaries are presented, along with a summary of circulation and salinity patterns under average conditions of tidal amplitude, wind and freshwater inflow normally experienced throughout the year. Section three of the report presents the current state of knowledge of nutrient processes taking place in the Nueces and Mission-Aransas estuaries, especially the effects of inflows on nutrient cycling and the contributions of nutrients from deltaic marsh areas.

Circulation and salinity models of the Nueces and Mission-Aransas estuaries were developed for use on a digital computer and were calibrated by sampling efforts in the estuaries. This allowed simulation of circulation and salinity patterns under various conditions of freshwater inflow, tidal cycle and wind effects. A careful analysis of the simulation runs had important implications for the placement or location of appropriate boundaries for the bay segments. It was generally found that the existing bay segment boundaries were adequate, except in the case of Oso Bay where it is recommended that a new segment be created (segment 2485). Oso Bay is currently included in the Corpus Christi Bay segment (segment 2481); a separation of these bays into two segments would allow a more realistic reflection of localized conditions.

The Nueces and Mission-Aransas estuaries are characterized by normal tides ranging from 0.5 foot (0.15 meters) in the bays to a maximum of about 2 feet (0.6 meters) along the Gulf shoreline. Wind is a major factor in influencing physical processes, including erosion, accretion and other changes in shoreline configurations. Because of the shallow depths throughout the estuary, wind can play a major role in the generation of waves and longshore currents. The peak influx of freshwater to the system normally corresponds with the months of September and October. Major impacts from these inflows include overbank flooding of marsh areas, extension and building of bay head and oceanic deltas, flushing of the bays, and salinity reduction.

An analysis of net circulation patterns simulated by the tidal hydrodynamic model indicated that the dominant circulation pattern in the Nueces and Mission-Aransas estuaries was a net movement of water from Laguna Madre through Corpus Christi, Redfish, Aransas and Carlos Bays and into the Guadalupe estuary. Net circulation patterns in Nueces Bay, Copano Bay and the upper portion of Corpus Christi Bay were dominated by internal currents generally unaffected by the dominant circulation pattern described above.

Simulated salinity concentrations throughout the Nueces and Mission-Aransas estuaries showed major differences between the high freshwater inflow period of September through October and the normal to below normal inflow period generally found for the rest of the year. Freshwater inflows to the estuarine system are low compared to other major estuaries of the Texas coast. The high inflow period of September through October normally is the result of tropical storm activity and is undependable in both duration and magnitude. Spring rains and resulting inflows may at times be heavy, but their undependability is a general reflection of the semi-arid conditions experienced throughout the Nueces Basin and adjacent coastal basins. Simulation efforts predicted lower salinity concentrations in Nueces and Corpus Christi Bays than have been actually observed in recent years. It is believed that some sources of high salinity inflow may not be adequately represented in the mass transport model (i.e., oil field brine discharges in and near Nueces and Corpus Christi Bays).

Nutrient contributions to the Nueces and Mission-Aransas estuaries have been derived primarily from river inflow, local runoff, and

biogeochemical cycling in deltaic and peripheral salt or brackish water marshes. The adjacent Gulf of Mexico is nutrient poor; resulting concentration gradients are such that a net transport of nutrients out of the bay/estuary system toward the Gulf normally occurs. Numerous complicating factors such as the magnitude of freshwater inflows, winds, currents, and biological activity all contribute to the complexity of processess that may be occurring at any given time.

The most important source of nutrients to the Nueces and Mission-Aransas estuaries is the freshwater contributed by the Nueces, Mission and Aransas Rivers and Copano, Chiltipin and Oso Creeks. The total nutrient contribution from the Nueces River dominated those from other major freshwater inflow sources. In comparison with the other sources, contributions from Oso Creek are unusually high in proportion to the percent of flow contribution to the estuary, particularly for total phosphorus and inorganic nitrogen. The cause for high nutrient concentrations in Oso Creek is uncertain, but may be the result of agricultural runoff and/or effluent from the Robstown and Corpus Christi Westside wastewater treatment plants which are the major sources of flow in Oso Creek.

Major sources of nutrient input to the Nueces estuary are the marshes of the Nueces delta. Annual net productivity (ANP) averaged approximately 7,000 dry weight pounds per acre (785 g/m^2) over the entire study area, with maximum ANP in *Spartina spartinae* habitats estimated at 15,100 dry weight pounds per acre (1,690 g/m^2). Estimated net periphyton production ranges from a minimum of 1.07 dry weight pounds per acre per day (0.120 $g/m^2/day$) in December to a maximum of 5.12 dry weight pounds per acre per day (0.574 $g/m^2/day$) in April. Specific estimates of the above ground net primary production of rooted vascular plants (macrophytes) are not available for the deltaic and intertidal marshes of the Mission-Aransas estuary. However, such values are expected to be intermediate to those of nearby marshes where the macrophyte production values have been measured. Although the high productivity of these deltaic marsh habitats makes available tremendous amounts of detritus for potential transport to the estuary, actual detrial transport is dependent on the episodic nature of the marsh inundation and dewatering process.

Although a great deal has been gained thus far by detailed investigations and data collection activities focused on the Nueces and Mission-aransas estuaries, many questions can not yet be answered. Texas estuaries are very complex systems, having numerous variables, and many relationships among these variables. Measurement of system variables and the relationships among them are extremely difficult and time consuming to make. Additional studies of the Nueces and Mission-Aransas estuaries will add to the knowledge gained to this point and allow more accurate descriptions of the processes taking place. Studies under the authorization of Senate Bill 137 were completed, with results published in 1981.

ANALYSIS OF BAY SEGMENT BOUNDARIES

A Texas estuary may be defined as the region from the tidally affected reaches of terrestial inflow sources to the Gulf of Mexico. Shallow bays, tidal marshes and bodies of water behind barrier islands are included under this definition. These estuarine systems are made up of subsystems, lesser but recognizable units with characteristic chemical, physical, and biological regimes. Estuaries are composed of interrelated parts: primary, secondary, and tertiary bays, which require separate treatment for proper understanding and management.

An estuary's primary bay (e.g., Aransas Bay) is directly connected to the Gulf of Mexico and is commonly characterized by brackish (50% seawater) to saline (100% seawater) salinities. Secondary bays (e.g., Copano Bay) empty into the primary bay of an estuary and are thus removed from direct flow exchange with the Gulf. Also, secondary bay salinities are generally more brackish than primary bay salinities. In most cases, tertiary bays (e.g., Mission Bay) may be found at the head of an estuary connected to one of the secondary bays. In terms of energy input to the estuarine systems, the most productive and dynamic of estuarine habitats are associated with tertiary bays, where sunlight can effectively penetrate the shallow, fresh to brackish water areas and support submerged vegetation. Substantial chemical energy is produced in these areas due to photosynthetic processes. These biostimulants are distributed through the estuarine system by tide and wave action.

Texas estuaries, due to their dynamic nature, are highly productive ecosystems. Severe droughts, floods, and hurricanes are the main factors that control and influence their productivity. Throughout the natural cycle the number of species remains low, while the number of organisms of each species may fluctuate widely with the seasonal regime, with drought and with flood. This process provides for a continuing shift in dominant organisms, therefore preventing a specific species from maintaining dominance. Such is not the case in a lake, where through the process of euthrophication biotic populations often become stagnant and dominated by a few species.

Texas has about 400 linear miles (644 kilometers) of coastline 373 miles, (600 kilometers) of open-ocean or gulf shoreline and 1,419 miles (2,284 kilometers) of bay shoreline, along which are located seven major estuarine systems and three smaller estuaries (Figure 1). Eleven major river basins, ten with headwaters originating within the boundaries of the State, have estuaries of major or secondary importance. These estuarine systems, with a total surface area of more than 1.3 million acres (526,000 hectares), include many large shallow bays behind the barrier islands. Additional thousands of acres of adjacent marsh and bayous provide habit for juvenile forms of important marine migratory species and also produce nutrients for the indigenous population in the estuaries. The ecosystems which have devleoped within these estuaries are dependent upon the amount and seasonal and spatial distribution of inflows of freshwater and associated nutrients from the rivers, coastal tributary streams, marsh areas and direct rainfall and runoff within the adjacent coastal basins.

The Nueces and Mission-Aransas estuaries are currently divided into seven bay segments (Figures 2 and 3): Corpus Christi Bay (segment 2481), Nueces Bay (segment 2482), Redfish Bay (segment 2483), Corpus Christi Inner Harbor (segment 2484), Aransas Bay (segment 2471), Copano Bay (segment 2472) and Saint Charles Bay (segment 2473). The results of the tidal hydrodynamic and salinity mass transport simulations indicated that, in general, the existing bay segment boundaries reflect appropriate homogenous areas for water quality planning purposes and should be retained, except for a single change explained below.

The simulation of net tidal hydrodynamic conditions in the Nueces and Mission-Aransas estuaries indicated that Copano, Nueces and Saint Charles Bays were dominated by internal net circulation patterns not significantly influenced by the net circulation patterns in Corpus Christi and Aransas Bays. The simulated salinities in these former bays were lower than those found in the latter bays.

Redfish Bay, Aransas Bay and the eastern portion of Corpus Christi Bay were dominated by net currents which directed water in a northerly direction through each of these bays in sequence, beginning with Corpus Christi Bay. Salinity concentrations simulated for these bays varied, however, from bay to bay. Oso Bay was not dominated by the circulation patterns of Corpus Christi Bay due to the restricted exchange point between them. The net exchange of flow between these two bays was from Oso Bay into Corpus Christi. It is recommended that an Oso Bay segment be designated (segment 2485) separate from Corpus Christi Bay (segment 2481) to more reasonably reflect localized conditions (Figures 4 and 5.)

PHYSICAL CHARACTERISTICS

Introduction

The Nueces and Mission-Aransas estuaries cover about 320 square miles (829 square kilometers) and consist of the tidal parts of the Aransas, Mission and Nueces Rivers and Copano Creek, Mission Bay, Copano Bay, Aransas Bay, Saint Charles Bay, Nueces Bay, Corpus Christi Bay, Redfish Bay and Oso Bay. Water depth at mean low water level varies from less than two feet (0.6 meter) in Mission Bay to 13 feet (4 meters) in Corpus Christi Bay, except in the Corpus Christi Ship Channel, where the depths are up to 45 feet (14 meters).

This study area lies in the warm, temperate zone of the South Central climatological division of Texas. Its climatic type is classified as subtropical (humid and hot summers with mild, dry winters). The climate is also predominantly marine because of the area's proximity to the Gulf of Mexico. Prevailing winds are southeasterly to south-southeasterly throughout the year. Day-to-day weather during the summer offers little variation except for occasional thunderstorms. Warm, tropical air from the Gulf of Mexico is responsible for mild winter temperatures and hot, humid summer weather.

Sedimentation and Erosion

The Nueces estuary's main source of sediment is the Nueces River system. This system heads in the Edwards Plateau and flows southeasterly through the Rio Grande Prairie. Sediment reaching the Mission-Aransas estuary comes from the Rio Grande Prairie via primarily the Mission and Aransas Rivers.

Annual sediment production rates were developed for stream channel sediment by the U.S. Soil Conservation Service. Sediment in a stream channel is generally divided into two classifications: bedload material and suspended load. As flow conditions change, particles making up the bedload at one point may become suspended and subsequently be redeposited. Bedload measurements can be accurately determined only by very elaborate instrumentation and are suited only to certain types of streams. In the laboratory, bedload is defined as the difference between total load and suspended load. In the field, it must generally be estimated.

Annual sediment production rates in the Edwards Plateau are low, ranging from 0.052 to 0.055 acre-foot per square mile (25 to 26 m^3/km^2) of drainage area. As the rivers flow over the Rio Grande Prairie the average annual sediment production rates reach a high of 0.18 acre-foot per square mile (86 m^3/km^2) of drainage area (22). Annual sediment production rates for Mission and Aransas Rivers are

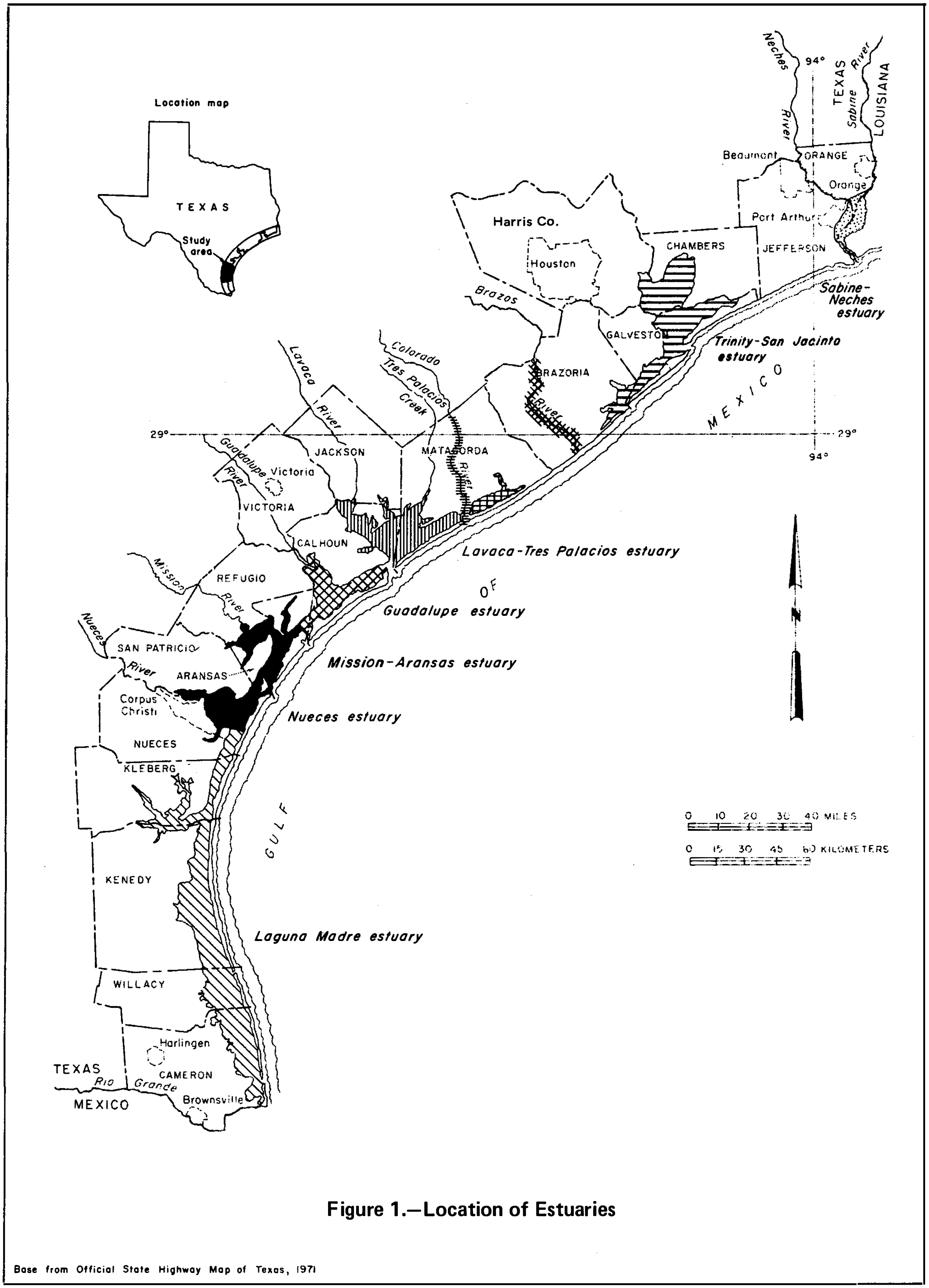


Figure 1.—Location of Estuaries

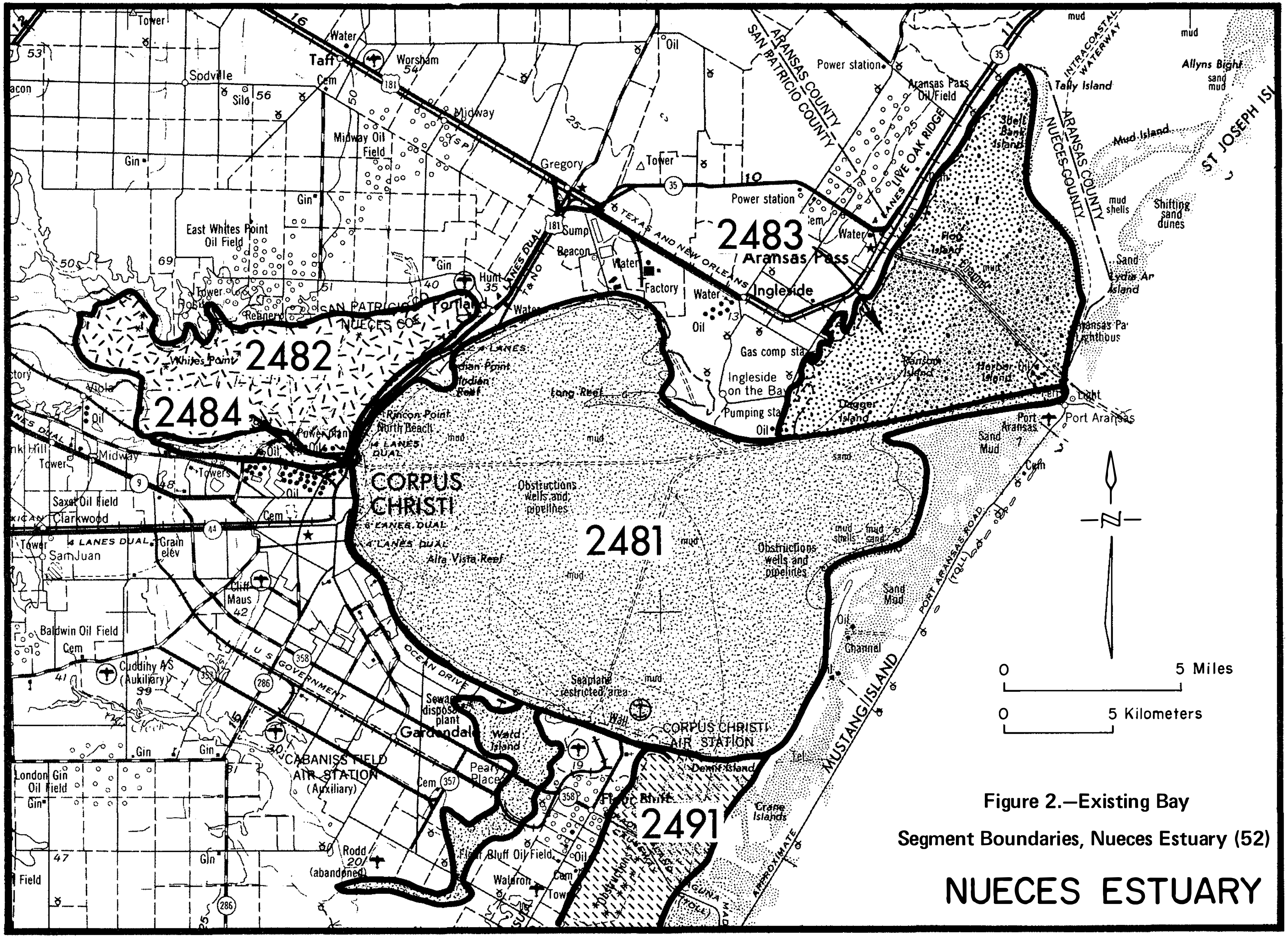


Figure 2.—Existing Bay Segment Boundaries, Nueces Estuary (52)

NUECES ESTUARY

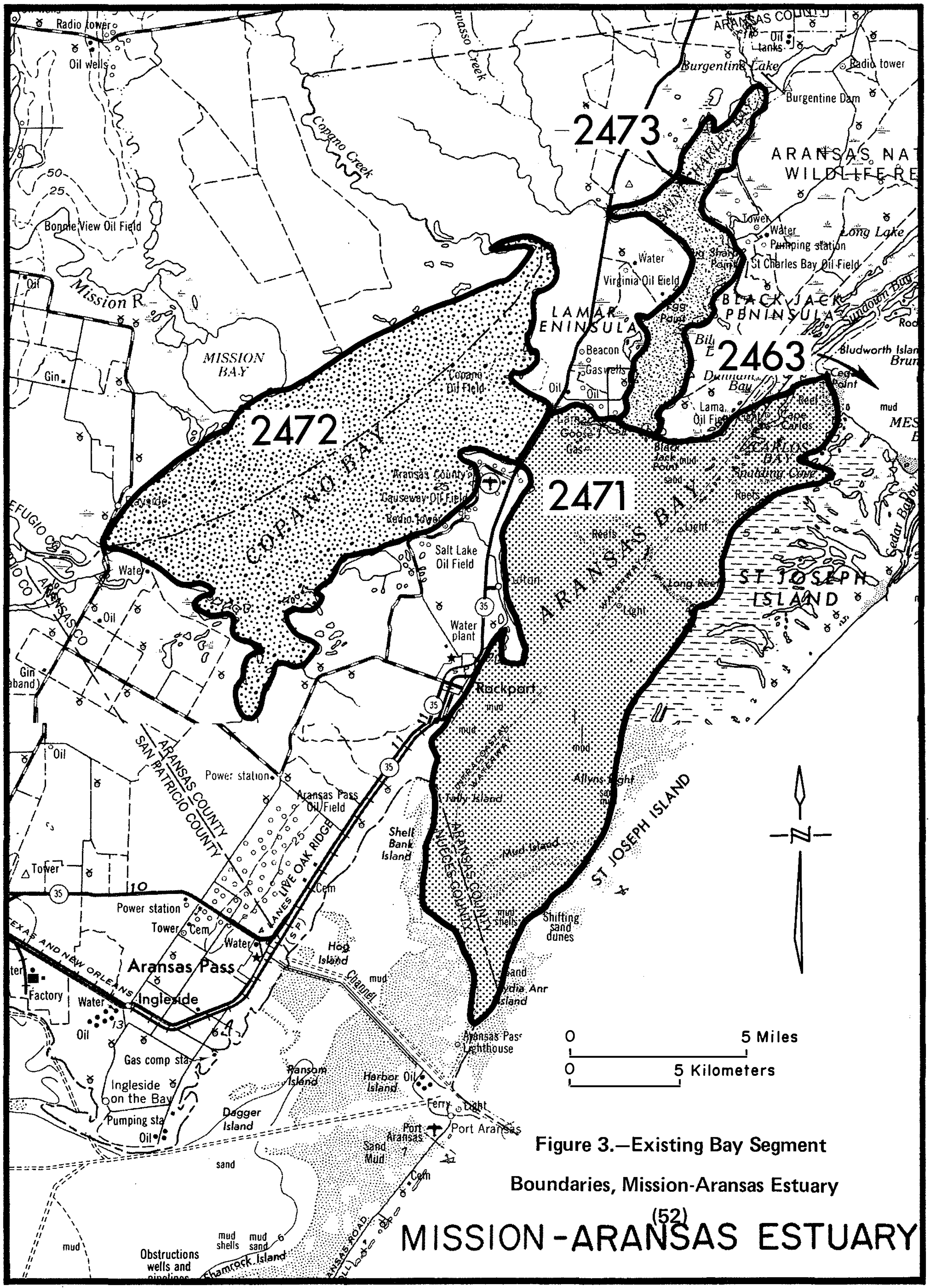


Figure 3.—Existing Bay Segment Boundaries, Mission-Aransas Estuary

(52)

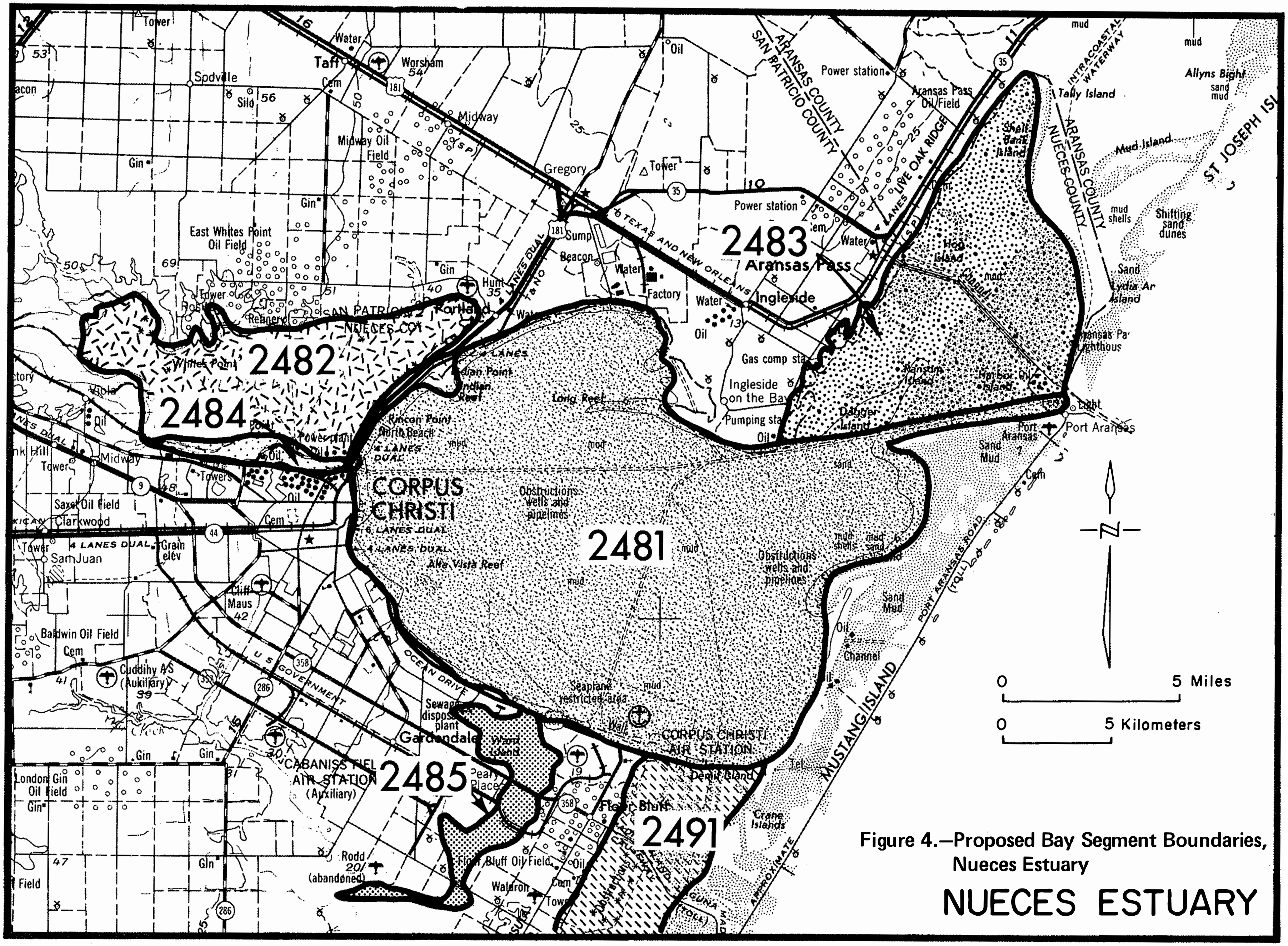


Figure 4.—Proposed Bay Segment Boundaries, Nueces Estuary

NUECES ESTUARY

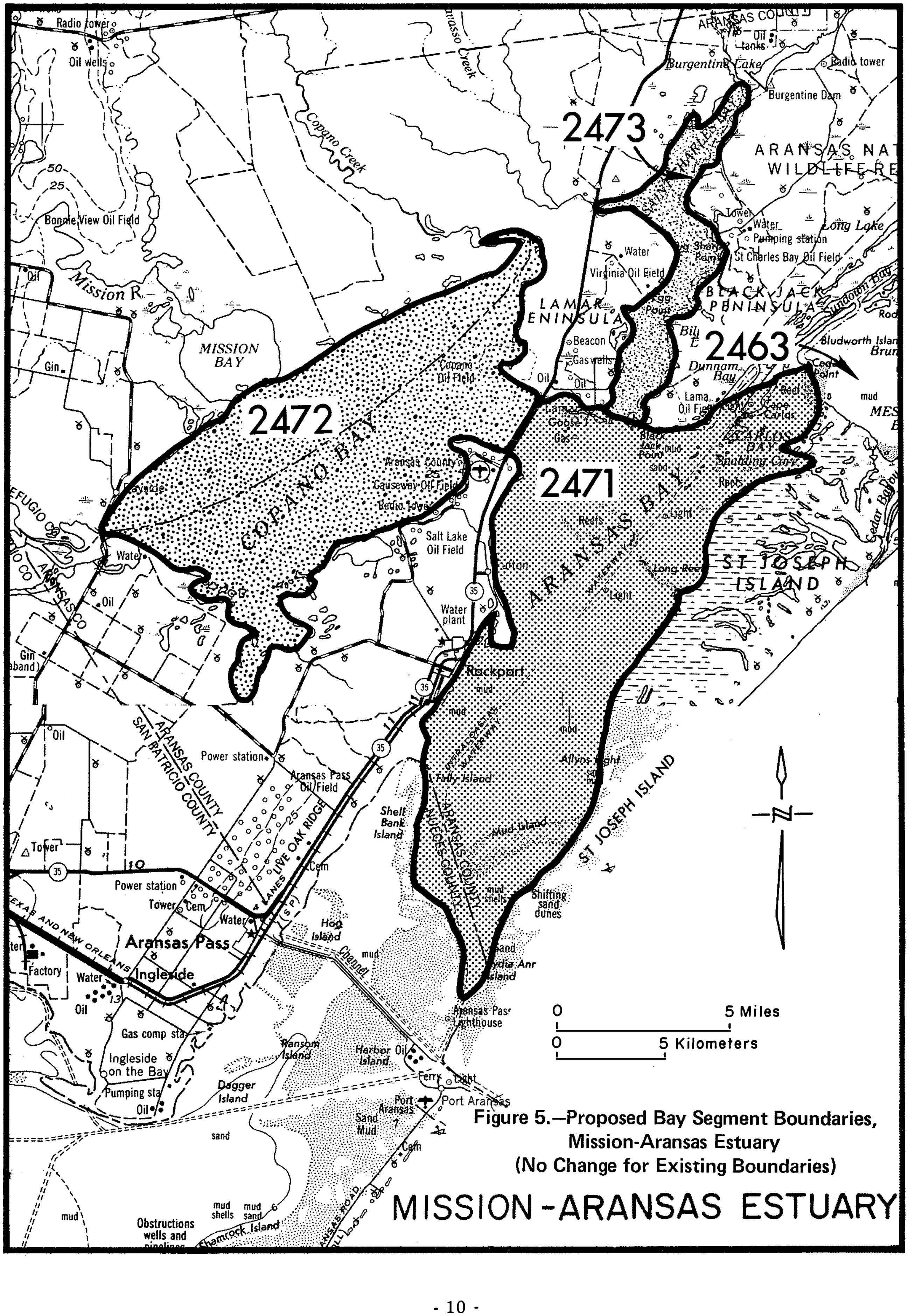


Figure 5.—Proposed Bay Segment Boundaries, Mission-Aransas Estuary (No Change for Existing Boundaries)

0.17 acre-foot per square mile (81 m^3/km^2) and 0.18 acre-foot per square mile (86 m^3/km^2), respectively.

Where a stream enters a bay, flow velocities decrease and the sediment transport capability is reduced; thus, bay-head deltas are formed where streams drop their bedload. The delta which formed at the mouth of the Nueces River is of a type which develops under conditions of high sediment inflow into a relatively quiescent body of water.

The marsh areas in the Nueces and Mission-Aransas estuaries are associated with deltas. Delta plains are covered with salt, brackish, and freshwater marshes. In order for marshes to propagate there must be a balance between sediment deposition and compactional subsidence. If there is excessive vertical accretion, marsh vegetation is replaced by mainland grasses, shrubs, and trees. Where subsidence is more rapid than deposition, the plants drown and erosion by waves and currents deepen the marsh to form lakes or enlarge the bay area.

The mainland shore of these estuaries is characterized by near vertical bluffs cut into Pleistocene sand, silt, and mud (Figure 6). Erosion of these bluffs furnishes sediment to the adjacent lakes, marshes and bays. The type of sediment deposited depends on whether the adjacent bluff is composed of predominantly sand or mud. Energy levels (erosional capacity) in the Nueces and Mission-Aransas estuaries are dominated by wind action since the range of astronomical tides is only about 0.5 foot (0.15 meters). Winds blowing across Corpus Christi, Aransas, and Copano Bays generate waves which cause erosion along the shoreline.

The Texas coastal zone is experiencing geological, hydrological, biological and land use changes as a result of natural processes and man's activities. What was once a relatively undeveloped expanse of beach is presently undergoing considerable development. Competition for space exists for such activities as recreation, seasonal and permanent housing, industrial and commercial development, and mineral and other natural resource production (30).

Shorelines are either in a state of erosion, accretion, or are stabilized either naturally or artificially. Erosion produces a net loss in land, accretion produces a net gain in land, and equilibrium conditions produce no net change in land area.

Most of the shoreline along the south side of Corpus Christi and Nueces Bays is stabilized. A state of erosion exists along the Ingleside and Portland shoreline. The mainland shoreline of Copano and Aransas Bays is mostly in a state of erosion, whereas the barrier island shoreline of both Corpus Christi and Aransas Bays is generally either in a state of equilibrium or accretion (Figures 7 and 8). Gulfward of the barrier island the shoreline is mostly in a state of equilibrium (27). This is an indication that the sediment volume being supplied is sufficient to balance the amount of sediment removed by waves and longshore drift.

Processes that are responsible for the present shoreline configuration and that are continually modifying shorelines in the Nueces and Mission-Aransas estuaries include astronomical and wind tides, longshore currents, normal wind and waves, hurricanes, river flooding, and slumping along cliffed shorelines. Astronomical tides are low, ranging from about 0.5 foot (0.15 meters) in the bays to a maximum of about 2 feet (0.6 meters) along the Gulf shoreline. Wind is a major factor in influencing coastal processes. It can raise or lower the water level along the Gulf and/or mainland shore according to the direction it is blowing. Wind can also generate waves and longshore currents (15, 10, 43).

The seasonal threat of wind and water damage associated with tropical cyclones occurring in the Gulf of Mexico exists each year from June through October. Wind damage from hurricanes and associated tornadoes can be costly, but the most severe losses occur from the flooding brought about by heavy rains and high storm tides along the coast. Gulf and mainland shorelines may be drastically altered during the approach, landfall, and inland passage of hurricanes (16). Storm surge flooding and attendant breaking waves erode Gulf shorelines from a few tens to a few hundreds of feet. Washovers along the barrier islands and peninsulas are common, and saltwater flooding may be extensive along the mainland shorelines.

Flooding of rivers and small streams normally corresponds with spring thunderstorms and the hurricane season. Some effects of flooding include: (1) overbank flooding into marsh areas of the floodplain and onto delta plains; (2) progradation of bayhead and oceanic deltas; (3) flushing of bays and estuaries; and (4) reduction of salinities.

Mineral and Energy Resources

The Texas coastal zone is richly endowed with mineral and energy resources. Dominant among these resources are oil and natural gas (Figures 9 and 10), which serve not only for fuel but also provide raw material for many petrochemical processes. In addition, the coastal zone contains important sources of chemical raw materials such as sulfur, salt, and shell for lime. The great abundance of these chemical and petroleum raw materials and their occurrence in a zone with ocean access help to make this area one of the major petrochemical and petroleum-refining centers of the world.

There are several oil and gas fields within the area surrounding Nueces and Mission-Aransas estuaries, both onshore and offshore. The production

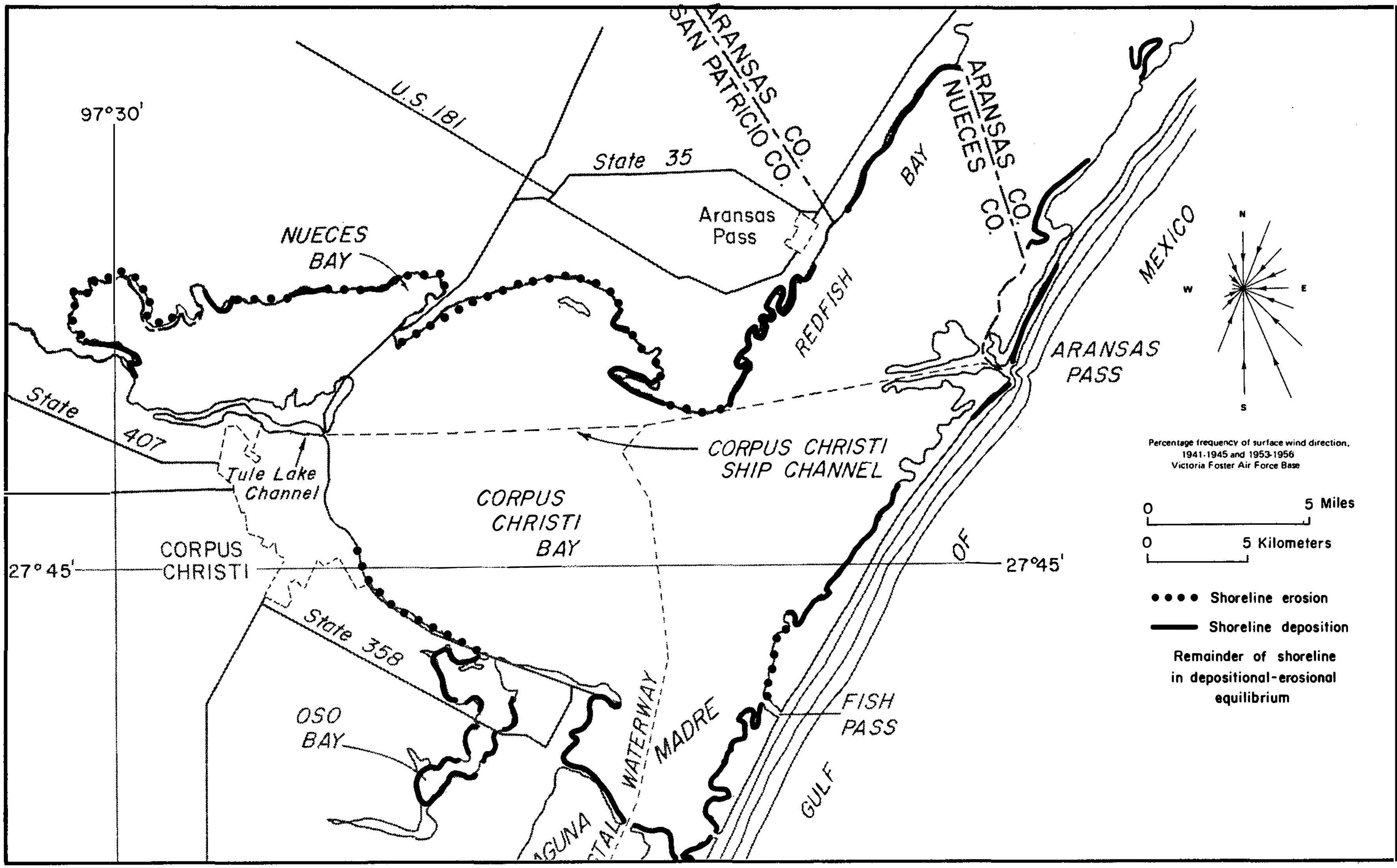


Figure 7.—Nueces Estuary, Shoreline Physical Processes (28)

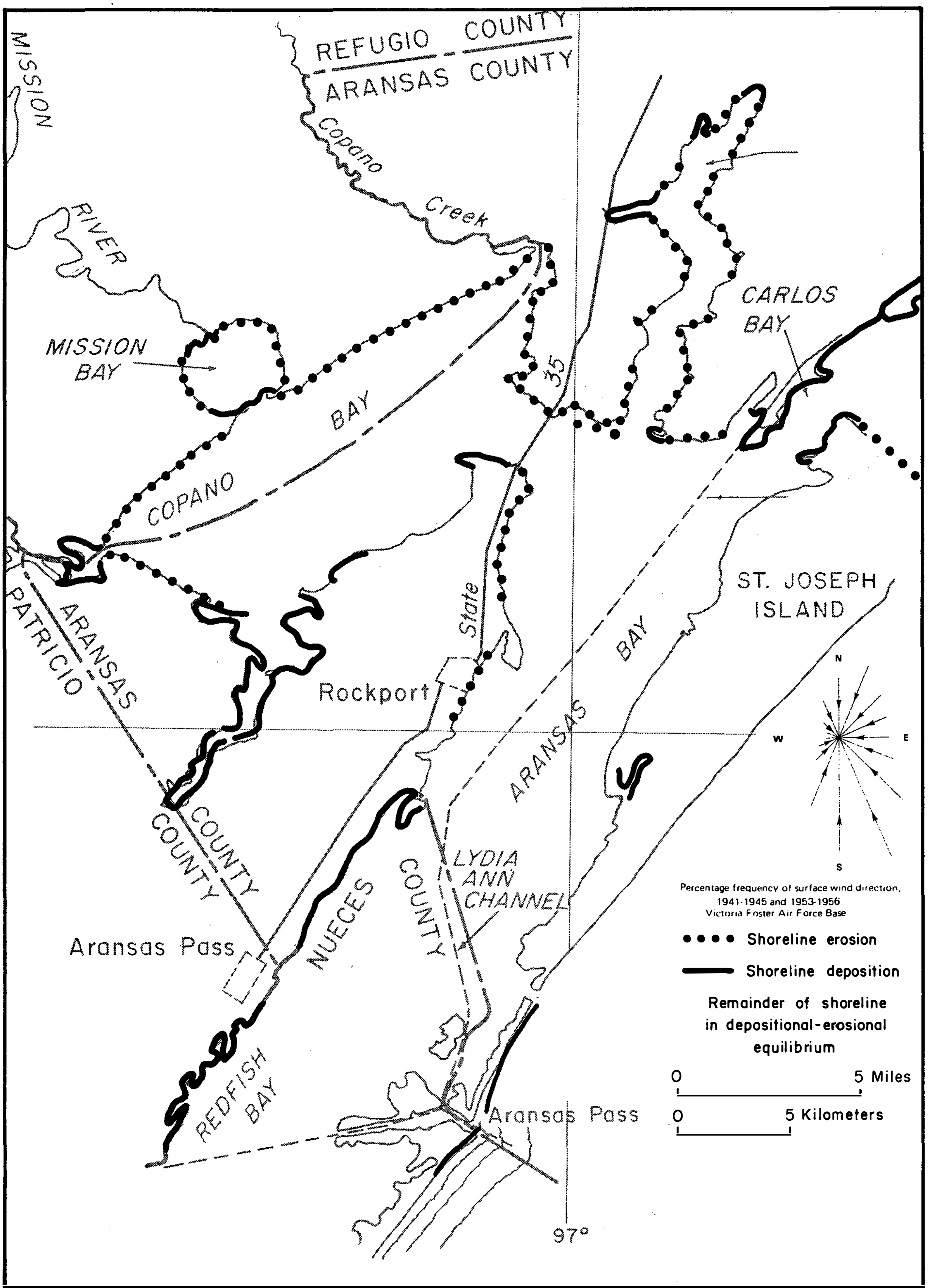


Figure 8.—Mission-Aransas Estuary, Shoreline Physical Processes (28)

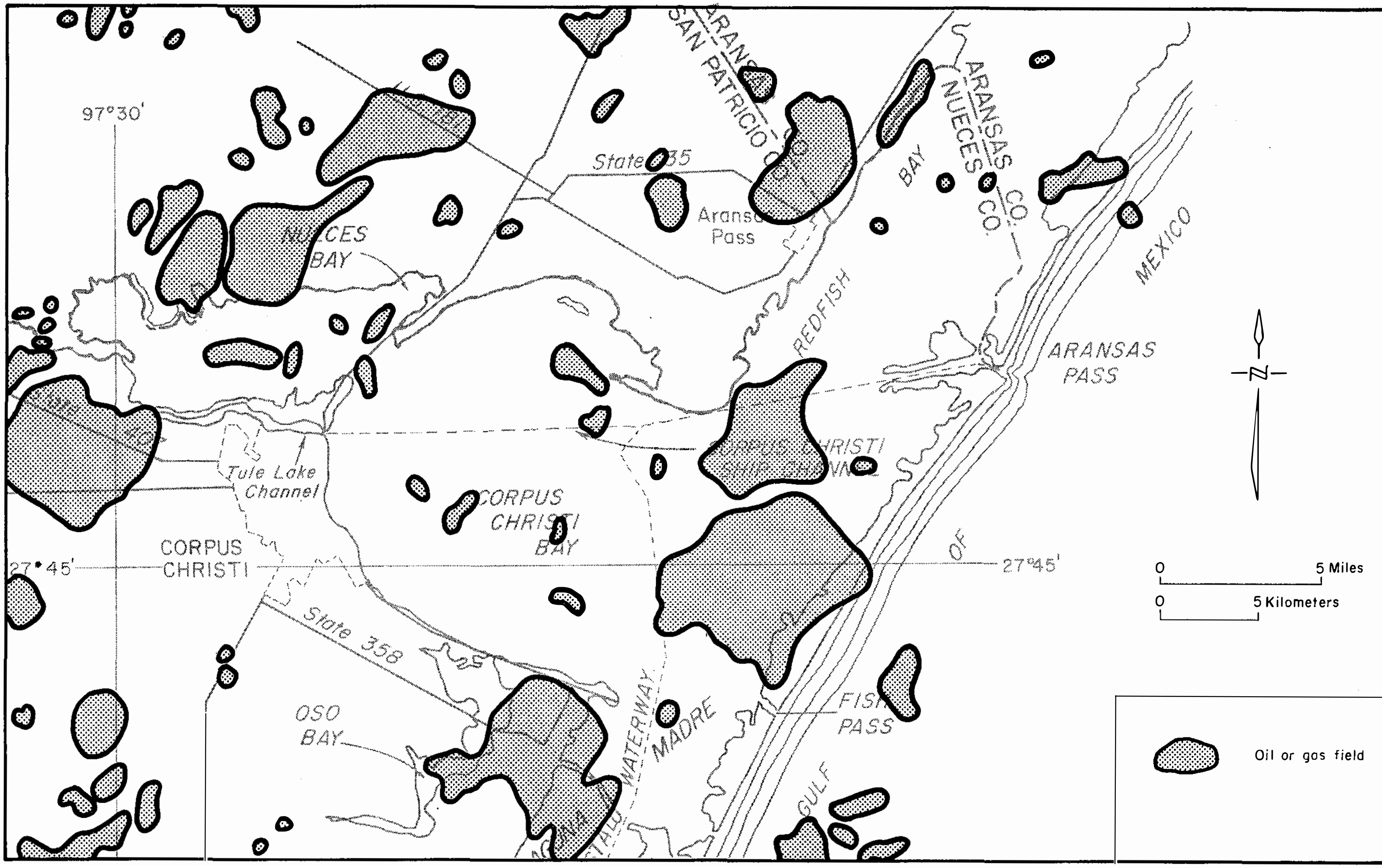


Figure 9.—Nueces Estuary, Oil and Gas Fields (28)

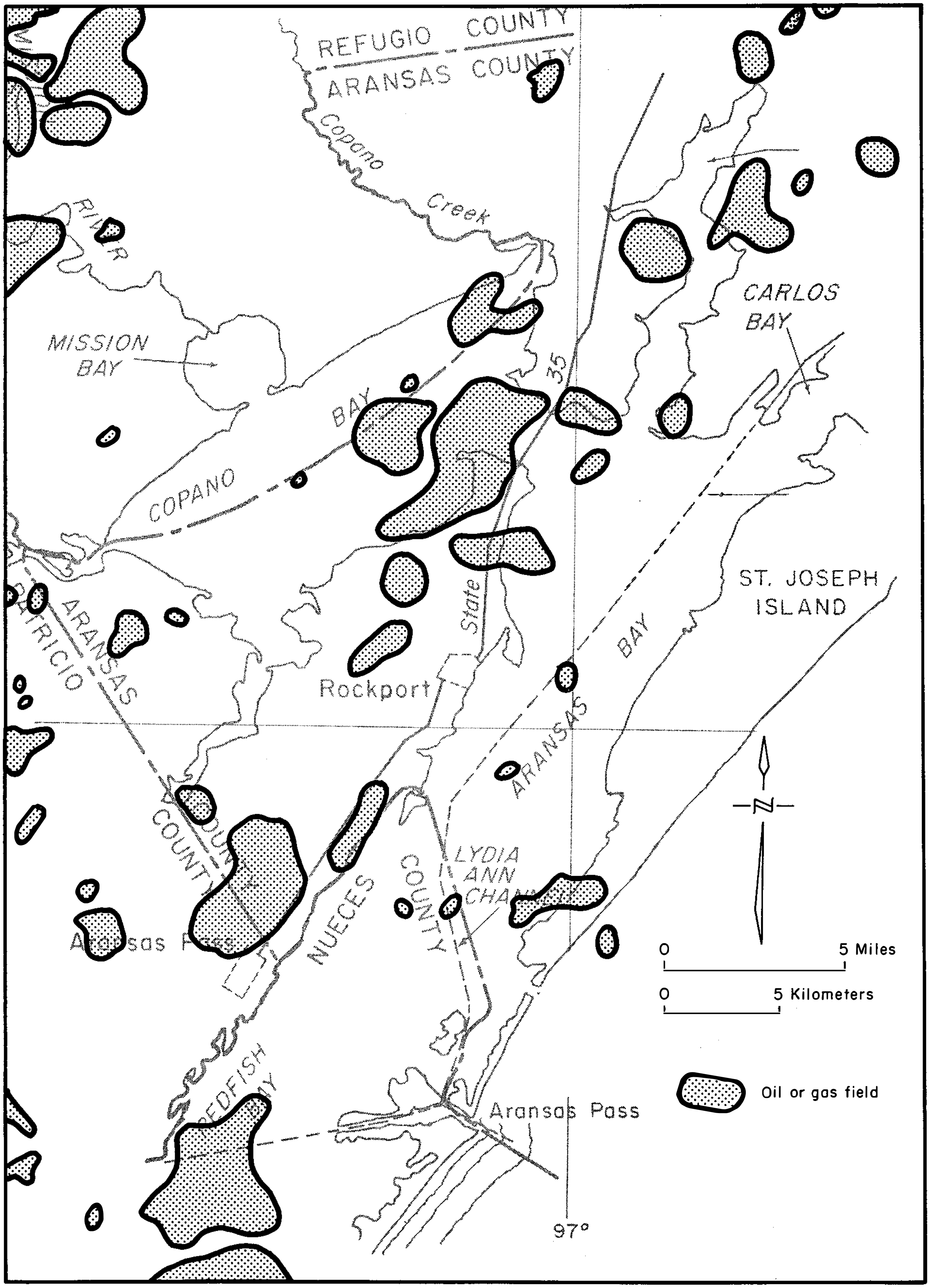


Figure 10.—Mission-Aransas Estuary, Oil and Gas Fields (28)

of oil, natural gas, and natural gas liquids plays a prominent role in the total economy of the area. In addition to the direct value of these minerals, oil and gas production supports major industries within the area and elsewhere in the coastal zone by providing readily available fuels and raw materials.

Notably absent in the Texas coastal zone are natural aggregates and bulk construction materials (e.g., gravel and stone for crushing). At the same time the demand for these materials is high in the heavily populated and industrialized areas of the coastal zone; therefore, a large portion of these materials must be imported from inland sources. Shell from the oyster *Crassostrea,* and smaller amounts from the clam *Rangia* is used as a partial substitute for aggregate. Dredged shell is suitable for aggregate, road base, lime, cement, and other chemical uses. If shell were not used, these resources would have to be transported approximately 150 miles (240 kilometers) from the nearest Central Texas source. The total resources of shell are finite, and at present rates of consumption will be depleted in the near future. Substitute materials will then have to be imported, either from inland sources or by ocean barge from more distant locations.

Some high quality sand deposits have potential specialty uses in industry, such as for foundry sands, glass sands, and chemical silica. An inventory and analysis of coastal zone sands, including those of the barrier islands, as well as the older sands of the Pleistocene uplands, indicate that these sands require upgrading and benefication to qualify for special industrial use (29). Since the nearest market for such upgraded sands would be the Houston area and there are other sources in close proximity to this metropolitan area, it is unlikely that sand deposits within the area surrounding Nueces and Mission-Aransas estuaries would be used to supply the upper coastal zone markets.

Groundwater Resources

Groundwater resources surrounding the Nueces and Mission-Aransas estuaries occur in a thick sedimentary sequence of interbedded gravel, sand, silt, and clay. The stratigraphic units included in this sequence are the Oakville, Lagarto and Goliad Formations of Tertiary Age; and the Lissie, and Beaumont Formations of Quaternary Age. These ancient sedimentary units are variable in composition and thickness and were deposited by the same natural processes that are now active in shaping the coastline. Thick layers of sand and gravel representing ancient river channel deposits grade laterally into silt and clay beds which were deposited by the overbank flooding of ancient rivers. Individual beds of predominantly sand and clay interfinger with each other and generally are hydrologically connected laterally and vertically. Because of this interconnection, groundwater can move from one bed to another and from one formation to another. The entire sequence of Quaternary sediments function as a single aquifer, which is referred to as the Gulf Coast Aquifer.

Near the Nueces and Mission-Aransas estuaries this fresh (up to 1,000 mg/l total dissolved solids) to slightly saline (1,000 to 3,000 mg/l total dissolved solids) portion of the aquifer extends to a maximum depth of about 1,800 feet (549 meters). The most productive part of the aquifer is from 200 to 500 feet (61 to 152 meters) thick (49).

Excessive pumping of groundwater, and in some cases oil and gas production can cause land surface subsidence and saltwater encroachment, which are both irreversible. Locally, the shallow aquifer may contain saltwater; whereas, the deeper aquifer sands may have freshwater. Excessive pumping of freshwater will allow saline waters to encroach into the freshwater zone, contaminating wells and degrading the general groundwater quality. The principal effects of subsidence are activation of surface faults, loss of ground elevation in critical low-lying areas already prone to flooding, and alteration of natural slopes and drainage patterns (Figure 11). Additional problems may arise if subsidence causes damage to sewer lines, water lines, petroleum transmission lines, chemical storage tanks, and other facilities. There could also be a problem when subsidence areas which previously had not been subject to tidal inundation become flood prone during high tide.

Data Collection Program

Studies by the Department of Water Resources of past and present freshwater inflows to Texas' estuaries have used all available sources of information on the physical, chemical, and biological characteristics of these estuarine systems in an effort to define the relationship between freshwater and nutrient inflows and estuarine environments. The Department realized during its planning activities that limited data were available on the estuaries of Texas. Several limited research programs were underway; however, these were largely independent of one another. The data collected under any one program were not comprehensive, and since sampling and measurement of environmental and ecological parameters under different programs were not accomplished simultaneously, the resulting data could not be reliably correlated. In some estuaries, virtually no data had been collected.

A program was therefore initiated by the Department, in cooperation with other agencies, to collect the data considered essential for analyses of the physical and water quality characteristics and ecosystems of Texas' bays and estuaries. To begin this program, the Department consulted with the

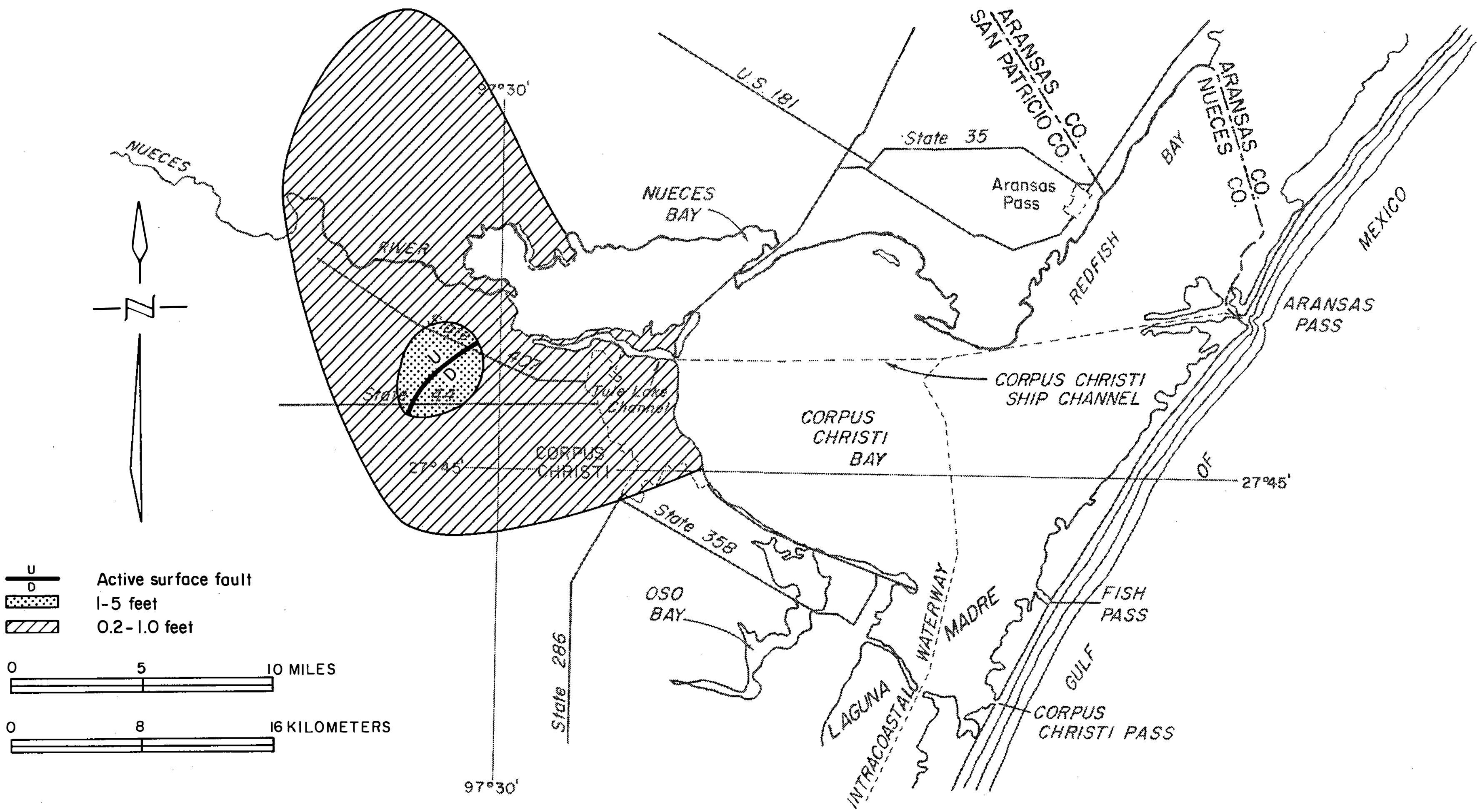


Figure 11.—Land-Surface Subsidence in the Corpus Christi Area (1942-1951) (27)*

***Recent Department of Highway and Public Transportation Data (1975) indicate a maximum of 5.3 ft. (1.6 m) of subsidence in this area**

U.S. Geological Survey and initiated a reconnaissance-level investigation program in September 1967. Specifically, the initial objectives of the program were to define: (1) the occurrence, source and distribution of nutrients; (2) current patterns, directions, and rates of water movement; (3) physical, organic, and inorganic water quality characteristics; and (4) the occurrence, quantity, and dispersion patterns of water (fresh and Gulf) entering the estuarine system. To avoid duplication of work and to promote coordination, discussions were held with other State, Federal and local agencies having interest in Texas estuarine systems and their management. Principally through this cooperative program with the U.S. Geological Survey, the Department is now collecting extensive data in all estuarine systems of the Texas Coast (Figures 12 and 13, Table 1).

Calibration of the estuarine models (discussed in a later section) required a considerable amount of data. Data requirements included information on the quantity of flow through the tidal passes during some specified period of reasonably constant hydrologic, meteorologic, and tidal conditions. In addition, a time history of tidal amplitudes and salinities at various locations throughout the bay was necessary. A comprehensive data collection program was undertaken on the Nueces and Mission-Aransas estuaries on June 3-6, 1974. Tidal amplitudes were measured simultaneously at numerous locations throughout the estuary (Figure 14). Tidal flow measurements were made at several different bay cross-sections (A, B, C, D, E, F, G, and H of Figure 14). In addition, conductivity data were collected at many of the sampling stations shown in Figures 12 and 13.

Circulation and Salinity

Summary

The movements of water in the shallow estuaries and embayments along the Texas Gulf Coast are governed by a number of factors including freshwater inflows, prevailing winds and tidal currents. An adequate understanding of mixing and physical exchange in these estuarine waters is fundamental to the assessment of the biological, chemical and physical processes governing these important aquatic systems.

To more fully evaluate the tidal hydrodynamic and salinity transport characteristics of estuarine systems, the Texas Department of Water Resources participated in the development of digital mathematical models representing the important mixing and physical exchange processes of the estuaries. These models are designed to simulate the tidal circulation patterns and salinity distributions in shallow, irregular and non-stratified estuaries. The basic concept utilized to represent each estuary was the segmentation of the physical system into a grid of discrete elements. The models utilize numerical analysis techniques to simulate the temporal and spatial behavior of circulation and salinity patterns in an estuary.

The numerical tidal hydrodynamic and salinity mass transport models were applied to the Nueces and Mission-Aransas estuaries to determine the effects of the mean monthly freshwater inflows upon the flow circulation and salinity characteristics of the estuarine system. The monthly simulations utilized typical tidal and meteorological conditions observed historically for each month simulated.

The net circulation patterns simulated by the tidal hydrodynamic model indicated that the dominant circulation pattern in the Nueces and Mission-Aransas estuaries was a net movement of water from Laguna Madre through Corpus Christi, Redfish, Aransas and Carlos Bays and into the Guadalupe estuary. Simulated water movements in the upper portions of Corpus Christi Bay were dominated by internal eddy currents induced by freshwater inflows from the Nueces River. Simulated net flows in Copano and Nueces Bays were governed by internal circulation currents rather than circulation patterns in adjacent bay systems.

The simulated salinity concentrations in the Nueces and Mission-Aransas estuaries (derived from the average monthly freshwater inflows over the period 1941 through 1976) showed major differences between the high inflow period of September through October and normal to below normal inflow periods. When inflows were high, average simulated salinity values of less than 25 parts per thousand (ppt) were found in both estuaries. The simulated mean salinities for Saint Charles and Copano Bays were never greater than 10 ppt during high inflow periods. The salinity concentrations simulated for Nueces Bay varied from under 10 ppt in the months of September and October to under 15 ppt in the remaining months. In Redfish and Aransas Bays simulation efforts predicted little difference between salinity concentrations during the high inflow period of September through October and the normal to below normal inflow period that takes place during the remainder of the year. Simulated salinities in Corpus Christi Bay ranged from 10-15 ppt during the September through October high inflow period to 15-25 ppt during the normal and below normal inflow period.

It should be noted that simulation efforts predicted lower salinity concentrations in Nueces and Corpus Christi Bays than have been actually observed in recent years. It is believed that some sources of high salinity inflow may not be adequately represented in the mass transport model (i.e., oil field brine discharges in and near Nueces and Corpus Christi Bays).

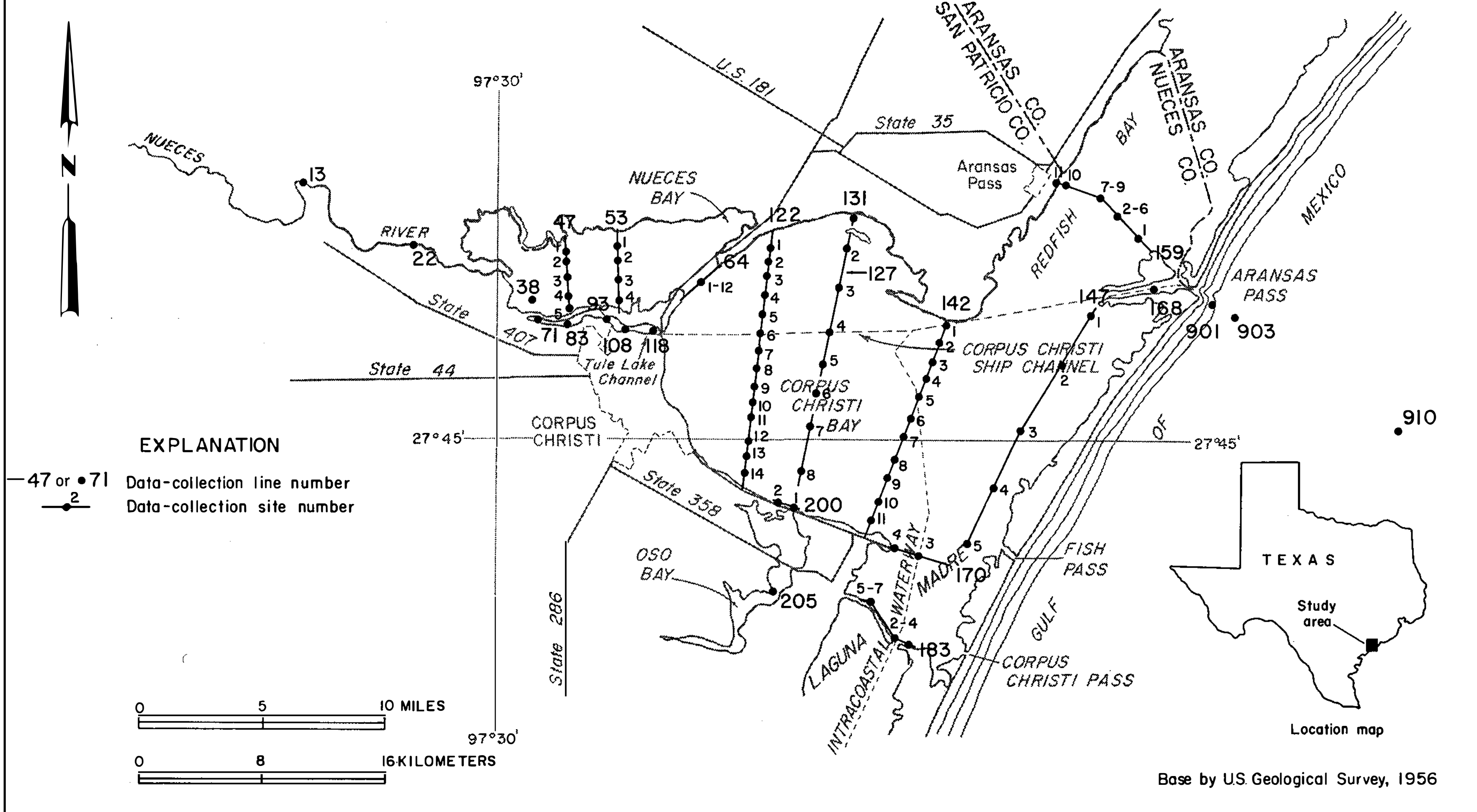


Figure 12.—Data Collection Sites in Nueces Estuary

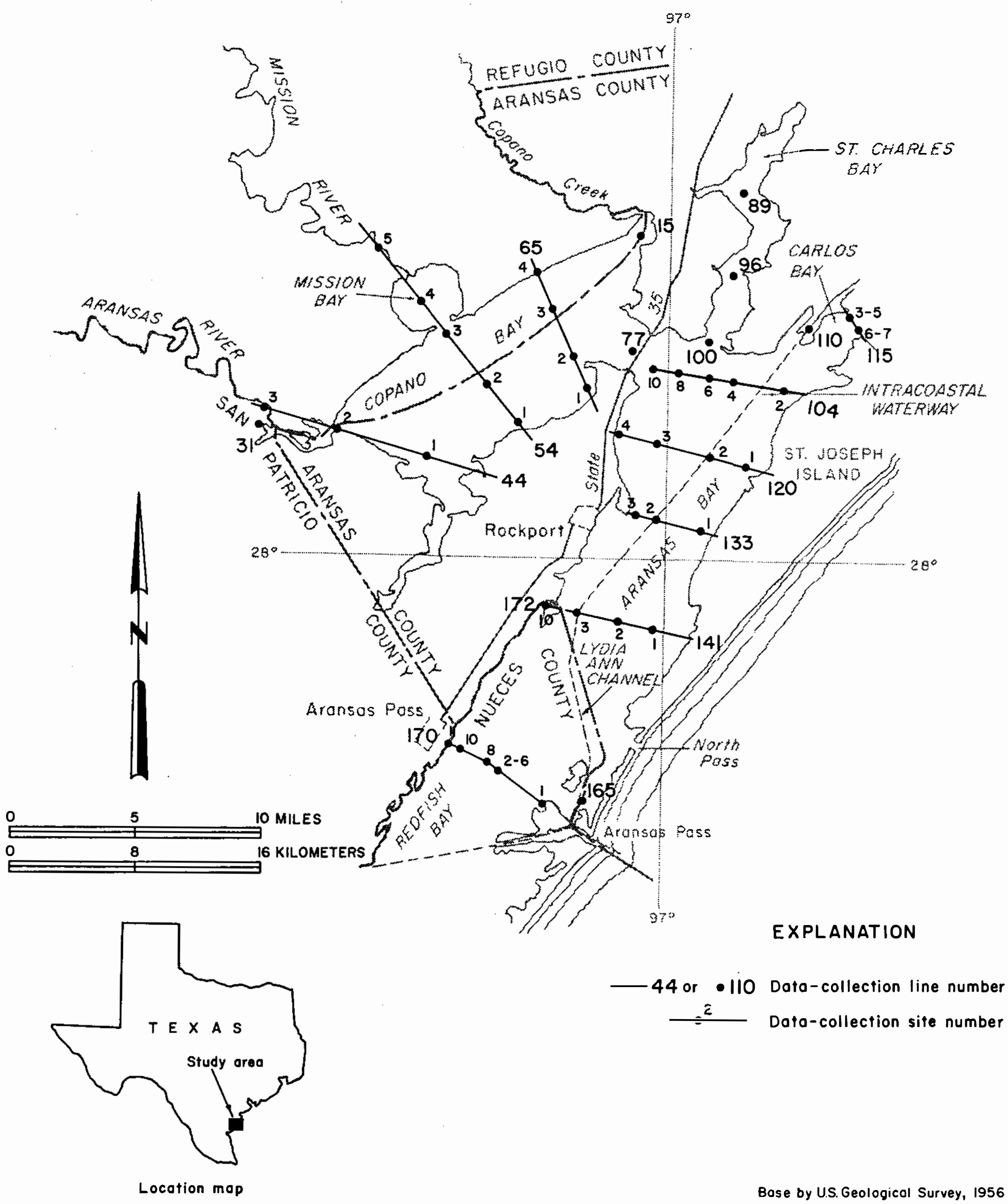


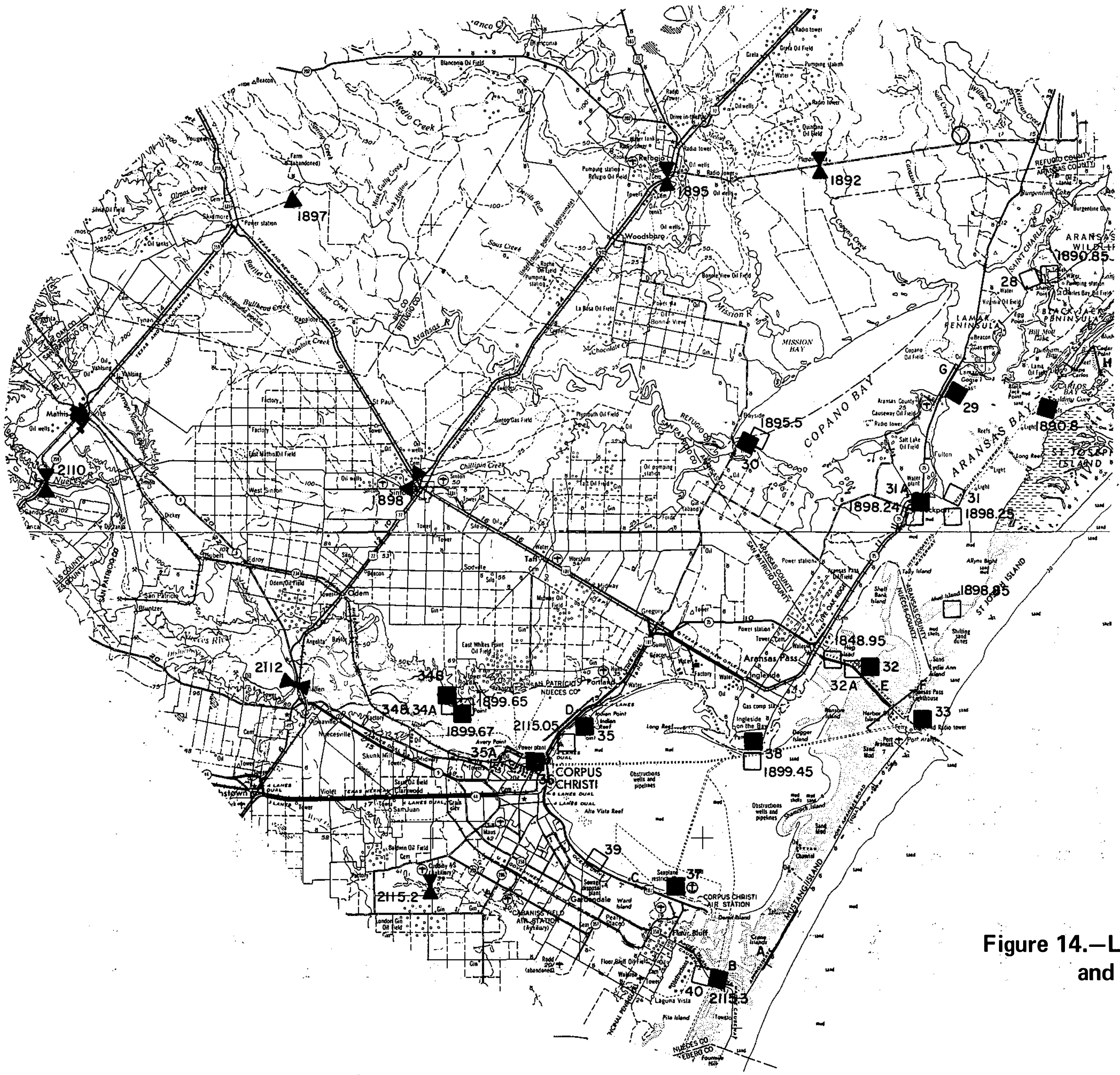
Figure 13.—Data Collection Sites in Mission-Aransas Estuary

Table 1.—USGS or Corps of Engineers (COE) Gages, Nueces and Mission-Aransas Estuaries

Station number	Station description	Period of record	Operating entity	Type of record
	Tide Gages			
28	St. Charles Bay, Indian Head Point	1977-	COE	Continuous Recording
29	Copano Bay, Hwy. 35 bridge	1968-	COE	Continuous Recording
30	Copano Bay, Bayside, Cities Service Pump Sta.	1966-	COE	Continuous Recording
31	Aransas Bay, Nine Mile Point Light	1971-75	COE	Continuous Recording
31A	Aransas Bay, Rockport Harbor, Tex. P & WL	1971-	COE	Continuous Recording
32	Redfish Bay, Aransas Pass Channel, Hwy. 361	1973-	COE	Continuous Recording
32A	Redfish Bay, Aransas Pass Channel MKR #12	1971-73	COE	Continuous Recording
33	Aransas Pass, Port Aransas, South Jetty	1968-	COE	Continuous Recording
34	Nueces Bay, Arco Well #10 (Wht. Pt.)	1971-75	COE	Continuous Recording
34A	Nueces Bay, White Point-Phillips 66	1969-71	COE	Continuous Recording
34B	Nueces Bay, Phillips Well #5 (Wht. Pt.)	1975-	COE	Continuous Recording
35	Nueces Bay, Hwy 181 Causeway	1971-	COE	Continuous Recording
35A	Corpus Christi Bay, Turning Basin, Pier 9	1968-69	OCE	Continuous Recording
36	Corpus Christi Bay, COE Area Office	1969-	COE	Continuous Recording
37	Corpus Christi Bay, Naval Air Station	1966-	COE	Continuous Recording
38	Corpus Christi Bay, Ingleside, Sun P.L. Dock	1969-	COE	Continuous Recording
39	Corpus Christi Bay, 4600 Bay-shore Dr.	1969-75	COE	Continuous Recording
40	North Laguna Madre, GIWW Marker #21	1971-75	COE	Continuous Recording
1890.80	Aransas Bay (Dun. Pt.) nr. Fulton	1971-	USGS	Continuous Recording
1890.85	Saint Charles Bay nr. Fulton	1971-76	USGS	Continuous Recording

Table 1.—USGS or Corps of Engineers (COE) Gages, Nueces and Mission-Aransas Estuaries — Continued

Station number	Station description	Period of record	Operating entity	Type of record
1895.55	Copano Bay nr. Bayside	1966-76	USGS	Continuous Recording
1898.24	Aransas Bay at Rockport	1975-76	USGS	Continuous Recording
1898.25	Aransas Bay nr. Rockport	1971-75	USGS	Continuous Recording
1898.85	Aransas Bay (Mud Isle) nr. Port Aransas	1971-75	USGS	Continuous Recording
1898.95	Redfish Bay (SH 361) nr. Aransas Pass	1971-76	USGS	Continuous Recording
1899.45	Corpus Christi Ship Channel nr. Ingleside	1969-76	USGS	Continuous Recording
1899.65	Nueces Bay (Wh. Pt.) nr. Corpus Christi	1969-76	USGS	Continuous Recording
1899.67	Nueces Bay nr. Whites Point nr. Corpus Christi	1974-	USGS	Continuous Recording
2115.05	Nueces Bay (US 181) nr. Corpus Christi	1971-76	USGS	Continuous Recording
2115.30	Laguna Madre (ICWW) nr. Corpus Christi	1976-	USGS	Continuous Recording
	Stream Gages			
1892	Copano Creek nr. Refugio	1970-	USGS	Continuous Recording
1895	Mission River at Refugio	1939-	USGS	Continuous Recording
1897	Aransas River nr. Skidmore	1964-	USGS	Continuous Recording
1898	Chiltipin Creek at Sinton	1970-	USGS	Continuous Recording
2112	Nueces River nr. Mathis	1939-	USGS	Continuous Recording
2115	Nueces River nr. Calallen	1966-67	USGS	Continuous Recording
2115.2	Oso Creek at Corpus Christi	1972-	USGS	Continuous Recording
	Partial Record Gages			
1891.00	Salt Creek nr. Refugio	1967-77	USGS	



EXPLANATION

USGS stream flow with water quality

USGS streamflow

USGS tide gage or COE tide gage

USGS tide gage or COE tide gage, discontinued

Partial record USGS streamflow with water quality

Partial record USGS streamflow with water quality - discontinued

N

0 5 10 Miles

0 5 10 15 Kilometers

Figure 14.—Location of Gaging Stations, Nueces and Mission-Aransas Estuaries

Description of Estuarine Mathematical Models

Introduction

The estuaries and embayments along the Texas Gulf Coast are characterized by large surface areas, shallow depths and irregular boundaries. These estuarine systems receive variable influxes of freshwater and return flows which enter through various outfall installations, navigation channels, natural stream courses, and as runoff from contiguous land areas. Once contained within the systems, these discharges are subject to convective movements and to the mixing and dispersive action of tides, currents, waves and winds. The flushing of many Gulf Coast estuaries occurs through narrow constricted inlets or passes and in a few cases, through dredged navigable channel entrances. While the tidal amplitude at the mouths of these estuaries are normally low, the interchange of Gulf waters with bay waters and the interchange of waters between various segments within a given system have a significant effect on the circulation and transport patterns within the estuarine system.

Of the many factors that influence the quality of estuarine waters, mixing and physical exchange are among the most important. These same factors also affect the overall ecology of the waters, and the net result is reflected in terms of the economic benefits derived from the waters. Thus, the descriptions of the tidal hydrodynamics and the transport characteristics of an estuarine system are fundamental to the development of any comprehensive multivariate concept applicable to the management of estuarine water resources. Physical, chemical, biological and economic analyses can be considered only partially complete until interfaced with the nutrient, hydrodynamic and transport characteristics of a given estuarine system, and vice versa.

Description of the Modeling Process

A shallow estuary or embayment can be represented by several types of models. These include physical models, electrical analogs and mathematical models, each of which has its own advantages and limitations. The adaptation of any of these models to specific problems depends upon the accuracy with which the model can faithfully reproduce the prototype behavior to be studied. Furthermore, the selected model must permit various alternatives to be studied within an allowable economic framework.

A mathematical model is a functional representation of the physical behavior of a system or process presented in a form available for solution by an acceptable method. The mathematical statement of a process consists of an input, a transfer function and an output. The output from a given system or component of a system is related to some function of the input by the transfer function.

A numerical model of an estuarine system consists of a series of elements arranged in time and space so that the output from one element becomes the input to the next and so on. Each input is operated on by the transfer function for the element and, through a succession of spatial and time steps, the entire functional behavior of the system is determined. One of the merits of the numerical representation is that it permits discretizing and more detailed characterization of the prototype.

Because of the nonlinearities of tidal equations, direct solutions in closed form seldom can be obtained for real circumstances unless many simplifying assumptions are made to linearize the system. When boundary conditions required by the real system behavior become excessive or complicated, it is usually convenient to resort to numerical methods in which the system is discretized so that the boundary conditions for each element can be applied or defined. Thus it becomes possible to evaluate the complex behavior of a total system by considering the interaction between individual elements satisfying common boundary conditions in succession. However, the precision of the results obtained depends on the time interval, element size selected, and the rate of change of the phenomena being studied. The greater the number of finite time intervals used over the total period of investigation, the greater the precision of the expected result.

Numerical methods are very well adaptable to discretized systems where the transfer functions may be taken to be time independent over short time intervals. The development of high-speed digital computers with large memory capacity makes it possible to solve the tidal equations directly by finite difference or finite element techniques within a framework that is both efficient and economical. The solutions thus obtained may be refined to meet the demands of accuracy at the burden of additional cost by reducing the size of finite elements and decreasing the time interval. In addition to the constraints imposed on the solution method by budget constraints or by desired accuracy, there is an optimum size of element and time interval imposed by mathematical considerations which allows a solution to be obtained which is mathematically stable, convergent and compatible.

Mathematical Model Development.

The mathematical tidal hydrodynamics and conservative mass transport models for the Nueces and Mission-Aransas estuaries (12) were designed to simulate the tidal cycle, circulation patterns, and salinity distributions in a shallow, irregular, non-stratified estuary. The two models are sequential

(Figure 15) in that the tidal hydrodynamic model computes temporal histories of tidal amplitudes and flows. These are then used as input to the conservative transport model to compute vertically averaged salinities (or any other conservative material) under the influence of various source salinities, evaporation, and rainfall. Both of these models have "stand alone" capabilities although it must be recognized that the transport model ordinarily can not be operated unless the tidally generated convective inputs are available.

(1) Hydrodynamic Model

Under the assumption that the bays are vertically well-mixed, and the tidally generated convection in either of the two area-wise coordinate directions can be represented with vertically integrated velocities, the mathematical characterization of the tidal hydrodynamics in a bay system requires the simultaneous solution of the two-dimensional dynamic equations of motion and the unsteady continuity equation. In summary, the equations of motion neglecting the Bernoulli terms but including wind stresses and the Coriolis acceleration can be written as follows:

$$\frac{\partial q_x}{\partial t} - \Omega\, q_y = -\, gd \frac{\partial h}{\partial x} - fq\, q_x + K\, V_w^{\,2} \cos\Theta \qquad [1]$$

$$\frac{\partial q_y}{\partial t} + \Omega\, q_x = -\, gd \frac{\partial h}{\partial y} - fq\, q_y + K\, V_w^{\,2} \sin\Theta \qquad [2]$$

The equation of continuity for unsteady flow can be expressed as follows:

$$\frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} + \frac{\partial h}{\partial t} = r - e \qquad [3]$$

In equations [1], [2] and [3], q_x and q_y are vertically integrated flows per foot of width at time t in the x and y directions, respectively (x and y taken in the plane of surface area); h is the water surface elevation (with respect to mean sea level (msl) as datum); d is the depth of water at (x, y, t) and is equal to (h - z) where z is the bottom elevation with respect to msl; $q = (q_x^2 + q_y^2)^{1/2}$; f is a nondimensional bed resistance coefficient determined from the Manning Equation; V_w is the wind speed at a specified elevation above the water surface; θ is the angle between the wind velocity vector and the x-axis; K is the nondimensional wind stress coefficient; and Ω is the Coriolis parameter equal to $2\omega\sin\phi$, where ω is the angular velocity of the earth taken as 0.73×10^{-4} rad/sec and ϕ is the latitude taken as 27.8° for the Nueces and Mission-Aransas estuaries; r is the rainfall intensity; and e is the evaporation rate.

The numerical solution utilized in the hydrodynamic model of the Nueces and Mission-Aransas estuaries involved an explicit computational scheme where equations [1], [2] and [3] were solved over a rectangular grid of square cells used to represent in a discretized fashion the physiography and various boundary conditions found in this bay system as is shown conceptually in Figure 16. This explicit formulation of the hydrodynamic model requires for stability a computational time step, $\Delta t < \Delta s/(2gd_{max})^{1/2}$ where Δs is the cell size and d_{max} is the maximum water depth encountered in the computational matrix. The numerical solutions of the basic equations and the programming techniques have been described previously (12).

(2) Conservation Mass Transport Model

The transport process as applied to salinity can be described through the convective-dispersion equation which is derivable from the principal of mass conservation. For the case of a two-dimensional, vertically-mixed bay system, this equation can be written as

$$\frac{\partial (C\bar{d})}{\partial t} + \frac{\partial (\bar{q}_x C)}{\partial x} + \frac{\partial (\bar{q}_y C)}{\partial y} = \frac{\partial}{\partial x}\left[D_x \frac{\partial (C\bar{d})}{\partial x}\right] + \frac{\partial}{\partial y}\left[D_y \frac{\partial (C\bar{d})}{\partial y}\right] + K_e\, C\bar{d} \qquad [4]$$

where C is the tidally averaged salinity or TDS concentration; $\bar{q}_x$ and $\bar{q}_y$ are the net flows over a tidal cycle in the x and y directions, respectively; D_x and D_y are the corresponding dispersion coefficients evaluated at a scale representative of total tidal mixing; and $\bar{d}$ is the average depth over a tidal cycle. The term $K_eC\bar{d}$ is a first-order reactive term included to represent the buildup of concentration due to evaporation from the bay surface and K_e is a coefficient determined volumetrically in accordance with methods described by Masch (12). The primary difference in the form of Equation [4] given above and that reported previously by Masch (12), is that Equation [4] is written in terms of net flows per foot of width rather than tidally averaged velocities.

The numerical technique employed in the salinity model involves an alternating direction implicit (ADI) solution of Equation [4] applied over the same grid configuration used in the tidal hydrodynamic model to determine the net flows and tidally averaged depths. Because of its implicit formulation, the ADI solution scheme is unconditionally stable and there are no restrictions on the computational time step, Δt. However, to maintain accuracy and to minimize round-off and truncation errors, a condition corresponding to $\Delta t/\Delta s^2 \leqslant 1/2$ was always maintained

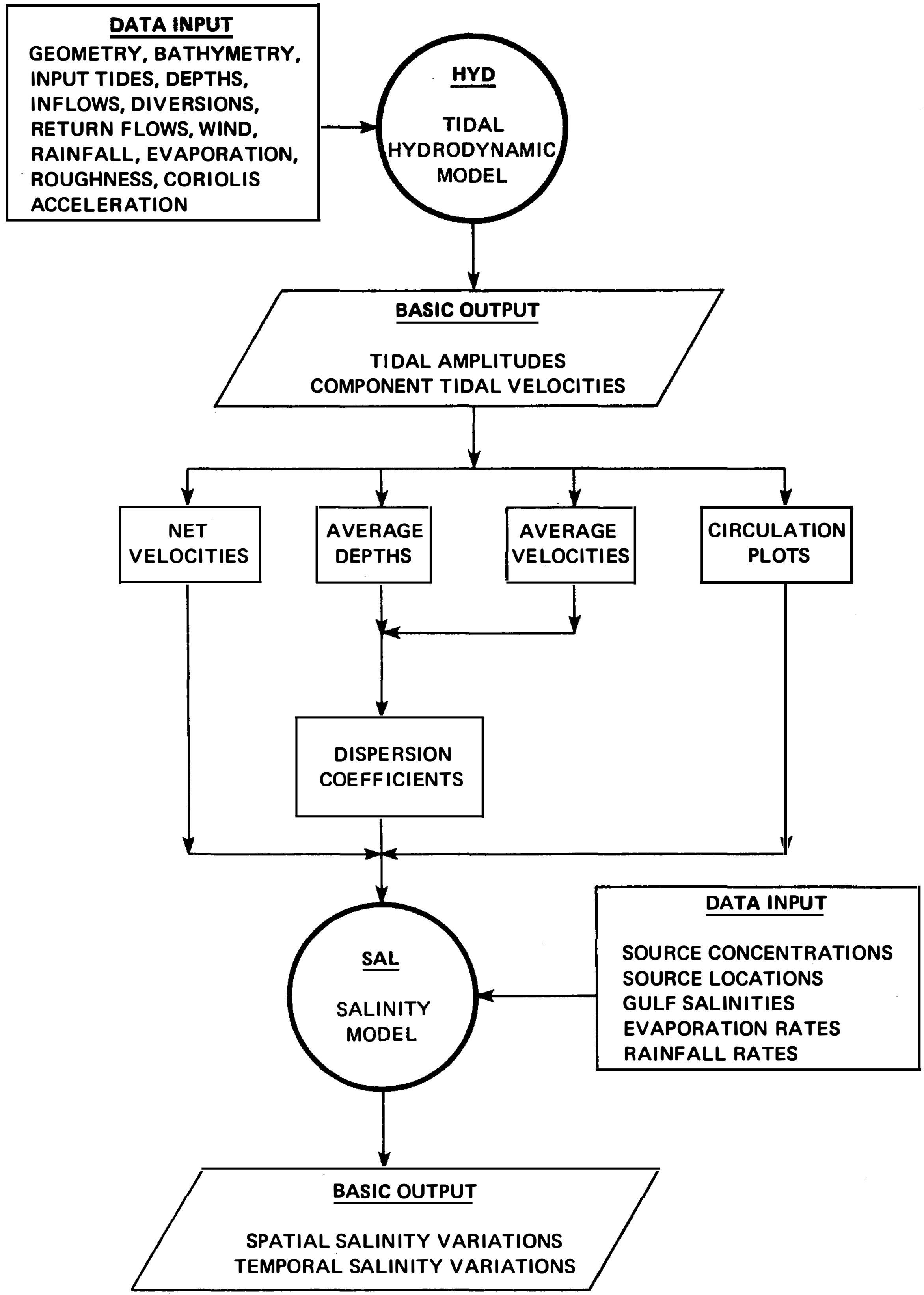


Figure 15.—Relationships Between Tidal Hydrodynamic and Salinity Models

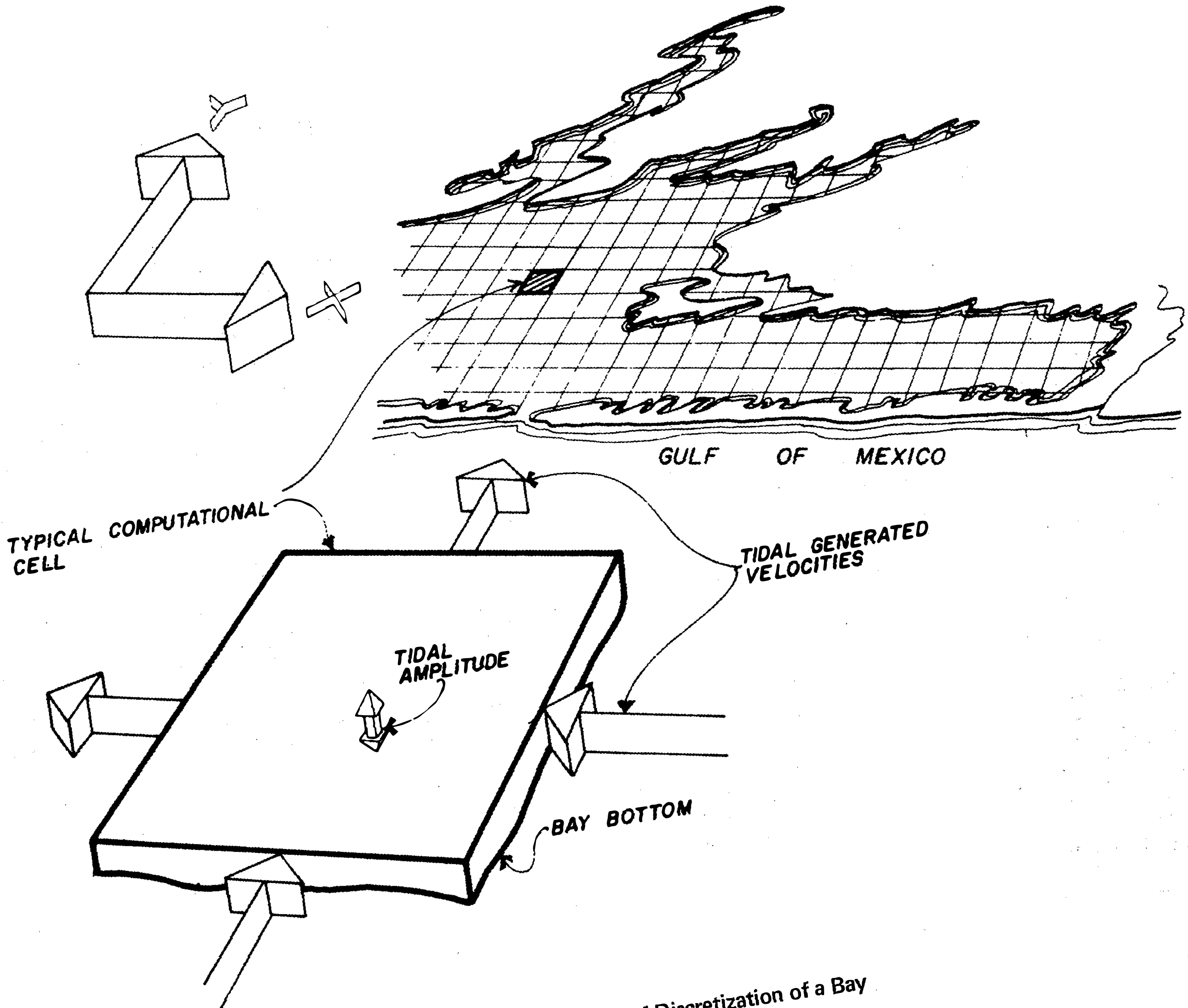


Figure 16.—Conceptual Illustration of Discretization of a Bay

throughout this work. Details of the numerical solution of Equation [4] and programming techniques have also been previously described by Masch (12).

The computational grid network used to describe the Nueces and Mission-Aransas estuaries is illustrated in Figure 17. The grid is superimposed on a map showing the general outline of the bay. Included in the grid network are the locations of islands (solid lines), submerged reefs (dash lines), inflow points, and tidal excitation cells. The x-axis of the grid system is aligned approximately parallel to the coastline, and the y-axis extends far enough landward to cover the lower reaches of all freshwater sources to the bay. The cell size (one square nautical mile) was based on the largest possible dimension that would provide sufficient accuracy, the density of available field data, computer storage requirements and computational time. Similar reasoning was used in selection of the computational time step except that the maximum possible time step in the hydrodynamic model was constrained by the criterion for mathematical stability. In the indexing scheme shown in Figure 17, cells were numbered with the indices $1 < i < IMAX = 41$ and $1 < j < JMAX = 28$. With this arrangement, all model parameters such as water depths, flows in each coordinate direction, bottom function, and salinity could be identified with each cell in the grid.

(3) Data Sets Required

The following data comprise the basic set for applying the tidal hydrodynamics model. Time varying data should be supplied at hourly intervals.

Physical Data

- topographic description of the estuary bottom, tidal passes, etc.
- location of inflows (rivers, wastewater discharges, etc.)

Hydrologic - Hydraulic Data

- tidal condition at the estuary mouth (or opening to the ocean)
- location and magnitude of all inflows and withdrawals from the estuary
- estimate of bottom friction
- wind speed and direction (optional)
- rainfall history (optional)
- site evaporation or coefficients relating surface evaporation to wind speed

The basic data set required to operate the conservative mass transport model consists of a time history of tidal-averged flow patterns, i.e., the output from the tidal hydrodynamics model, the salinity concentrations of all inflows to the estuary, and an initial distribution within the estuary.

Application of Mathematical Models, Nueces and Mission-Aransas Estuaries

The historic monthly total freshwater inflows to the Nueces and Mission-Aransas estuaries for the years 1941 through 1976 were computed from gaged flow and precipitation records. Using these computed inflows, the mean inflows for each month were determined (Table 2). The average monthly freshwater inflows for the Nueces and Mission-Aransas estuaries over the period 1941 through 1976 are distributed according to the histogram given in Figure 18. The month with the greatest contribution of freshwater inflows is September, with over 24 percent of the total annual inflow; March has the lowest average historical inflow, accounting for slightly less than two percent of the total inflows into the estuaries. The tidal hydrodynamics model was operated using these mean monthly inflows along with typical tidal and meteorological conditions for each month as input to simulate average circulation patterns in the Nueces and Mission-Aransas estuaries for each month of the year.

The output of the tidal hydrodynamics model consists of a set of tidal amplitudes and net flows computed for each cell in the 41 × 28 computational matrix representing the Nueces and Mission-Aransas estuaries. The computed net flows are the average of the instantaneous flows calculated by the model over the tidal cycle. The circulation pattern represented by these net flows should not be interpreted as a set of currents that can be observed at any time during the tidal cycle, but rather a representation of the net movement of water created by the combined action of the Gulf tides, freshwater inflow and meteorological conditions during the tidal cycle.

The resultant circulation patterns can be best illustrated in the form of vector plots wherein each vector (or arrow) represents the net flow through each computational cell. The orientation of the vector represents the direction of flow and the length of the vector represents the magnitude of flow.

The tidal amplitudes and flows calculated by the tidal hydrodynamics model were used as input to operate the salinity transport model to simulate the salinity distributions in the Nueces and Mission-Aransas estuaries for each of the mean monthly inflow periods. The resultant salinity distributions are illustrated in the form of salinity contour plots wherein lines of uniform salinity are shown in increments of five parts per thousand (ppt).

Simulated Flow Patterns

The simulated steady-state net flows in the Nueces and Mission-Aransas estuaries are given in

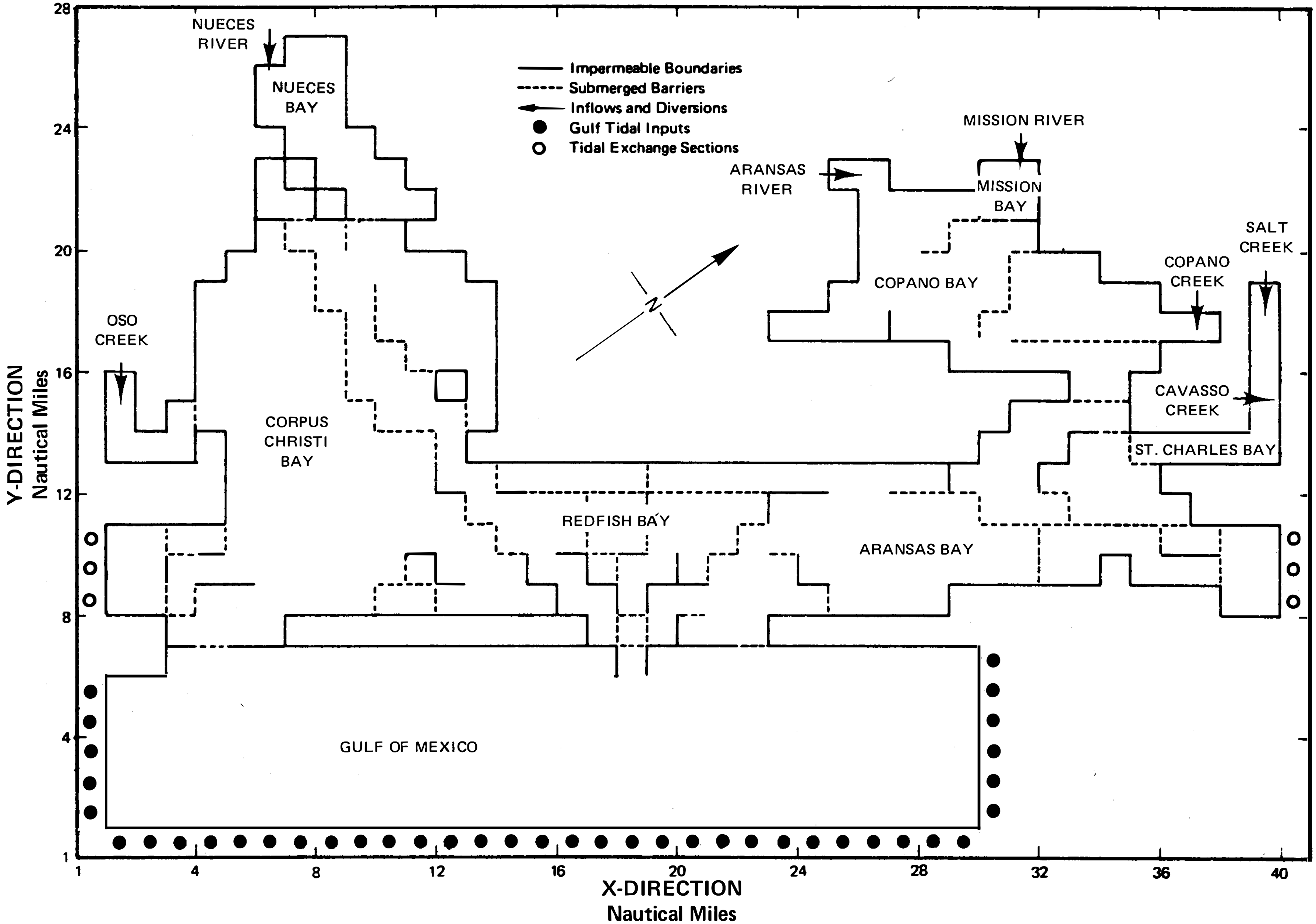


Figure 17.—Computational Grid, Nueces and Mission-Aransas Estuaries (12)

Table 2.—Mean Monthly Freshwater Inflow Nueces and Mission-Aransas Estuaries 1941-1976

Month	Nueces[1] River	Oso[1] Creek	Cavasso[2] Creek	Copano[1] Creek	Salt[2] Creek	Aransas[1] River	Mission[1] River	Total
January	325	16	2	18	26	24	34	445
February	342	32	4	47	59	110	149	743
March	276	3	0	11	8	5	8	311
April	319	37	3	57	131	91	138	776
May	1,625	83	11	115	62	268	371	2,535
June	1,159	67	10	82	150	188	238	1,894
July	862	62	7	52	99	163	428	1,673
August	488	45	7	32	120	125	101	918
September	2,419	151	22	158	213	722	704	4,389
October	1,853	91	16	115	148	298	364	2,885
November	454	10	2	12	72	18	18	586
December	162	25	5	28	86	65	83	454

[1] Total gaged and ungaged flow in ft^3/sec.
[2] Total ungaged flow in ft^3/sec.

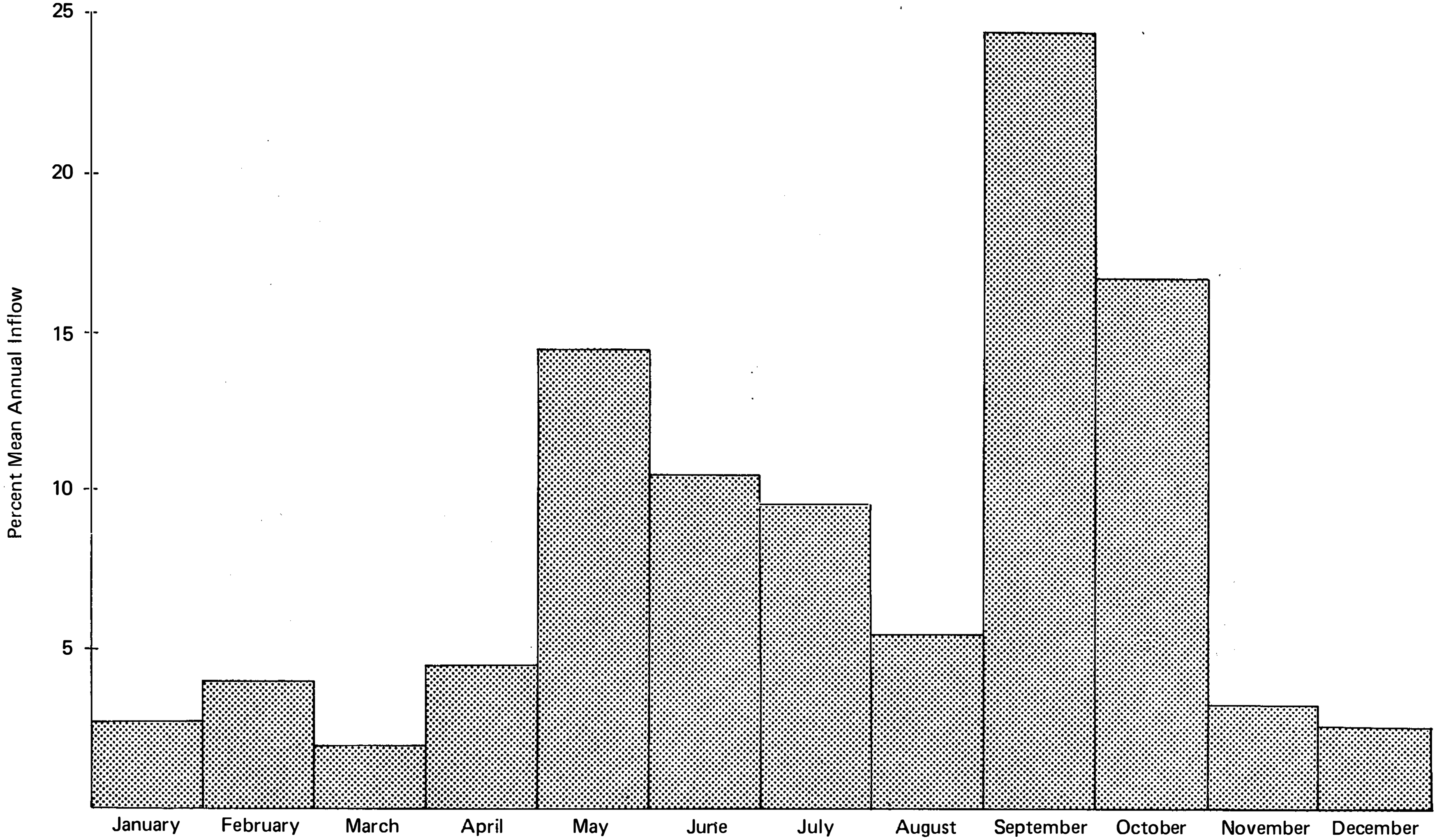


Figure 18.—Monthly Distribution of Mean Annual Total Gaged and Ungaged Inflow, Nueces and Mission-Aransas Estuaries (1941-1976)

Figures 19 through 30 for each of the twelve months. The magnitude and direction of net flow in each computational "cell" is indicated by an arrow or vector. The magnitude of flow is given by the length of each vector, with one inch corresponding to approximately 22,000 cubic feet per second (ft^3/sec) or (623 m^3/sec).

Examination of the circulation plots for each of the numerical simulations (using the averge monthly inflows) revealed that the general circulation patterns in the Nueces and Mission-Aransas estuaries were similar for all months. The simulated circulation patterns in these estuaries appeared to be wind-dominated. The prevailing southeasterly wind generated the predominant current which moved water from the eastern portion of Corpus Christi Bay, through Redfish, Aransas and Carlos Bays into Mesquite Bay of the Guadalupe estuary.

The circulation pattern in Corpus Christi Bay generally consisted to two closed circulation eddies: a clockwise circulation vortex in the southern portion of the bay and a counter-clockwise vortex in the northern portion of the bay. The simulated net flow circulation in Nueces Bay was not significantly influenced by the currents in Corpus Christi Bay since the *net* flow contribution between the two bays was from Nueces Bay to Corpus Christi Bay.

The simulated Copano Bay circulation patterns were relatively unaffected by the currents in Aransas Bay, nearby. Flow exchange between Copano and Aransas Bays was relatively small compared to the exchange between the other bays of the Nueces and Mission-Aransas estuaries.

Net flow between the Nueces estuary and Laguna Madre was predominantly in a northeasterly direction into Corpus Christi Bay through the dredged channels, including the Intracoastal Waterway. Only during the month of September was the flow direction reversed, with Corpus Christi Bay contributing water into Laguna Madre. The simulated net flow through Aransas Pass was predominantly directed out of the Nueces estuary and into the Gulf of Mexico. Only during the months of September and October were the simulated net flows directed into the estuary through Aransas Pass. The simulated monthly flows at the exchange points between the Mission-Aransas and Guadalupe estuaries (Cedar Dugout and the Intracoastal Waterway) were always directed from the Mission-Aransas estuary into Mesquite Bay.

Simulated Salinity Patterns

To test the reliability of the salinity transport model to properly replicate historically observed salinity concentrations the recorded historical freshwater inflow rates and tidal elevations for 1971 through 1974 were used to simulate the salinity distribution in the Nueces and Mission-Aransas estuaries. After comparing the simulated to the observed salinities for this period, it was determined that the simulated salinities in Redfish, Aransas, and Copano Bays generally agreed with the observed data throughout. During extended low-flow periods the model consistently underestimated the observed salinities in Nueces and Corpus Christi Bays. An investigation of observed data for 1968 through 1977 revealed that during low-flow periods, the Nueces estuary did not demonstrate a salinity gradient typical of Texas Gulf Coast estuaries (i.e., low salinities in the vicinity of the river mouth, gradually increasing in the direction of the Gulf pass). Such a typical condition occurred in the Nueces estuary only during periods of high flow and for a short time thereafter. Otherwise, the salinities consistently remained 20 to 30 parts per thousand (ppt) throughout Nueces and Corpus Christi Bays with little appreciable salinity gradient. The results of the model simulations predicted the occurrence of a salinity gradient at all times, with the gradient's severity increasing during low inflow periods and decreasing during high inflow periods. The presence of additional sources of influent water containing high total dissolved solids (TDS) concentrations is suspected as the cause for observed salinities being higher than those simulated by the numerical model in Nueces and Corpus Christi Bays. Thus, the salinity transport model for the Nueces and Mission-Aransas estuaries may not account for all sources of salinity in Nueces and Corpus Christi Bays.

The hydrodynamic simulations resulting from the mean monthly inflows were used to execute the salinity transport model. The application of the salinity model was undertaken for each of the average historical monthly conditions. An evaluation of the simulated monthly salinities in the Nueces and Mission-Aransas estuaries resulting from these model operations revealed only two distinct salinity distribution patterns, one occurring during the high inflow month of September and continuing into October, and the other occurring throughout the remainder of the year (Figures 31 and 32).

During the months of September and October the simulated salinities were less than 10 ppt in Nueces Bay and ranged from about 10 ppt to 15 ppt in the area adjacent to Laguna Madre to about 20 pptin the vicinity of Redfish Bay. Redfish Bay had simulated salinities ranging from just under 20 ppt to over 25 ppt in the Aransas Pass area. The simulated salinities in Aransas Bay decreased from approximately 25 ppt in the vicinity of Aransas pass to less than 15 ppt in the extreme northern portion adjacent to Lamar Peninsula. Copano, Mission, and Saint Charles Bays generally had simulated salinities of less than 10 ppt.

For the remainder of the year the simulated salinities in the lower portion of Nueces Bay ranged from 10 ppt to slightly less than 15 ppt. The simulated salinities throughout most of Corpus Christi Bay

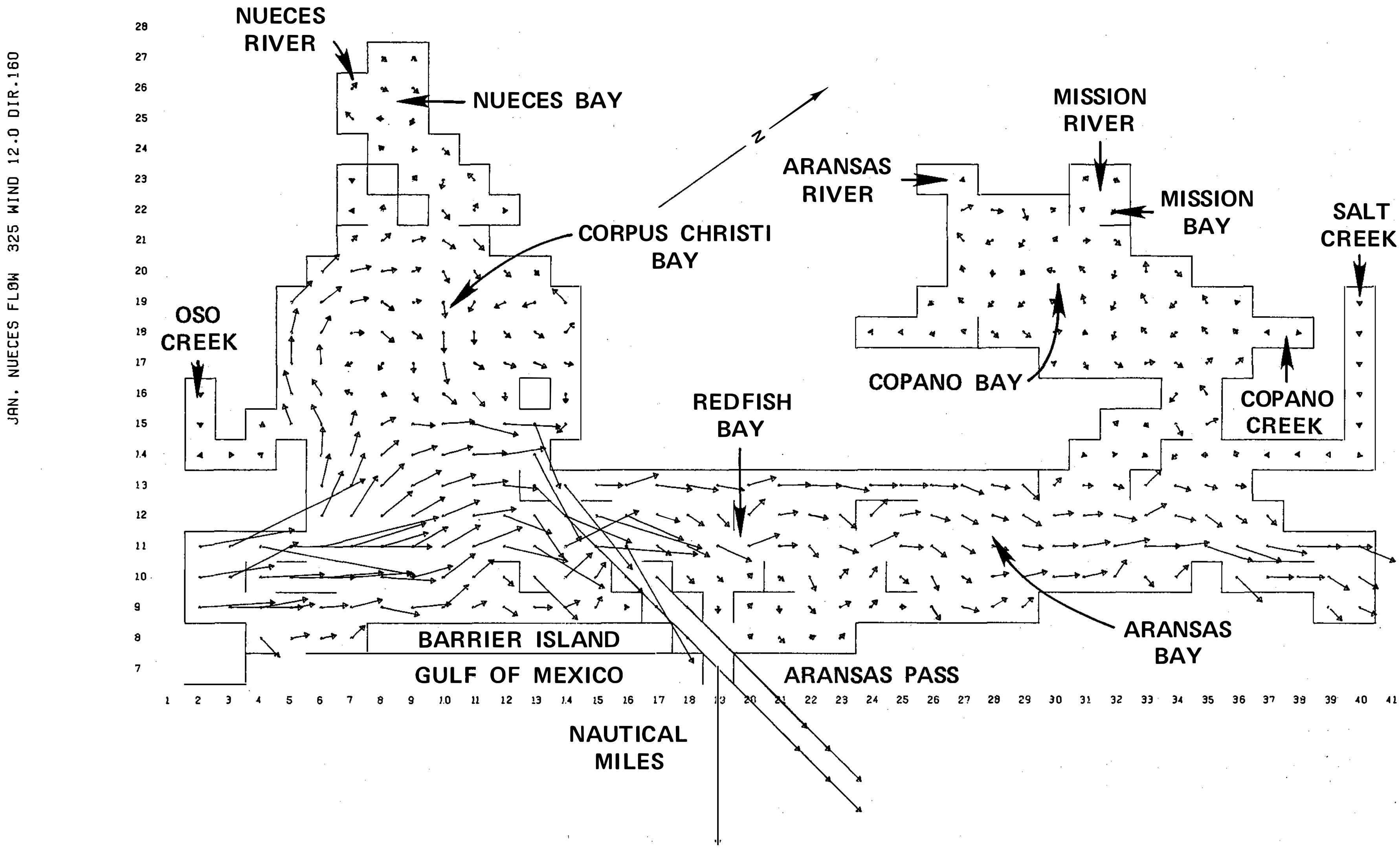


Figure 19.—Simulated Net Steady-State Flows in the Nueces and Mission-Aransas Estuaries Under January Average Inflows (1941-1976)

FEB. NUECES FLOW 425 WIND 12.9 DIR.160

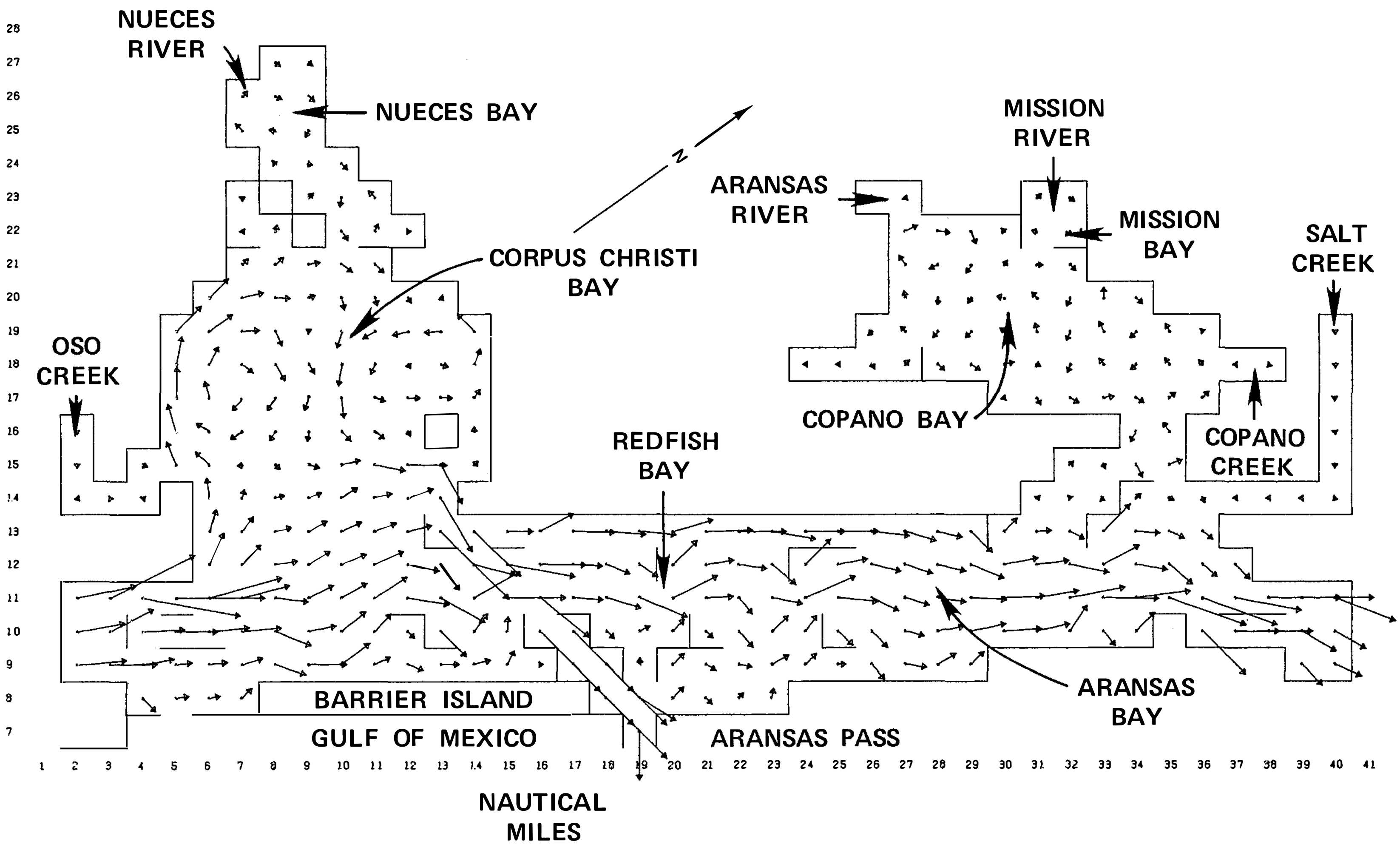


Figure 20.—Simulated Net Steady-State Flows in the Nueces and Mission-Aransas Estuaries Under February Average Inflows (1941-1976)

MAR. NUECES FLØW 276 WIND 14.0 DIR.160

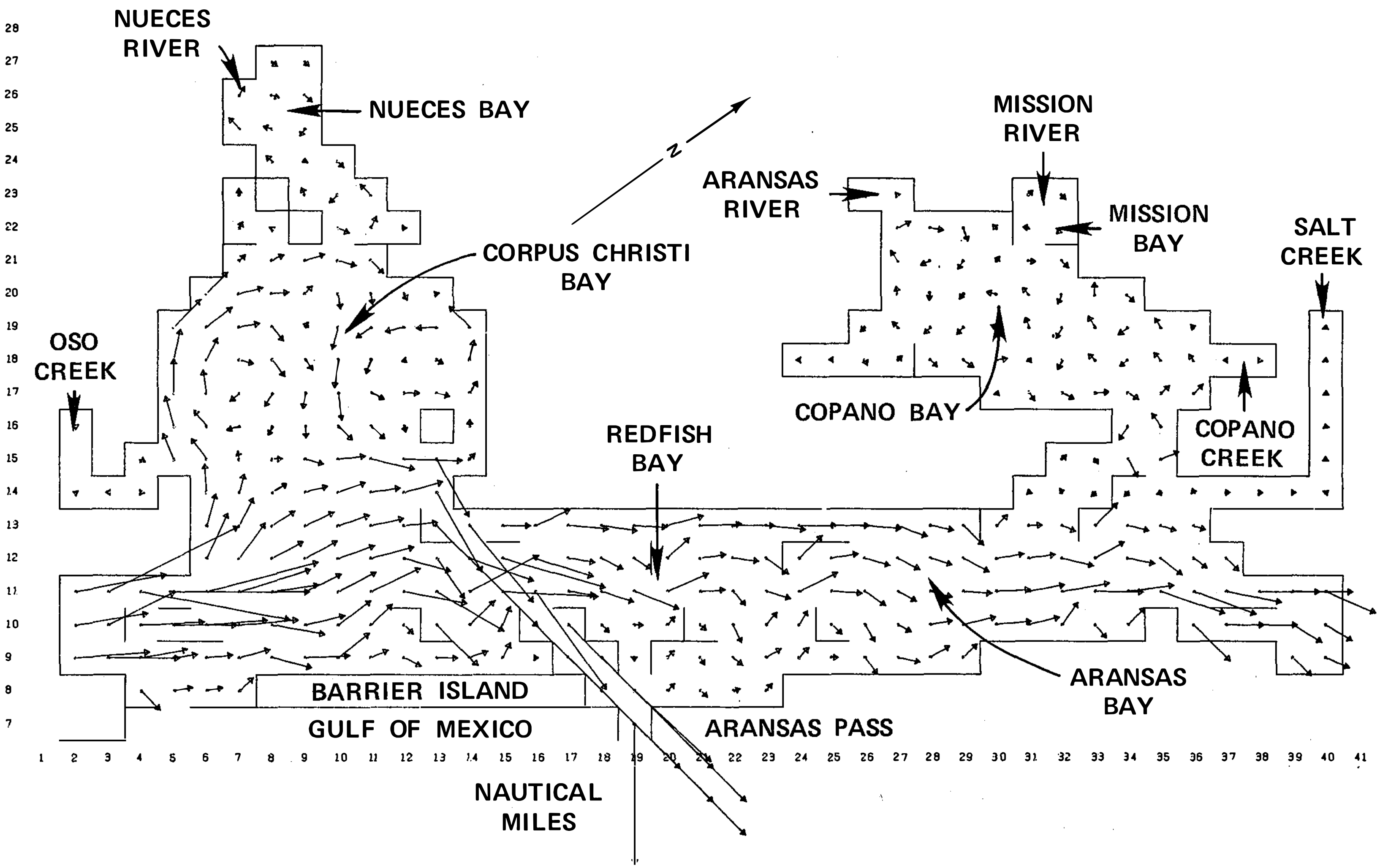


Figure 21.—Simulated Net Steady-State Flows in the Nueces and Mission-Aransas Estuaries Under March Average Inflows (1941-1976)

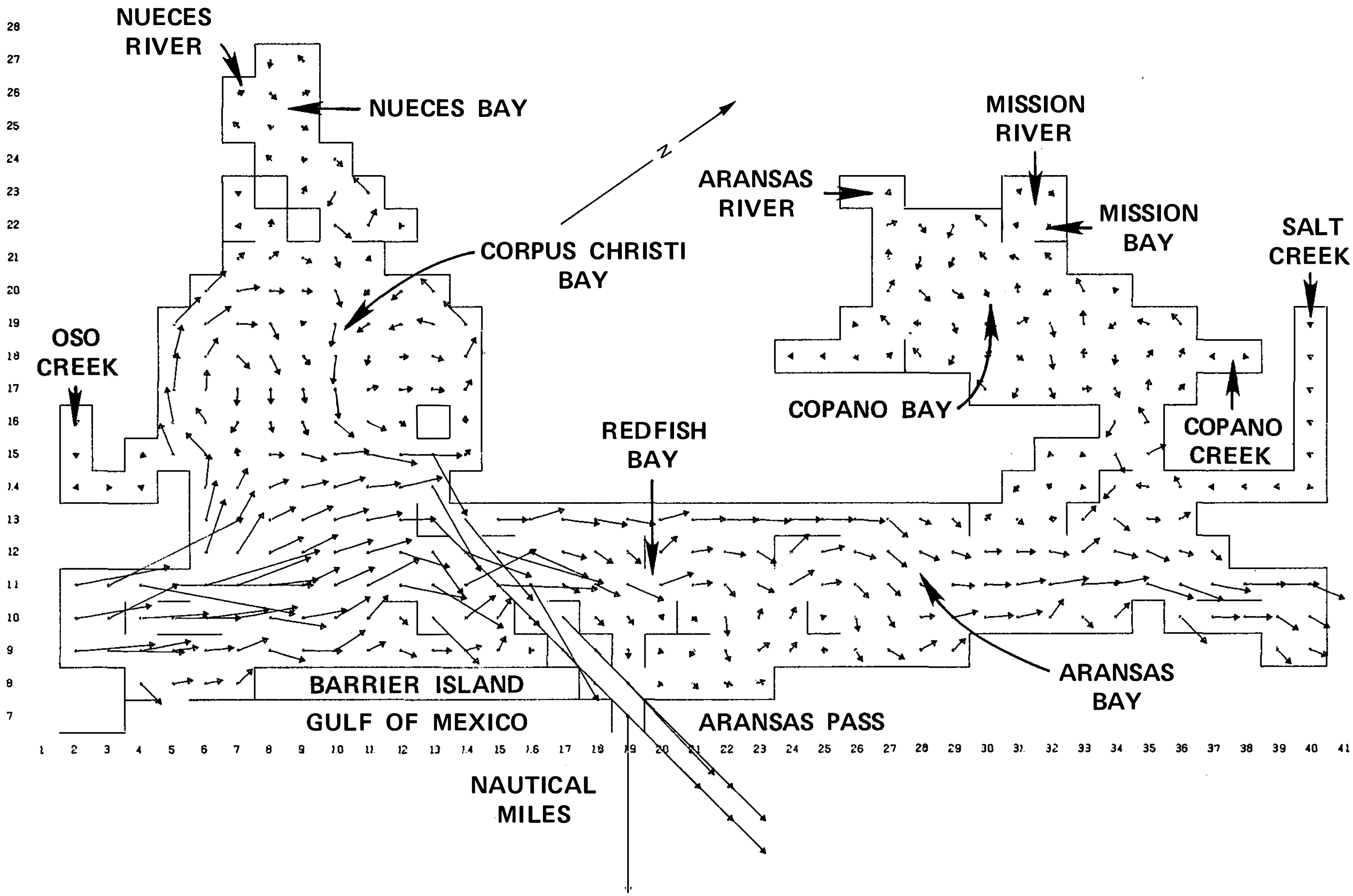
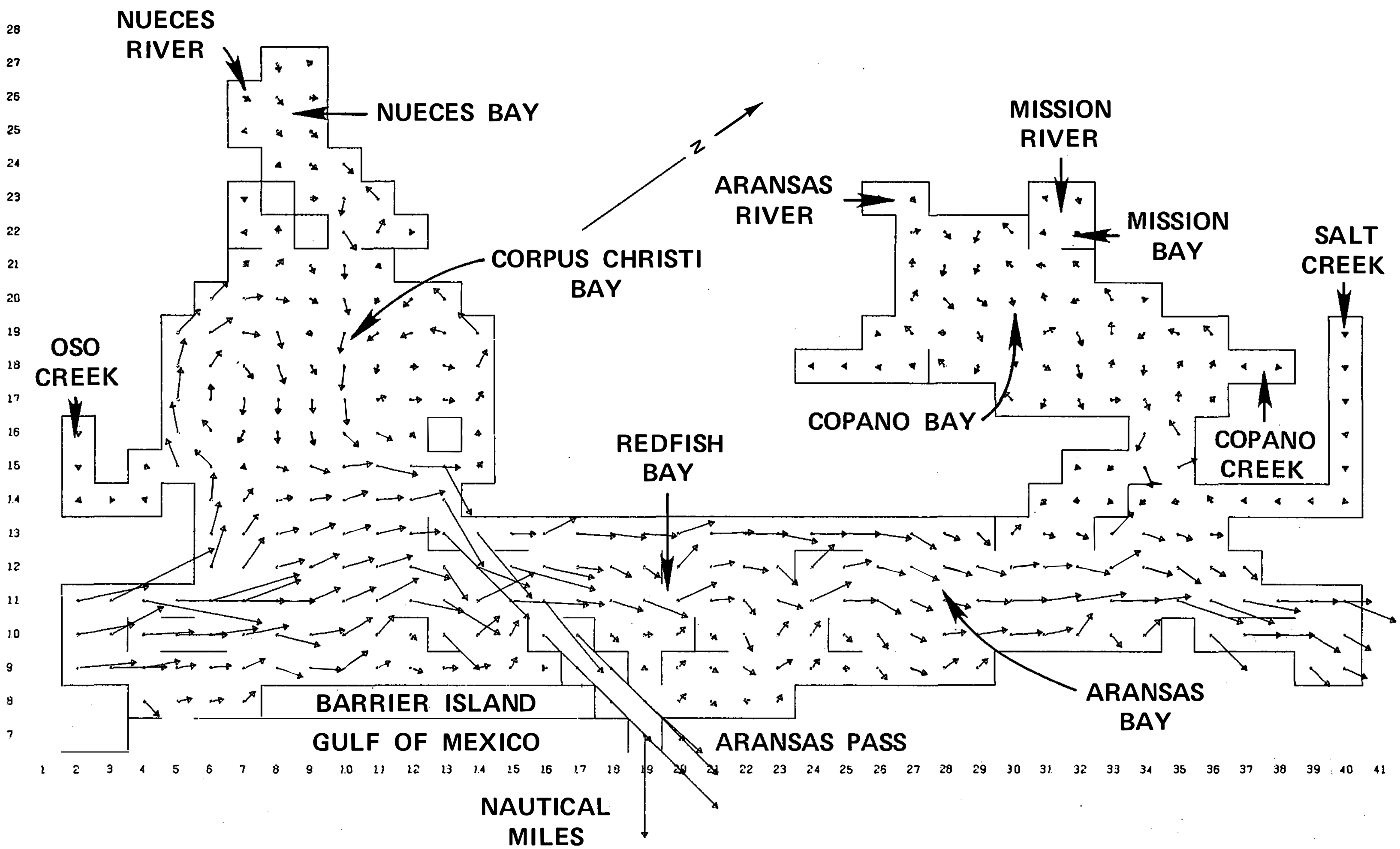


Figure 22.—Simulated Net Steady-State Flows in the Nueces and Mission-Aransas Estuaries Under April Average Inflows (1941-1976)



MAY, NUECES FLOW 1625 WIND 12.9 DIR.135

Figure 23.—Simulated Net Steady-State Flows in the Nueces and Mission-Aransas Estuaries Under May Average Inflows (1941-1976)

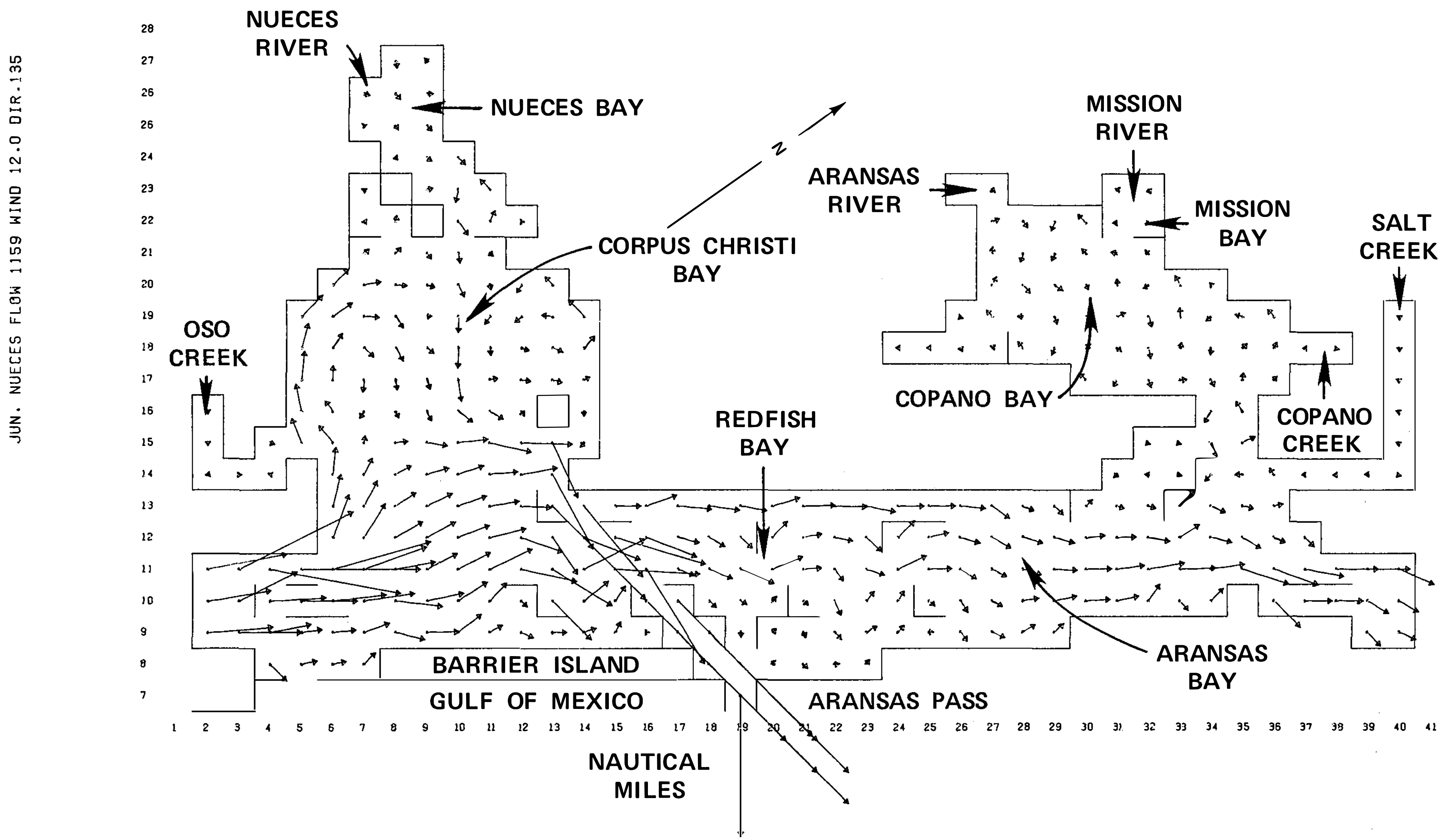


Figure 24.—Simulated Net Steady-State Flows in the Nueces and Mission-Aransas Estuaries Under June Average Inflows (1941-1976)

JUL. NUECES FLOW 862 WIND 11.6 DIR.160

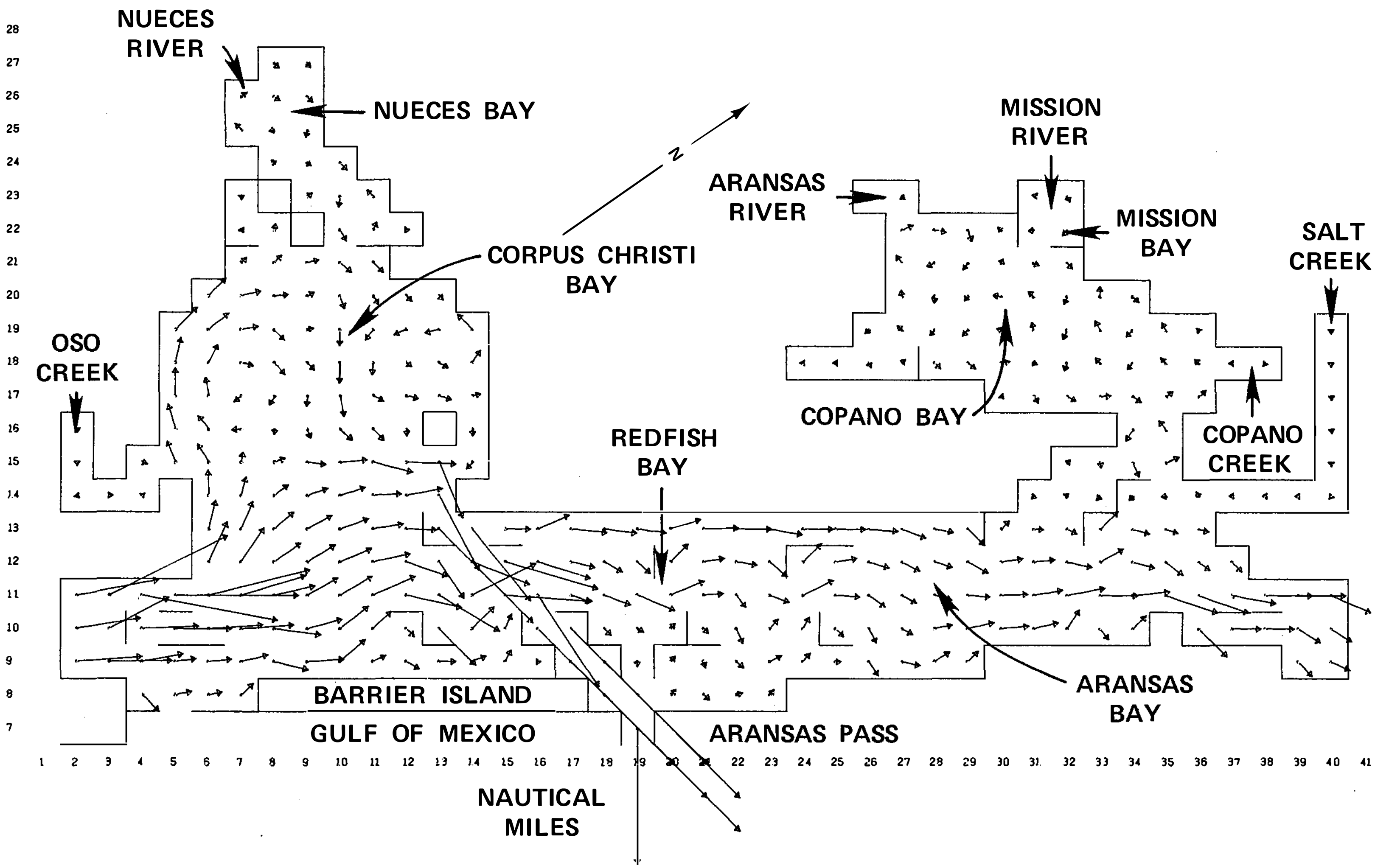


Figure 25.—Simulated Net Steady-State Flows in the Nueces and Mission-Aransas Estuaries Under July Average Inflows (1941-1976)

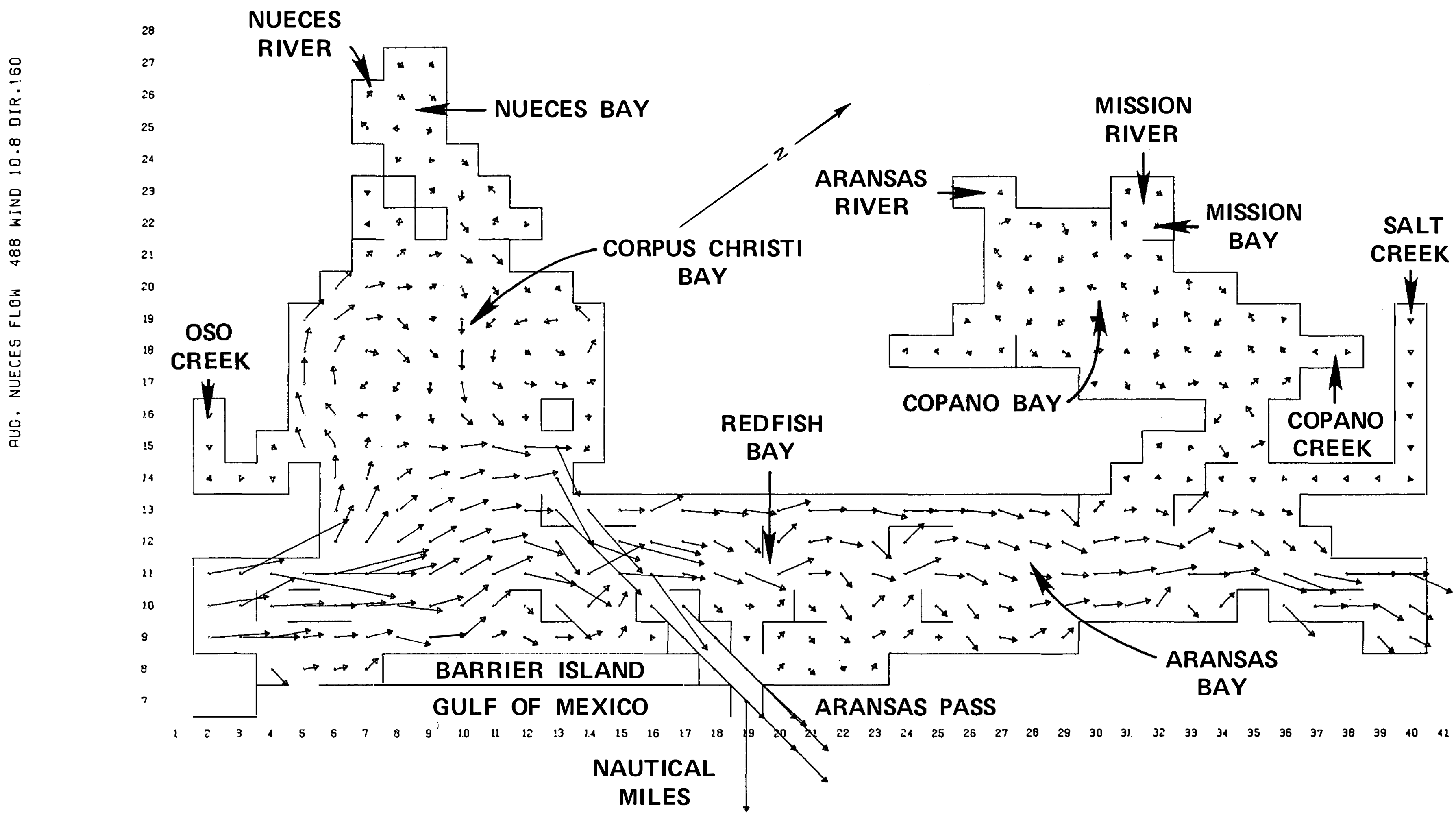


Figure 26.—Simulated Net Steady-State Flows in the Nueces and Mission-Aransas Estuaries Under August Average Inflows (1941-1976)

SEP. NUECES FLOW 2419 WIND 10.2 DIR.135

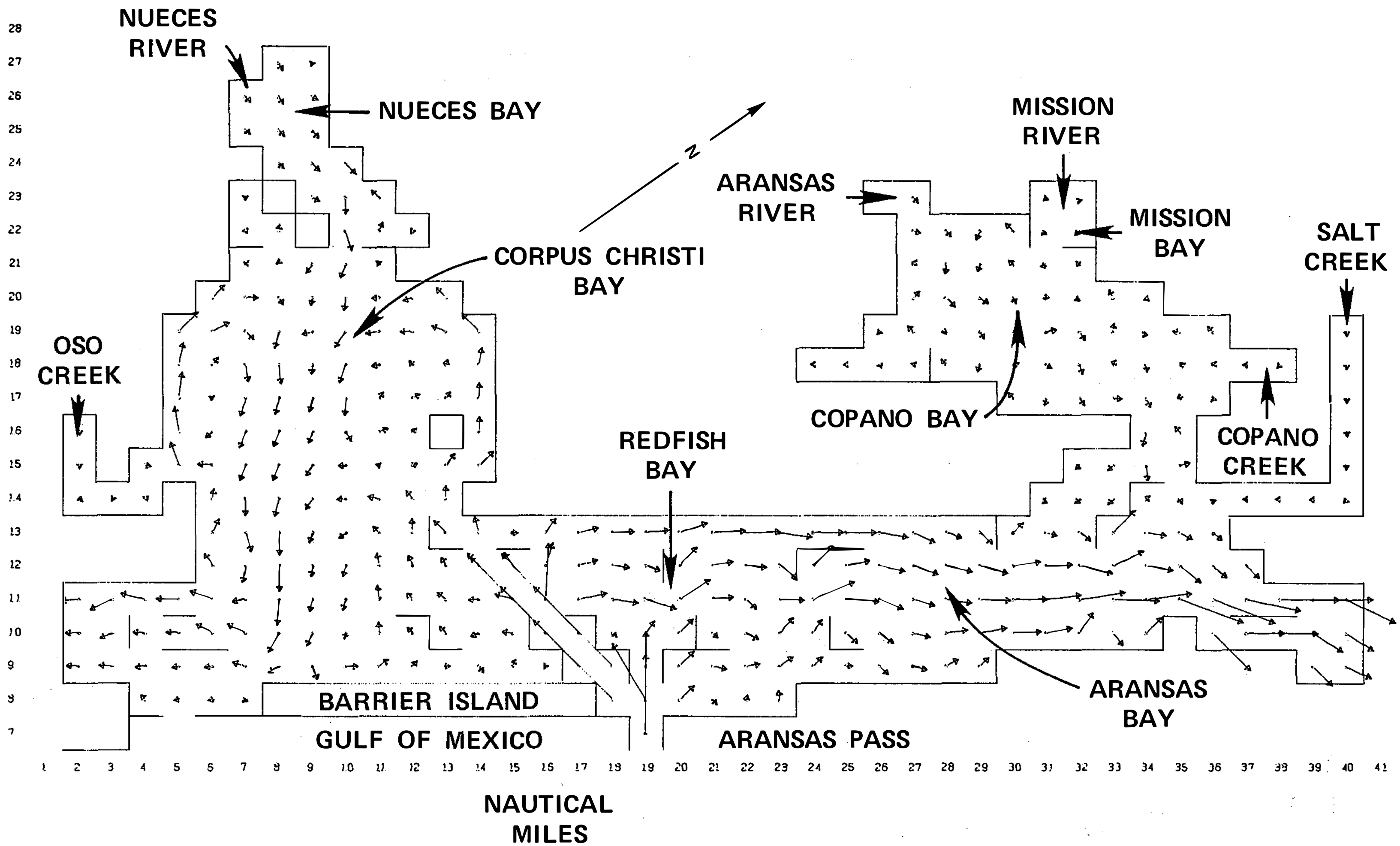


Figure 27.—Simulated Net Steady-State Flows in the Nueces and Mission-Aransas Estuaries Under September Average Inflows (1941-1976)

OCT. NUECES FLOW 1853 WIND 10.1 DIR.135

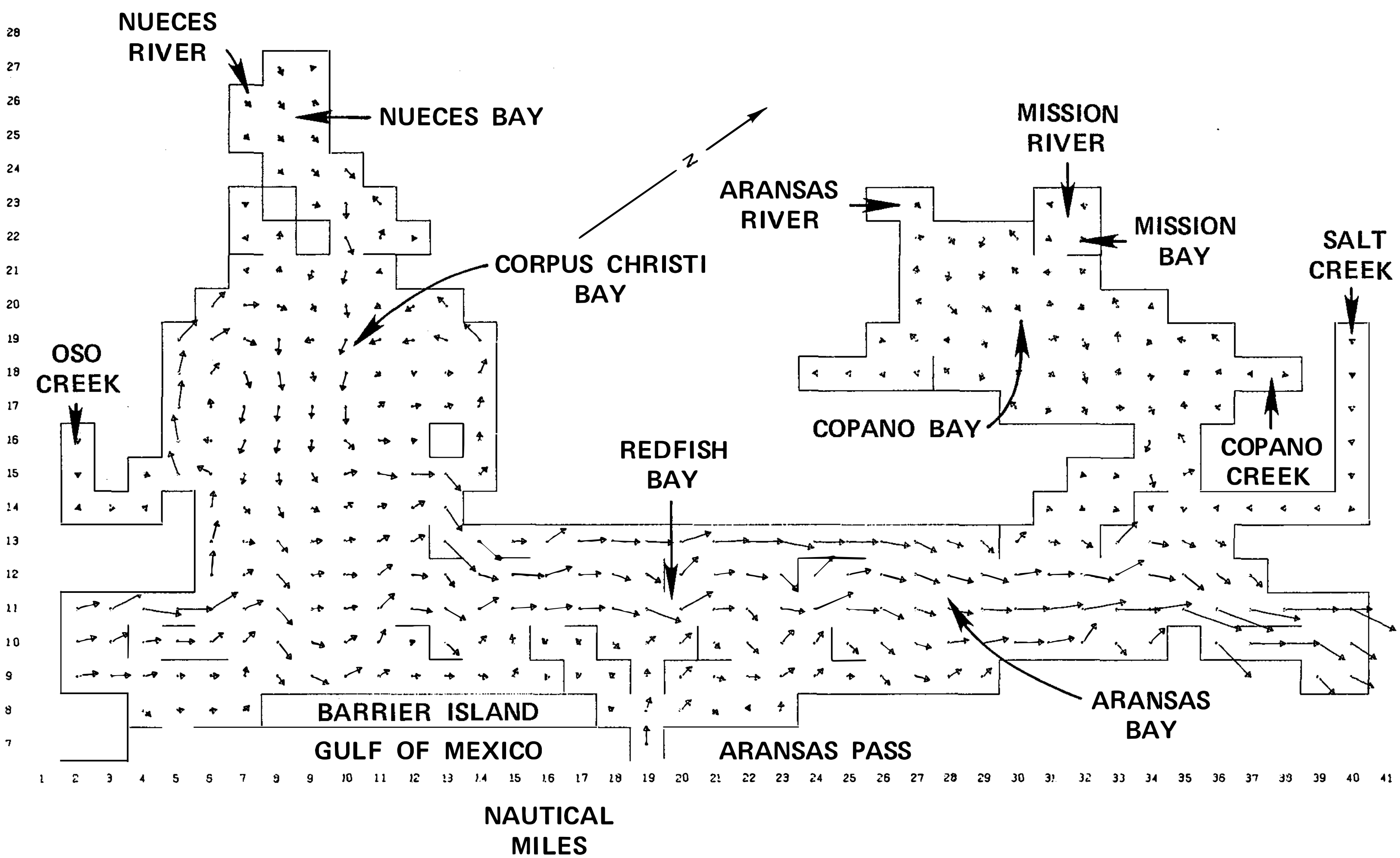


Figure 28.—Simulated Net Steady-State Flows in the Nueces and Mission-Aransas Estuaries Under October Average Inflows (1941-1976)

NØV. NUECES FLØW 454 WIND 11.3 DIR.160

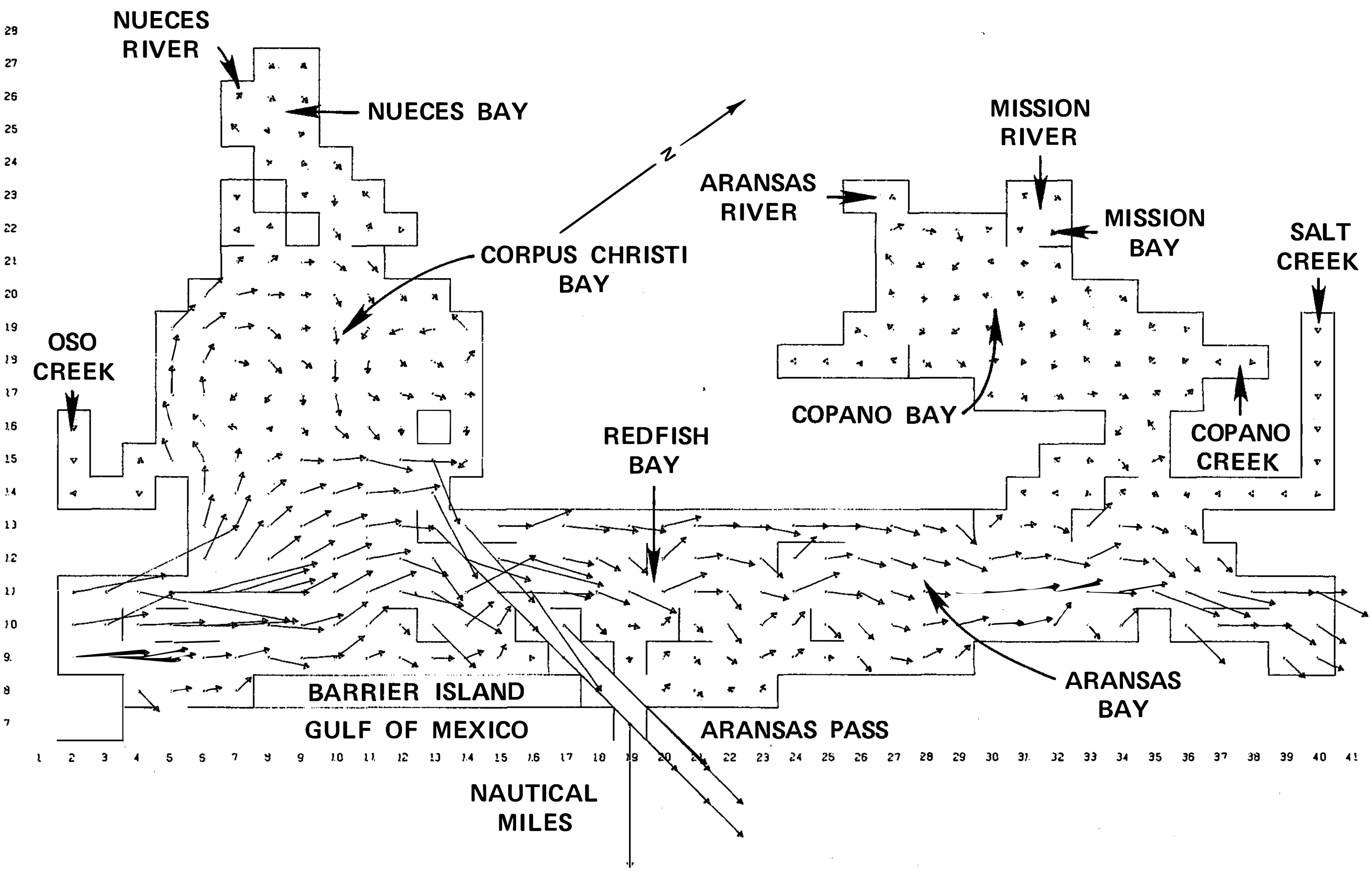


Figure 29.—Simulated Net Steady-State Flows in the Nueces and Mission-Aransas Estuaries Under November Average Inflows (1941-1976)

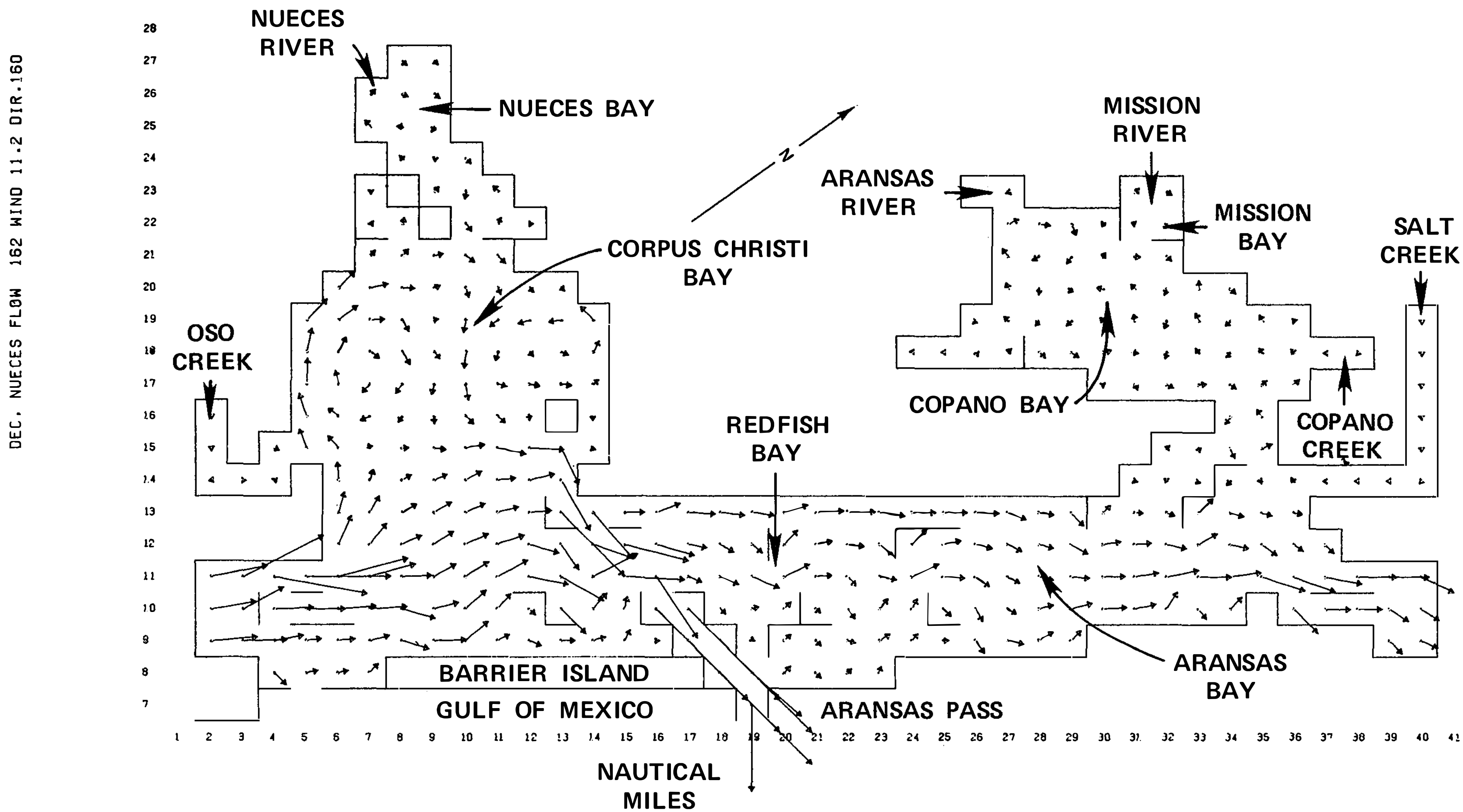


Figure 30.—Simulated Net Steady-State Flows in the Nueces and Mission-Aransas Estuaries Under December Average Inflows (1941-1976)

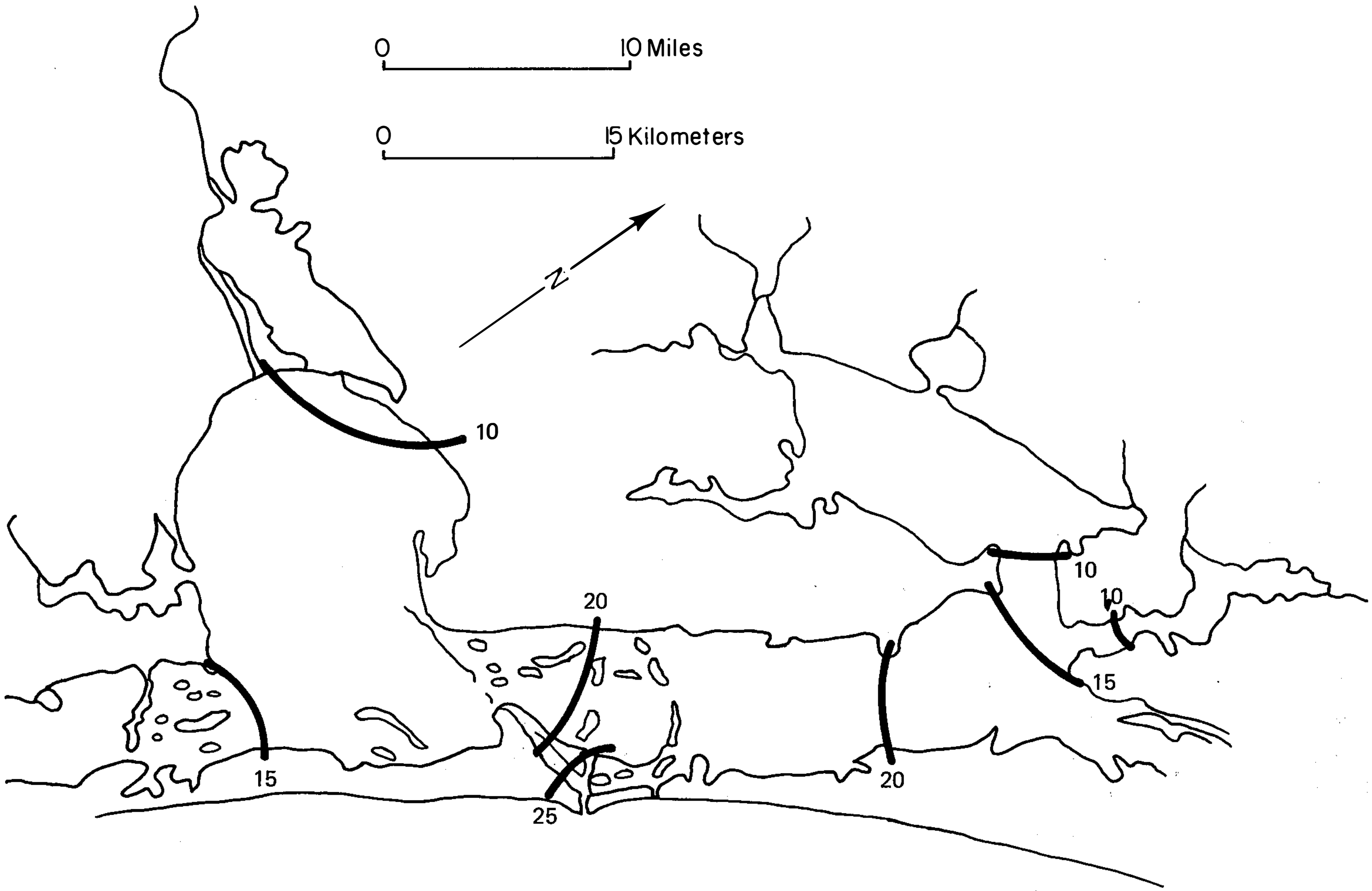


Figure 31.—Simulated Salinities in the Nueces and Mission-Aransas Estuaries Under September and October Average Inflows (1941-1976)

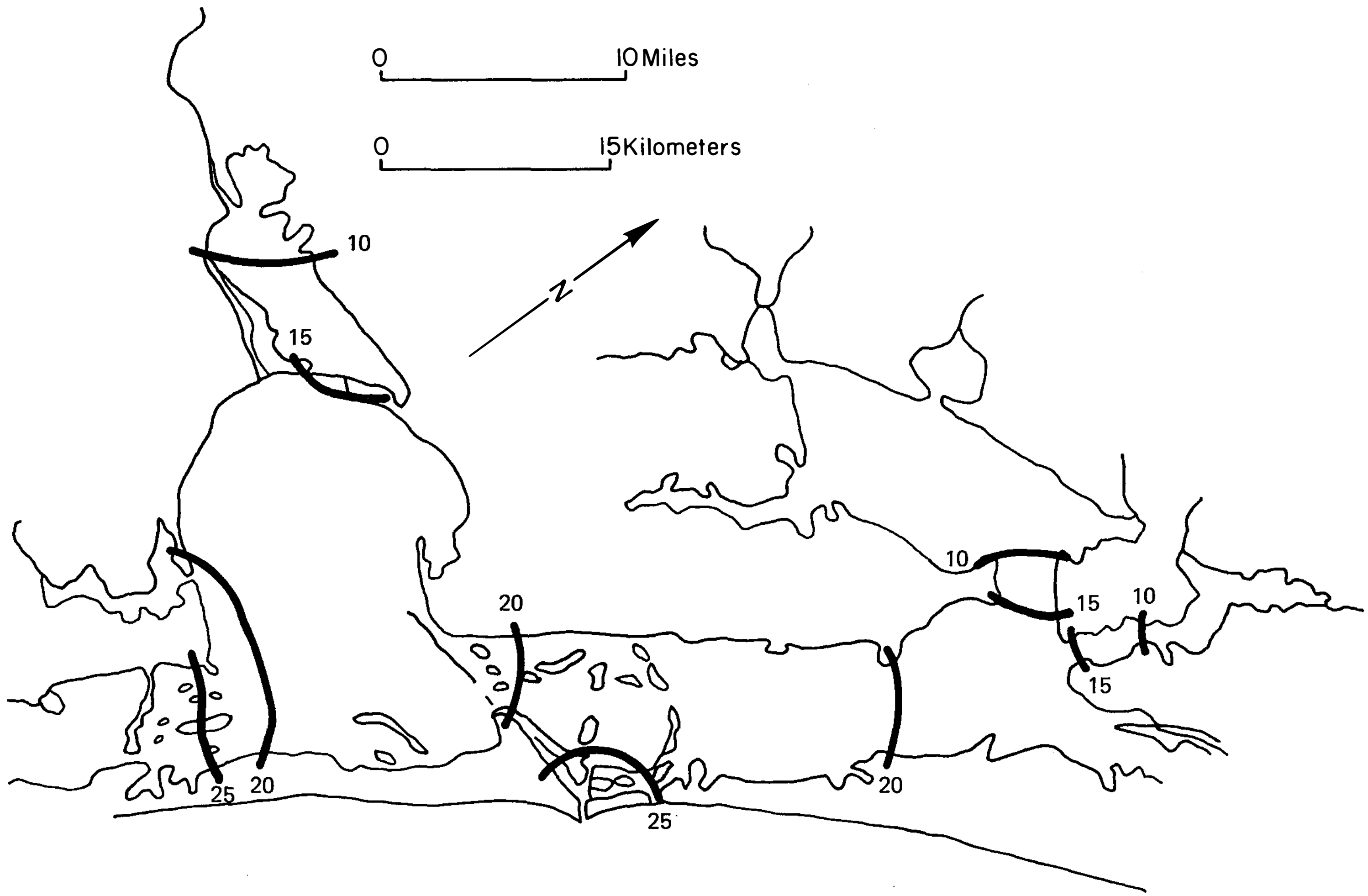


Figure 32.—Simulated Salinities in the Nueces and Mission-Aransas Estuaries Under Average Inflow Conditions for All Months Except September and October (1941-1976)

ranged from a low of 15 to 20 ppt, increasing to a high of 25 ppt in the area adjacent to Laguna Madre. The simulated salinities increased slightly, to approximately 20 ppt, in the area; otherwise, the remainder of the system showed little variation in simulated salinity patterns from the September through October case.

Observed Salinity Patterns

An examination of measured salinities data for 1968 through 1977 reveals two distinct salinity distribution patterns (Figures 33 and 34). During normal and low-flow periods the salinities in Nueces Bay generally ranged from 20 to 25 ppt. Throughout Corpus Christi Bay the salinities were a consistent 25 to 30 ppt. The salinities ranged from 25 ppt in the area of Redfish Bay adjacent to Corpus Christi Bay, to approximately 15 ppt in the area of Aransas Bay adjacent to Copano Bay. The salinities in Copano, Mission, and Saint Charles Bays were generally 10 ppt or less.

During and immediately subsequent to high inflow periods the observed salinities in Nueces Bay ranged from less than 1 ppt up to 10 ppt. The salinities in Corpus Christi Bay generally ranged from 10 to just over 15 ppt, increasing to 20 ppt in the vicinity of Laguna Madre and Aransas Pass. The salinities in Redfish and Aransas Bays were generally around 15 ppt, increasing to slightly over 20 ppt in the vicinity of Aransas Pass and decreasing to between 10 and 15 ppt in the area adjacent to Copano Bay. Copano, Saint Charles, and Mission Bays had observed salinities ranging from less than 1 ppt to slightly less than 10 ppt.

NUTRIENT PROCESSES

Summary

Nutrient contributions to the Nueces and Mission-Aransas estuaries are derived primarily from (1) river inflow; (2) local runoff; and (3) biogeochemical cycling in deltaic and peripheral salt or brackish water marshes. In addition, nutrients may be contributed by point source dischargers. The adjacent Gulf of Mexico is nutrient poor; resulting concentration gradients are such that a net transport of nutrients out of the bay/estuary system toward the Gulf normally occurs. Numerous complicating factors such as the magnitude of freshwater inflows, winds, currents, and biological activity all contribute to the complexity of processes that may be occurring at any given time.

Freshwater inflow is a major source of nutrients into the Nueces and Mission-Aransas estuaries. The major contributory channels are Copano Creek, Chiltipin Creek, the Mission River and the Aransas River which empty into the Copano Bay extension of the Mission-Aransas estuary. The major sources of freshwater inflow and the associated nutrient load to the Nueces estuary are the Nueces River and Oso Creek. Contributions of nutrients from the Aransas River may be intermitted as an earthen dam about one mile upstream from the confluence with Copano Bay probably prohibits inflows to the bay during low-flow periods.

U.S. Geological Survey discharge and water quality data over the period of record (1970-1977) were used to calculate the potential nutrient loading contribution from Copano Creek, Mission River, and Chiltipin Creek. The U.S. Geological Survey has not collected water quality data for the lower reaches of the Arnasas River; however, some data from the Texas Department of Water Resources statewide water quality monitoring network (1967-1977) are available. U.S. Geological Survey data are available for Oso Creek (1972-1977), while Texas Department of Water Resources monitoring network data are available for the lower Nueces River above Calallen Dam (1972-1977).

The results of analyses of nutrient loadings from each freshwater inflow source should be interpreted as estimates based on limited data. The estimated loadings reflect the order of magnitude and range that might be expected during periods of similar climatic and river inflow conditions.

Field studies were conducted (6, 24) in the Nueces River delta in order to gain insight into nutrient contributions from this brackish intertidal marsh to the Nueces estuary. These studies involved seasonal intensive field sampling efforts over a one or two day period. As is the case with riverine water quality, an analysis of the deltaic marsh contribution is inadequate based upon data collected over one or two years on a seasonal basis. In order to determine the actual value of nutrient loading from the intertidal marsh to the estuarine system more data are needed, particularly for extreme events such as floods, hurricanes, and droughts.

The following sections describe the methodology and results of computations to estimate the nutrient contribution to the Nueces and Mission-Aransas estuaries. In addition, the discussion focuses upon the role that deltaic marshes play in biological productivity, by trapping, storing, and converting inorganic nutrients to plant biomass, and the subsequent transport of biomass to the estuarine system.

Nutrient Loading

Contributions from Freshwater Inflow Sources

The mean annual total discharge measured at the closest non-tidally influenced gage for the six major freshwater inflow sources to the Nueces and

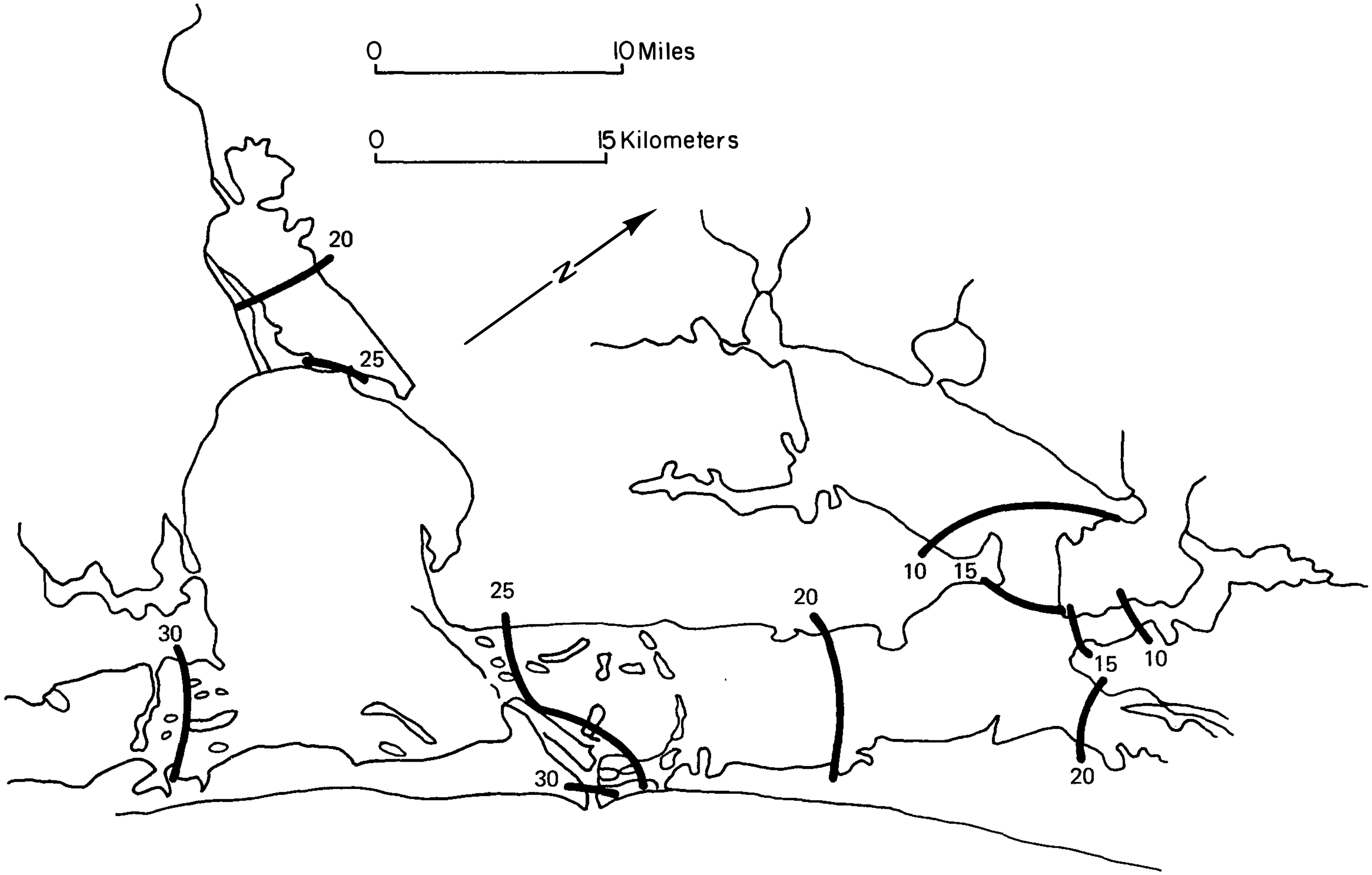


Figure 33.—Observed Salinities in the Nueces and Mission-Aransas Estuaries During Normal to Low Flow Periods (1968-1977)

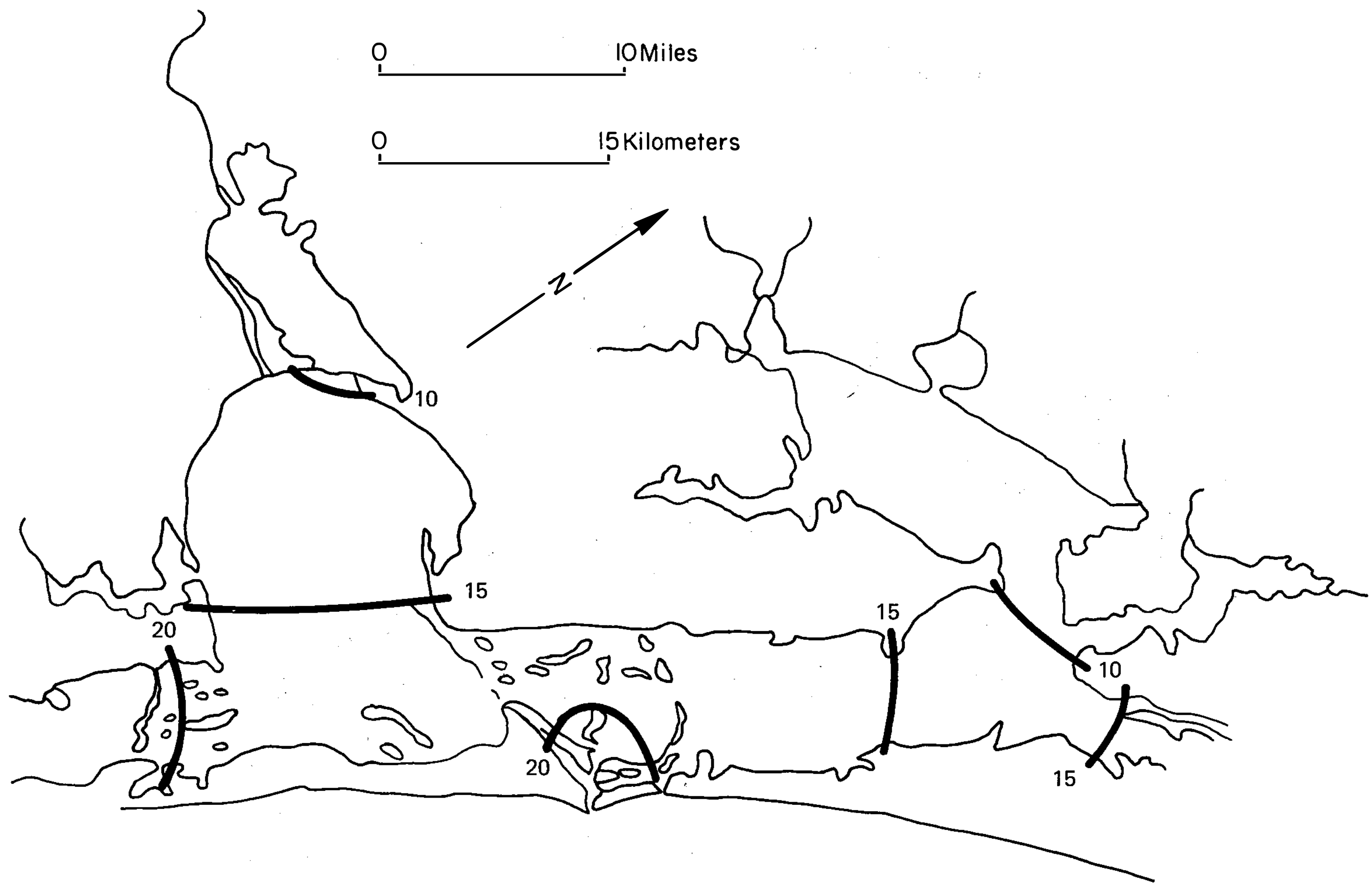


Figure 34.--Observed Salinities in the Nueces and Mission-Aransas Estuaries During High Flow Periods (1968-1977)

Mission-Aransas estuaries is about 800,000 acre-feet (986 million m^3). Seventy-three percent of this inflow (586,000 acre-feet or 723 million m^3) is contributed by the Nueces River. Contributions from the remaining sources are as follows: Oso Creek, 3.1 percent (25,000 acre-feet or 31 million m^3); Chiltipin Creek, 4.7 percent (37,900 acre-feet or 47 million m^3); Aransas River, 4.4 percent (35,400 acre-feet or 44 million m^3); Mission River, 10 percent (80,600 acre-feet or 99 million m^3); and Copano Creek, 4.4 percent (35,200 acre-feet or 43 million m^3).

Water quality data collected by the U.S. Geological Survey indicated organic nitrogen concentrations in Copano Creek near Refugio, Texas to range from 0.06 mg/l to 5.7 mg/l. Organic nitrogen concentrations from other sources were recorded as follows: Mission River (0.0 - 2.0 mg/l), Chiltipin Creek (0.0 - 9.0 mg/l), and Oso Creek (0.0 - 3.1 mg/l). Monthly water quality analyses performed during a 1975 through 1976 study (6) indicated in organic nitrogen concentrations in the Nueces River ranging from 0.2 to 1.3 mg/l. The range of potential inorganic nitrogen loadings (kg/day) resulting from sources influent to the estuaries is given in Table 3. No USGS organic nitrogen data were available for either the Nueces or Aransas Rivers.

Texas statewide monitoring network data indicated that inorganic nitrogen concentrations ranged from 0.06 mg/l to 0.92 mg/l in the Nueces River and from 0.4 mg/l to 2.65 mg/l in the Aransas River. A look at other sources revealed inorganic nitrogen concentrations of 0.01 - 0.92 mg/l in Copano Creek, 0.0 - 5.72 mg/l in the Mission River, 0.0 - 5.5 mg/l in Chiltipin Creek, and 0.18 - 16.77 mg/l in Oso Creek. The range of potential organic nitrogen loadings (kg/day) from sources influent to the estuaries is given in Table 4. Inorganic nitrogen concentrations reported by Wiersema et al. (6) in the lower Nueces River ranged from less than 0.14 mg/l to 0.22 mg/l.

Total phosphorus concentrations reported by the U.S. Geological Survey were similar in almost all of the contributory streams (generally 0.01 - 0.6 mg/l). Oso Creek is an exception, with total phosphorus concentrations generally two to ten times higher than those recorded elsewhere. Concentrations in the Aransas River are consistently higher than in the majority of contributing streams during the spring season. The range of potential total phosphorus loadings (kg/day) from sources influent to the estuaries is given in Table 5.

Total organic carbon (TOC) concentrations reported in the Texas water quality monitoring network and by Wiersema (6) for the Nueces River were generally less than 10 mg/l. In each of the other contributory streams TOC concentrations were significantly higher. The upper limit of TOC extremes ranged from about 30-50 mg/l, with the exception of one value (80 mg/l) reported from the Aransas River. The range of potential total organic carbon loadings (kg/day) from sources influent to the estuaries is given in Table 6.

Seasonal Patterns of Nutrient Loading

Monthly mean organic nitrogen concentrations exhibited no definite seasonal patterns (Figure 35). In general, concentrations in the Mission River were roughly half of those of other streams. Monthly mean inorganic nitrogen concentrations recorded from Oso and Chiltipin Creeks were, as a rule, greater than those concentrations in the remaining streams (Figure 36). Concentrations in Oso Creek were particularly high. Oso Creek is the only stream that exhibited a definite seasonal pattern for monthly mean inorganic nitrogen concentrations, ranging from a low point in late summer to highest values occurring in the period December through February.

Total phosphorus concentrations exhibited patterns similar to those of inorganic nitrogen (Figure 37). With the exception of consistently high values (2 to 10 times greater) for Oso Creek and consistently low values for the Mission River, there appeared to be no readily observable differences in phosphorus concentrations among contributory streams. Mean total phosphorus concentrations do appear to follow a seasonal trend in Oso Creek similar to that shown by inorganic nitrogen. Mean monthly total organic carbon concentrations appear to be highest in Copano Creek and lowest in the Mission River (Figure 38). The lack of sufficient data for the Aransas and Nueces Rivers precluded an evaluation of seasonal TOC concentration trends in those streams.

The range of potential nutrient loadings to the Nueces and Mission-Aransas estuaries (from the six major contributing streams) was calculated using the maximum and minimum concentrations observed for each nutrient species (in each of the twelve months, for the entire period of record) and the mean monthly discharge measured at the first non-tidally influenced gaging station. Potential Aransas and Nueces River nutrient loadings have been calculated by a slightly altered procedure. Since few data points existed for individual months, observed maximum and minimum concentrations over the period of record for each species have been used rather than monthly maximum/minimum as was done for the other four streams. The results are presented in Tables 3 through 6.

Even though concentrations of various nutrient species may be higher in the other streams, the total nutrient contribution from the Nueces River dominated those from other major freshwater inflow sources. This demonstrates the importance of freshwater inflow as the dominant factor in determining nutrient loading. In comparison with the other sources, contributions from Oso Creek are

Table 3.—Range of Potential Inorganic Nitrogen Loadings from Sources Influent to the Nueces and Mission-Aransas Estuaries (kg/day)

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mission R.	High	27	137	118	79	224	34	39	27	2,662	*	27	538
	Low	13	135	8	3	62	30	6	0	224	*	8	48
Copano Cr.	High	4	7	1	74	68	65	38	6	120	119	10	3
	Low	1	0	0	14	24	12	5	3	50	3	2	1
Oso Cr.	High	92	66	330	68	109	1,155	472	43	1,957	1,199	152	90
	Low	11	15	52	6	33	152	70	10	41	98	18	15
Chiltipin Cr.	High	13	17	12	35	32	854	815	109	330	155	79	13
	Low	0	0	0	0	10	10	4	1	49	13	2	0
Aransas R.	High	97	58	17	42	260	193	53	33	1,188	148	11	15
	Low	3	2	1	1	7	6	2	1	34	4	0	0
Nueces R.	High	899	809	807	690	2,978	2,531	1,388	1,346	4,605	4,364	1,028	390
	Low	127	114	114	98	421	358	196	190	651	617	145	55

*No available data

Table 4.—Range of Potential Organic Nitrogen Loadings from Sources Influent to the Nueces and Mission-Aransas Estuaries (kg/day)

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mission R.	High	78	*	41	*	668	*	158	*	1,704	*	141	*
	Low	2	*	2	*	0	*	4	*	96	*	3	*
Copano Cr.	High	28	15	6	458	419	513	160	21	359	670	32	15
	Low	6	5	2	96	130	67	64	12	30	98	11	5
Oso Cr.	High	13	6	81	14	131	432	277	31	389	388	27	5
	Low	5	0	32	8	64	0	2	0	213	91	0	5
Chiltipin Cr.	High	24	14	5	13	208	595	528	116	1,221	362	22	11
	Low	0	1	0	2	70	124	0	0	226	111	0	0

*No available data

Table 5.—Range of Potential Total Phosphorus Loadings from Sources Influent to the Nueces and Mission-Aransas Estuaries (kg/day)

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mission R.	High	4	28	3	14	38	34	10	17	96	20	8	198
	Low	2	7	1	6	5	13	1	3	43	10	0	12
Copano Cr.	High	2	2	1	39	46	42	26	5	85	49	4	2
	Low	1	1	0	20	7	18	7	3	30	18	3	1
Oso Cr.	High	29	28	218	36	50	452	918	65	1,006	891	68	44
	Low	17	6	37	3	50	226	117	18	155	139	8	29
Chiltipin Cr.	High	1	2	1	4	106	336	176	35	366	220	17	1
	Low	0	0	0	0	56	18	7	2	92	49	2	0
Aransas R.	High	38	189	53	135	842	627	170	108	3,853	481	37	48
	Low	1	2	1	2	10	8	2	1	48	6	1	1
Nueces R.	High	899	809	807	690	2,978	2,531	1,385	1,346	4,605	4,364	1,028	390
	Low	127	114	114	98	421	358	196	190	651	617	145	55

Table 6.—Range of Potential Total Organic Carbon Loadings from Sources Influent to the Nueces and Mission-Aransas Estuaries (kg/day)

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mission R.	High	1,345	*	933	*	7,155	*	1,720	*	31,943	*	1,969	*
	Low	0	*	192	*	2,337	*	287	*	0	*	295	*
Copano Cr.	High	348	250	92	3,938	8,609	7,504	3,599	*	*	7,217	866	265
	Low	261	108	43	1,607	6,181	2,765	1,599	*	*	2,113	478	207
Oso Cr.	High	115	102	839	93	725	10,689	3,628	529	5,468	3,882	550	86
	Low	89	38	262	13	363	1,809	2,988	224	2,286	959	167	75
Chiltipin Cr.	High	51	94	96	153	*	5,951	4,064	2,234	15,264	4,398	563	29
	Low	27	51	65	45	*	3,105	1,478	372	8,548	2,846	241	20
Aransas R.	High	666	3,332	941	2,372	14,837	11,035	2,999	1,901	67,855	8,467	647	843
	Low	50	250	71	178	1,113	828	225	143	5,089	635	49	63
Nueces R.	High	13,686	12,314	12,279	10,496	45,310	38,519	21,129	20,477	70,075	66,405	15,641	5,934
	Low	1,955	1,759	1,754	1,499	6,473	5,503	3,018	2,925	10,011	9,486	2,234	848

*No available data

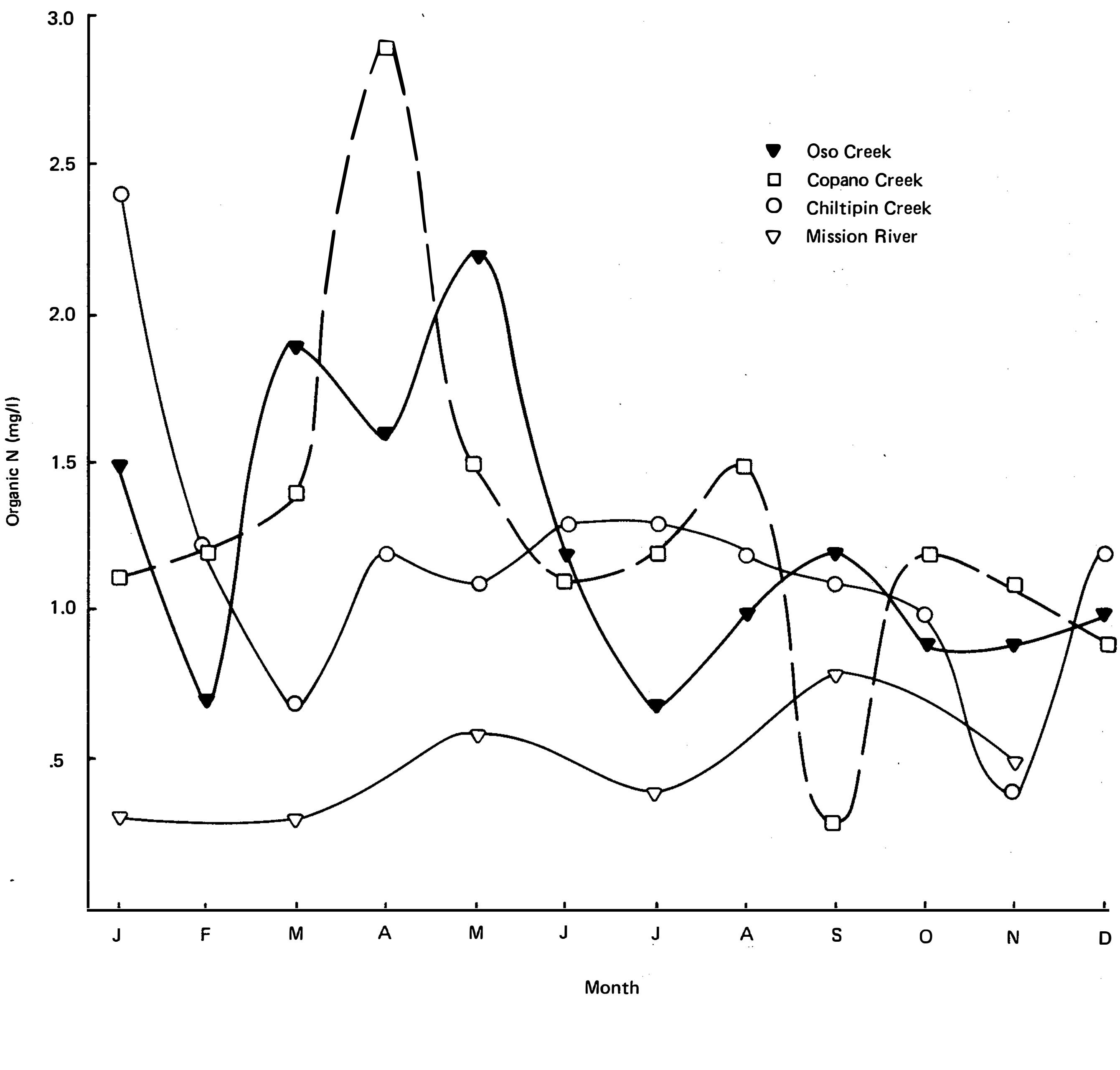


Figure 35.—Mean Monthly Organic Nitrogen Concentrations of Streams Contributory to the Nueces and Mission-Aransas Estuaries

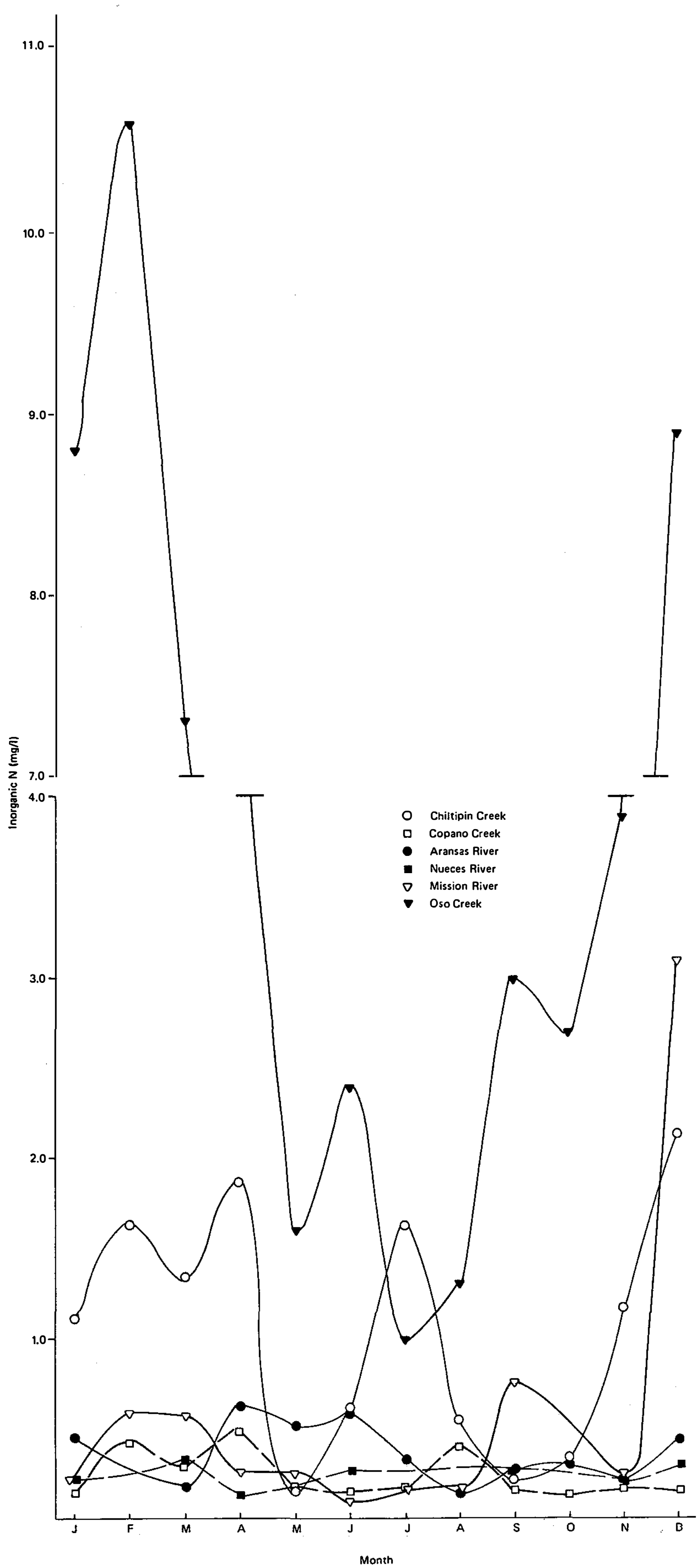


Figure 36.—Mean Monthly Inorganic Nitrogen Concentrations of Streams Contributory to the Nueces and Mission-Aransas Estuaries

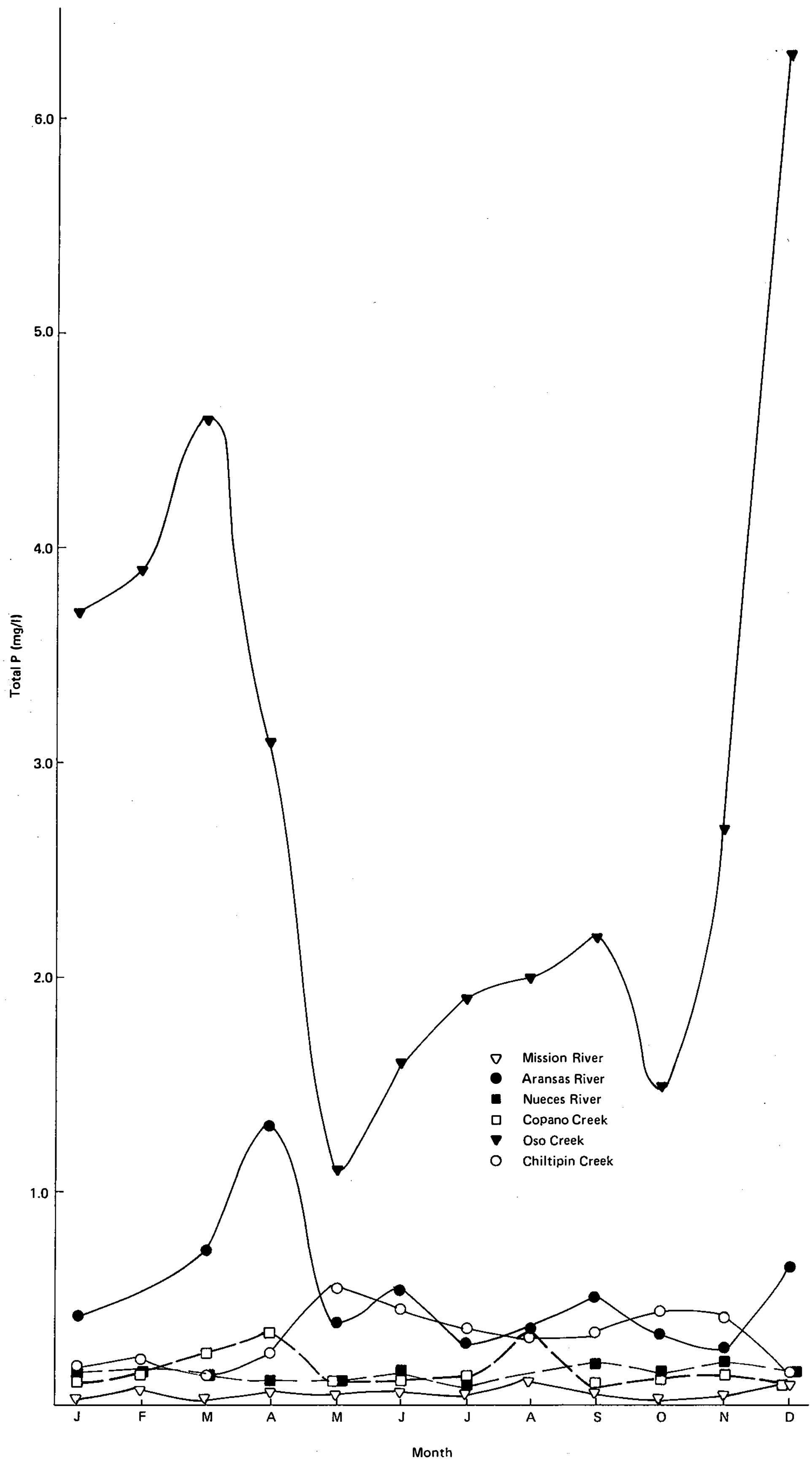


Figure 37.—Mean Monthly Total Phosphorus Concentrations of Streams Contributory to the Nueces and Mission-Aransas Estuaries

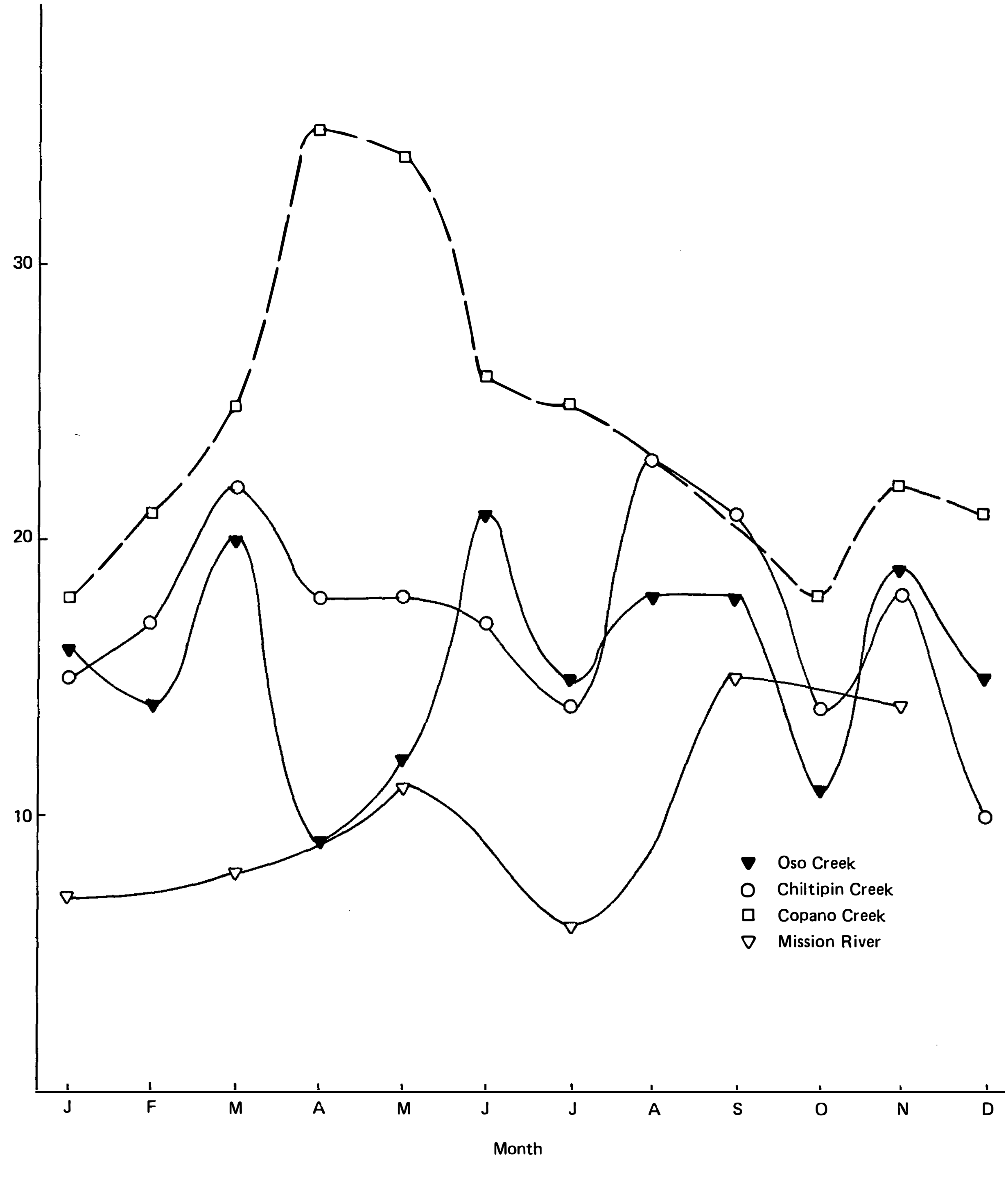


Figure 38.—Mean Monthly Total Organic Carbon Concentrations of Streams Contributory to the Nueces and Mission-Aransas Estuaries

unusually high in proportion to the percent of flow contribution to the estuary, particularly for total phosphorus and inorganic nitrogen. This is due to the unusually high concentration of these species in this watercourse. The cause for these high concentrations is unknown, but they may result from agricultural runoff and/or effluent from the Robstown wastewater treatment plant, a major source of flow in Oso Creek.

Marsh Vegetative Production

An estuarine marsh is a complex physical, hydrological, and biogeochemical system which provides (1) shoreline stabilization, (2) "nursery" habitats for economically important estuarine-dependent fisheries, (3) maintenance of water quality by filtering upland runoff and tidal waters, and (4) detrital materials (small decaying particles of plant tissue) that are a basic energy source of the aquatic food web. The most striking characteristic of a marsh is the large amount of photosynthesis (primary production) that takes place within the system as a result of the plant community, including macrophytes, periphytes, and benthic algae. As a result, the marshes are large-scale contributors to estuarine productivity, providing a tremendous amount of substrate and source of nutrients for the microbial transformation processes at the base of the food web. Deltaic marshes are especially important since they form a vital link between the inflowing river and its associated estuary.

The Nueces and Mission-Aransas estuaries receive major hydrologic input from the Nueces River and the marshes of the Nueces delta. Adams (17) delineated eight hydrological units in the Nueces delta and estimated above ground net primary production of the rooted vascular plants (macrophytes) at 92.4 million dry weight pounds per year (42,000 metric tons/year) over the 13,220 acre (5,350 hectare) study area. Annual net productivity (ANP) average approximately 7,000 dry weight pounds per acre (785 g/m^2) over the entire study area, with maximum ANP in *Spartina spartinae* habitats estimated at 15,100 dry weight pounds per acre (1,690 g/m^2).

In addition, Wiersema et al. (6) estimated net periphyton production to range from a minimum of 1.07 dry weight pounds per acre per day (0.120 $g/m^2/day$) in December to a maximum of 5.12 dry weight pounds per acre per day (0.574 $g/m^2/day$) in April. Assuming that an average 25 percent of the study area was inundated, the periphyton ANP can be estimated at approximately 3.31 million dry weight pounds (1,500 metric tons).

Specific estimates of the above ground net primary production of rooted vascular plants (macrophytes) are not available for the deltaic and intertidal marshes of the Mission-Aransas estuary. However, such values are expected to be intermediate to those of nearby marshes where the macrophyte production values have been measured. In this regard, the Nueces delta marshes to the west have an estimated ANP average of 7,000 dry weight pounds per acre (785 g/m^2), while those of the Guadalupe delta to the east have an estimated ANP average of 10,800 dry weight pounds per acre (1,211 g/m^2). Maximum macrophyte production under favorable conditions may exceed 15,120 dry weight pounds per acre (1,695 g/m^2) in this Texas coastal region.

Although the high productivity of these deltaic marsh habitats makes available tremendous amounts of detritus for potential transport to the estuary, actual detrital transport is dependent on the episodic nature of the marsh inundation and dewatering process. Cooper (3) suggests that the vast majority of the primary production in the higher, irregularly-flooded vegetative zones goes into peat production and is not exported. The lower, frequently-flushed vegetative zone characterized by *Spartina alterniflora* may export about 45 percent of its net production to the estuarine waters (17).

Marsh Nutrient Cycling

Deltaic and other brackish and salt marshes are known to be sites of high biological productivity. Emergent macrophytes and blue-green algal mats serve to trap nutrients and sediment as flow velocities decrease. These nutrients are incorporated into the plant biomass during growth periods and are sloughed off and exported to the bay as detrital material during seasons of plant senescence and/or periods of inundation and increased flows into the open bay. The periphery of the Nueces and Mision-Aransas estuaries is primarily sand, mud flats, and intertidal marsh. One extensive deltaic marsh system exists at the point where the Nueces River enters Nueces Bay. Predominant marsh and wetland macrophyte species reported in the Nueces delta are *Batis maritima, Borrichia frutescnes, Monanthochloe littoralis, Salicornia virginica, Spartina alterniflora,* and *Spartina spartinae* (19, 7).

Studies by Armstrong et al. (31), Dawson and Armstrong (36), Armstrong and Brown (35), and Armstrong and Gordon (33, 34) have been conducted to determine the role of the plants and deltaic sediments in nutrient exchange processes. In most cases these patterns seem to be similar from species to species (33). The rates of nutrient exchange for marsh macrophytic species and associated sediment in the Nueces delta were found to be similar in magnitude to exchange rates in other Texas coastal marsh systems. Seasonal exchange rates measured under controlled laboratory conditions are presented in Figures 39-44. Total organic carbon is released by each of the subject species. Unfiltered total Kjeldahl nitrogen measurements also reflect the occurrence of a release process: ammonia nitrogen is taken up,

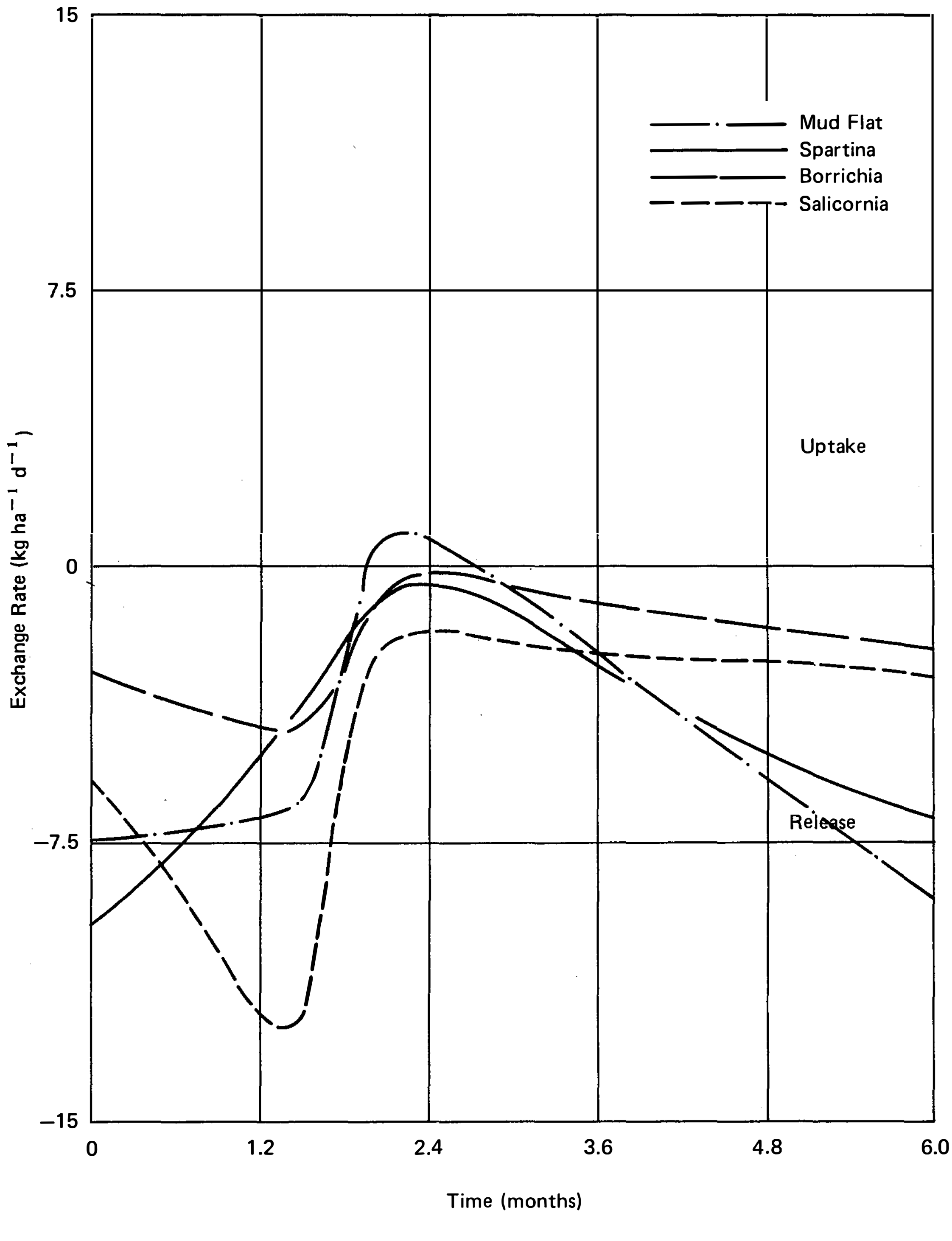


Figure 39.—Exchange Rates for Total Organic Carbon in Nueces River Delta (34)

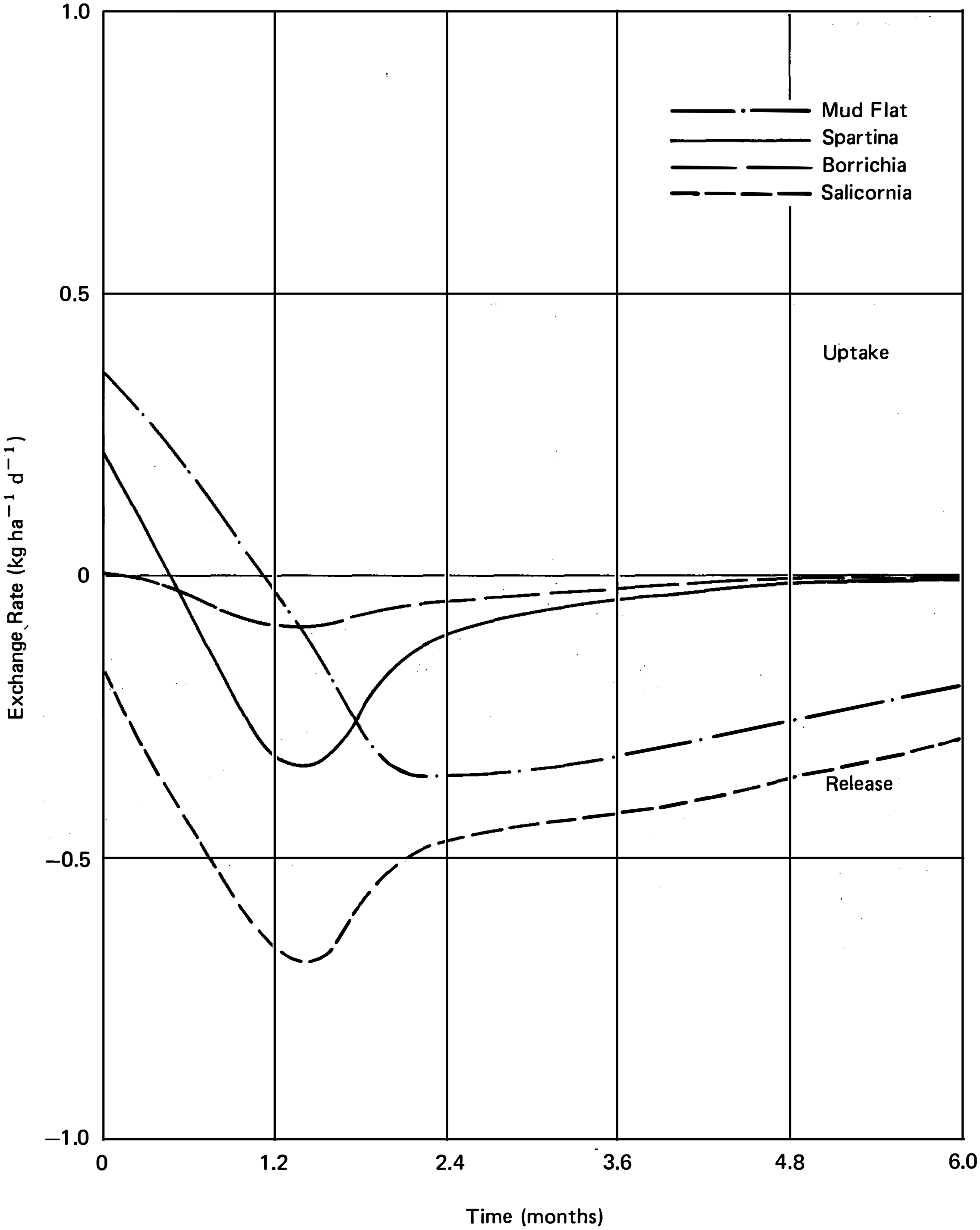


Figure 40.—Exchange Rates for Unfiltered Total Kjeldahl Nitrogen in Nueces River Delta (34)

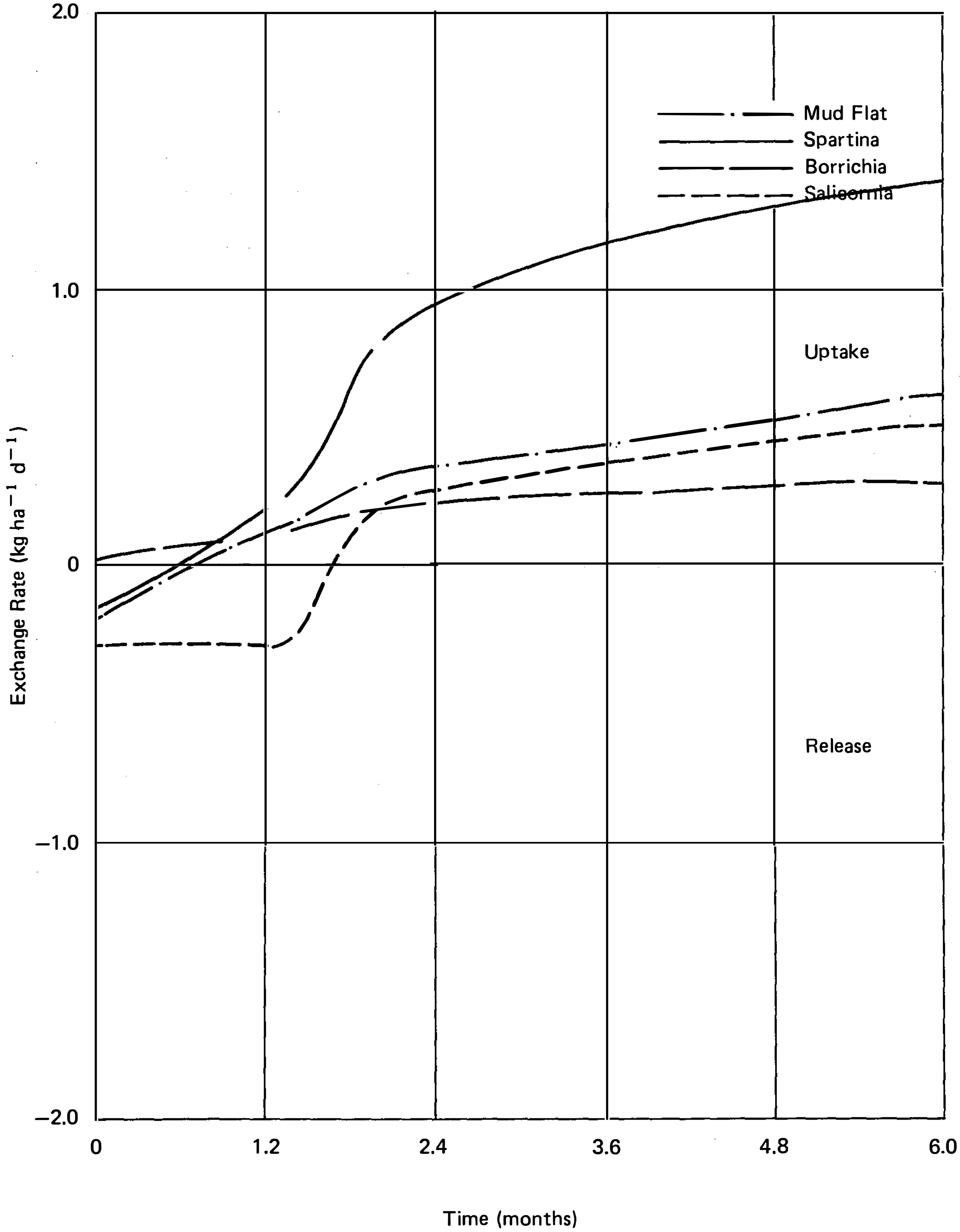


Figure 41.—Exchange Rates for Ammonia Nitrogen in Nueces River Delta (34)

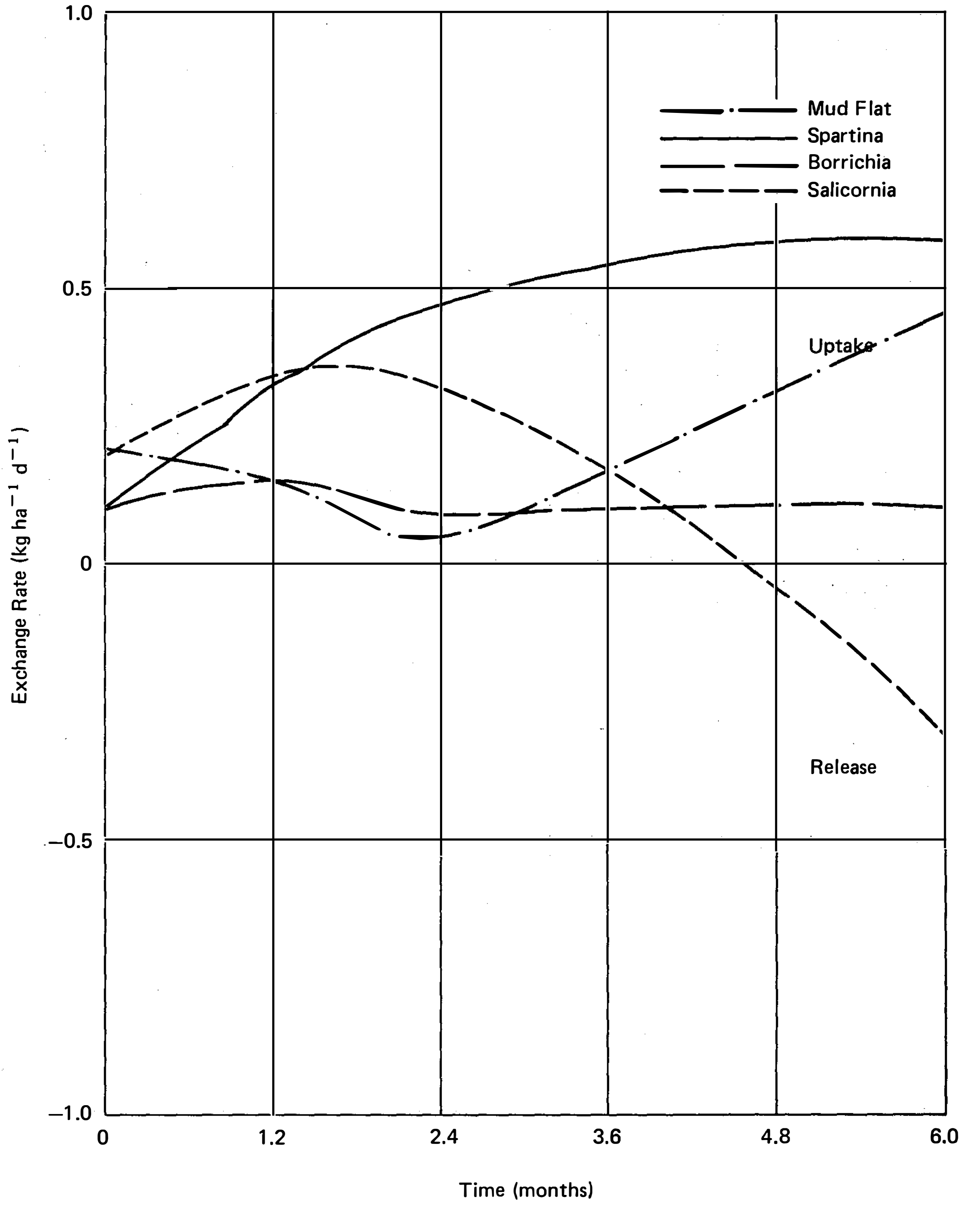


Figure 42.—Exchange Rates for Nitrate Nitrogen in Nueces River Delta (34)

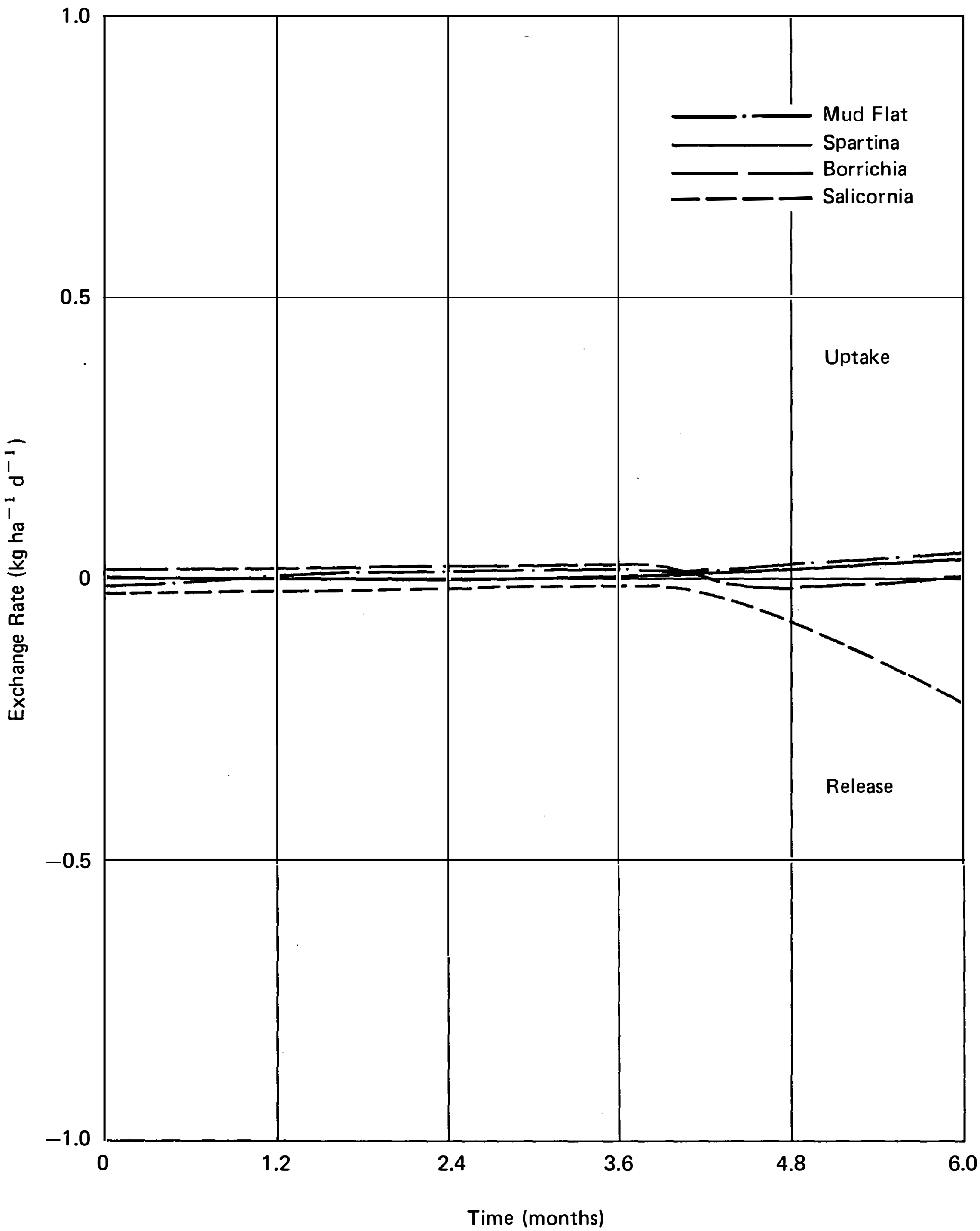


Figure 43.—Exchange Rates for Nitrite Nitrogen in Nueces River Delta (34)

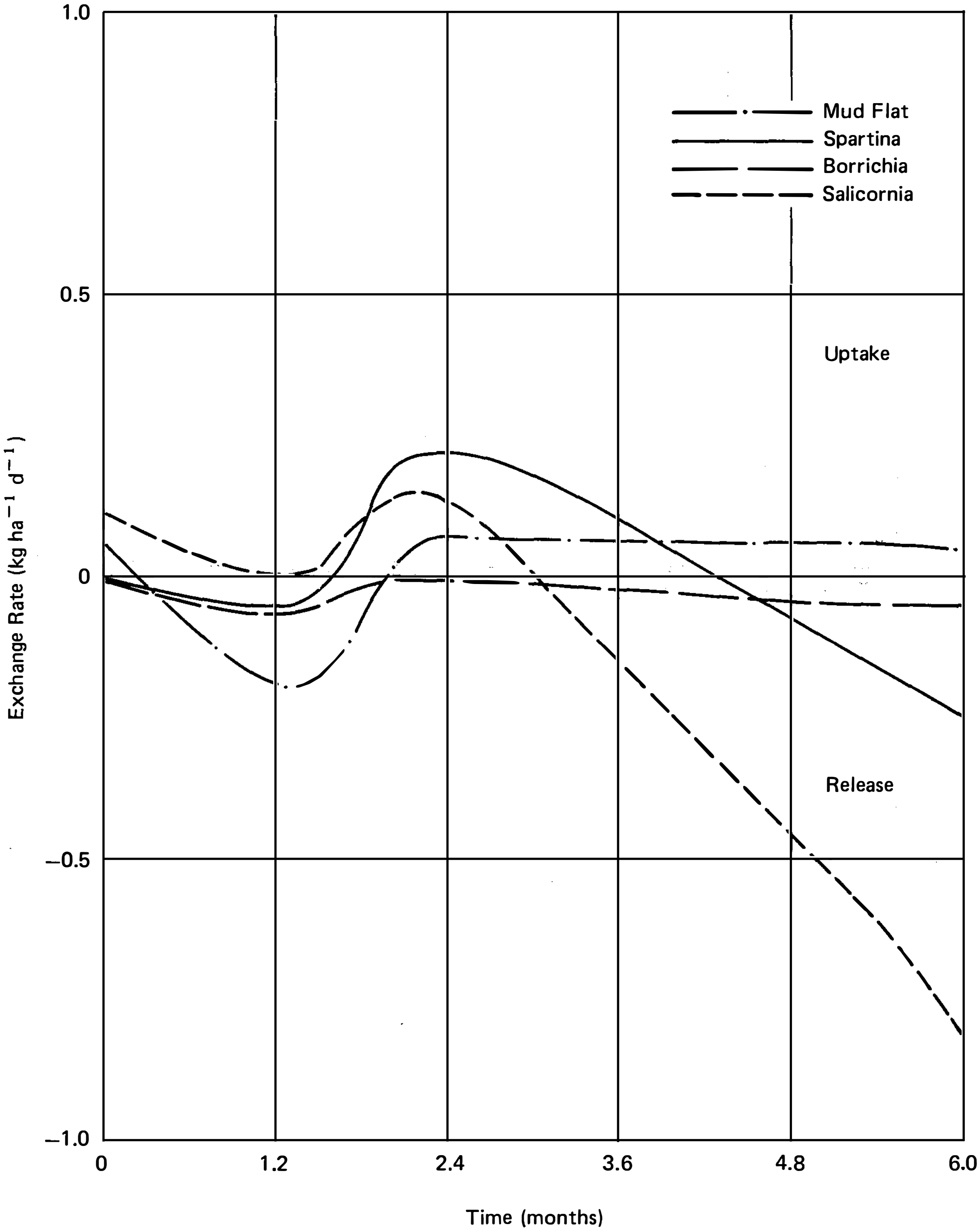


Figure 44.—Exchange Rates for Unfiltered Total Phosphorus in Nueces River Delta (34)

particularly as the growing season progresses. With the exception of the *Salicornia* reactors, the same pattern appears to hold for nitrate nitrogen uptake. The aberrance of this one species may be due to the low volume of the experimental reactor which precluded the growth of algal mats; such mats are apparently responsible for a significant amount of nitrogen uptake. Nitrite nitrogen exchange rates are practically zero; the low concentrations indicate that nitrite is being converted to nitrate almost as quickly as it is formed.

Export of total phosphorus and orthophosphate is indicative that plant growth in the Nueces delta is not phosphorus limited. This coupled with the evidence of inorganic nitrogen uptake would indicate that nitrogen is probably the limiting nutrient in the system. Based on the above data, average seasonal exchange rates have been calculated for six nutrient parameters. These are presented in Table 7.

The areal extent of the Nueces delta composed of algae covered mud flats and emergent marsh vegetation has been determined to be about 4,990 hectares (12,330 acres) (19). Assuming that the exchange rates presented in Table 7 are consistent throughout a finite period of inundation, then the Nueces delta marsh could export as much as 36,900 kg/day total organic carbon, 1,550 kg/day Kjeldahl nitrogen (largely as organic nitrogen), and 1,250 kg/day total phosphorus to the Nueces estuary. This would be in addition to the nutrients delivered to the estuary in the form of large clups (branches, grass stems, etc.) or as particulate detrital materials from senesced or decayed macrophytes that would also be flushed out of the delta during an inundation event.

The 1975 through 1976 study by Wiersema et al. (6) indicated that the deltaic marsh was acting as a nutrient sink. It should be noted that flow regimes were low during the study, so that the delta was never inundated. They also observed that large amounts of plant detritus and animal biomass were produced in the marsh.

The deltaic marshes are important sources of nutrients for the estuarine system. Periodic inundation events are natural and necessary in order for the marshes of the Nueces and Mission-Aransas estuaries to deliver their potential nutrient stores to the open waters of the bays. This will occur as the slug of freshwater moving across the delta sweeps decayed macrophyte and dried algal mat material out of the system. There is evidence (36) that following a period of emersion, a sudden inundation event over the delta marshes will result in a short period of high nutrient release from the established vegetation and sediments. This period may last for one or two days and is followed by a period in which release rates decrease rapidly until they approach the seasonal equilibrium. During periods of high river discharge and/or extremely high tides that immediately follow prolonged dry periods, the contribution of carbon, phosphorus, and nitrogen from the deltaic marshes to the estuarine system can be expected to increase dramatically.

Table 7.—Average Seasonal Exchange Rates for Nutrient Species in the Nueces River Delta (kg ha ^{1} day ^{1}) (34)

Months from beginning of year (Jan. 1)	0	1.3	2.0	6.0
Total Organic Carbon	-6.6	-7.4	-.7	-5.3
Total Kjeldahl Nitrogen	-.06	-.31	-.26	-.18
Ammonia Nitrogen	-.19	.01	.38	.71
Nitrate Nitrogen	.15	.24	.24	-.39
Nitrite Nitrogen	.01	.0	.0	.0
Total Phosphorus	.05	-.06	.09	-.25

- values indicate release
+ values indicate uptake

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BIBLIOGRAPHY

1. California, Univ. Instit. of Marine Resources. "Coastal Zone Bibliography: Citations to Documents on Planning, Resources Management and Impact Assessment," by Jens Sorensen et al. 133 p. in 2 Fiche. 1973. Their TR-43 Sea Grant Publication No. 8. Prepared for Office of Sea Grant [Fiche/COM73/11567]

2. California, Univ. Instit. of Marine Resources. "Coastal Zone Bibliography: Citations to Documents on Planning, Resources Management and Impact Assessment," by Bonnie Jenks et al. 2nd ed., 1976. 161 p. Their IMR 76-8 [33.916/C125I/76-8]

3. Cooper, A. W. "Salt Marshes." In: *Coastal Ecological Systems of the United States,* Volume 2, page 55-98. The Conservation Foundation, Washington, D.C.: 1974.

4. Cruz, A. A., de la. "The Role of Tidal Marshes in the Productivity of Coastal Waters." *Association Southeastern Biology Bulletin,* Vol. 20 pp. 147-156. 1973

5. Environment Monitors. "The Ecological Impact of Mercury Discharge on an Enclosed Secondary Bay," by W. George Blanton et al. 231 p. 1972.

6. Espey, Huston and Associates, Inc. "Marsh Biology and Nutrient Exchange in Three Texas Estuaries," by J. M. Wiersema, P. T. Price, and D. B. Adams. Report to the Texas Department of Water Resources. v.p. 1977.

7. Espey, Huston and Associates, Inc. "Marsh Plant Production and Potential Detritus in Lavaca, San Antonio and Nueces Bays," by D. B. Adams et al. v.p. and 3 maps in pocket. 1977. Their Document No. 7688. Prepared for Texas Water Development Board. [581.526/ES6M]

8. Espey, Huston and Associates, Inc. "Marsh Vegetation of the Colorado River Delta, Texas," by D. B. Adams and C. A. Tingley. Report to the Texas Department of Water Resources. 14 p. 1977.

9. Espey, Huston and Associates, Inc. "A Study of the Placement of Materials Dredged from Texas Ports and Waterways." 1976. 3 Vol. (V. 3-Executive Summary) Prepared for General Land Office of Texas. [627.73/ES6S]

10. Hays, M.O. "Sedimentation on a Semi-arid, Wave-Dominated Coast (South Texas) with Emphasis on Hurricane Effects." Ph.D. Dissertation. University of Texas at Austin. 350 p. Austin, Texas: 1965.

11. Masch, Frank D., and Associates. "Tidal Hydrodynamics and Salinity Models for Coastal Bays, Evaporation Considerations," by R. J. Brandes and F. D. Masch. Report to the Texas Water Development Board. 40 p. Austin, Texas: September 1972.

12. Masch, Frank D. "Tidal Hydrodynamic and Salinity Models for Corpus Christi and Aransas Bays, Texas." 1972. 98 p. A report to Texas Water Development Board. [333.9/M37TI]

13. Nueces County Navigation District No. 1. "Plan of Nueces County Navigation District No. 1 to Develop a Multipurpose Deep Draft Inshore Port in the Vicinity of Harbor Island, Texas." v.p. 1974.

14. Odom, E. P. *Fundamentals of Ecology* (3rd Edition). W. B. Saunders Co., 574 p. Philadelphia: 1971.

15. Price, W. A. "Dynamic Environments: Reconnaissance Mapping, Geologic and Geomorphic of Continental Shelf of Gulf of Mexico." *Gulf Coast Assoc. Geol. Socs. Trans.,* Vol. 4, pp. 75-107. 1954.

16. Shepard, F. P. *Submarine Geology.* Harper and Row. 517 p. New York: 1973.

17. Teal, J. M. "Energy Flow in the Salt Marsh Ecosystems in Georgia." *Ecology.* Vol. 43, pp. 614-624. 1962.

18. Texas A&M University, Environmental Engineering Division, "Field and Analytical Studies of the Corpus Christi Ship Channel and Contiguous Water," by Richard E. Withers et al. 1973. 111 p. Final Report for the Texas Water Quality Board. [628.168/T31F]

19. Texas A&M University, Remote Sensing Center, "Monitoring of Texas Coastal Wetlands," by Arthur R. Benton, Jr. et al. 1977. v.p. Technical Report RSC-88.

20. Texas A&M University, Remote Sensing Center. "Monitoring of Texas Coastal Wetlands with Aerial Photography: Phase I, Feasibility Study," by A. R. Benton, Jr. et al. Technical Report RSC-64. 34 p. and appendices. 1975.

21. Texas A&M University, Sea Grant Program. "A Quantitative Analysis of Shoreline Change, Sargent, Texas," by James E. Sealy. TAMU-SG-75-209. 1975. [333.916/T31C/75-209]

22. Texas Board of Water Engineers. "Inventory and Use of Sedimentation Data in Texas." Bull. 5912. 85 p. Austin, Texas: 1959.

23. Texas Department of Water Resources. "Biogeochemical Cycling of Carbon, Nitrogen and Phosphorus Nutrients in River Delta Marshes of Lavaca Bay, Texas." (LP-39) v.p. 1978. Originally published by the Center for Research in Water Resources as Technical Reports CRWR-121, January 24, 1975; CRWR-129, August 21, 1975; and CRWR-147, December 31, 1976.

24. Texas Department of Water Resources. Unpublished data, 1977.

25. Texas Department of Water Resources. "Mathematical Simulation Capabilities in Water Resources Systems Analysis." (LP-16) 62 p. Austin, Texas: 1978.

26. Texas Parks & Wildlife Department. "Fishery Resources of the Corpus Christi Bay System and Factors Relating to Their Viability; Preliminary Draft." 1975. 38 p. [639.2/T315F]

27. Texas, University at Austin, Bureau of Economic Geology. "Environmental Geologic Atlas of the Texas Coastal Zone," by L. F. Brown, Jr. v.p. 1972-1976.

28. Texas, University at Austin, Bureau of Economic Geology. "Historical Changes and Related Coastal Processes, Gulf and Mainland Shorelines, Matagorda Bay Area, Texas," by J. H. McGowen et al. 72 p. 1975. 2 V. [551.36/T31H]

29. Texas, University at Austin, Bureau of Economic Geology. "Sand Resources of the Texas Gulf Coast," by L. E. Garner. Report of Investigations 60. 85 p. 1967.

30. Texas, University at Austin, Bureau of Economic Geology. "Shoreline Changes of Matagorda Island and San Jose Island (Pass Cavallo to Aransas Pass): An Analysis of Historical Changes of the Texas Gulf Shoreline," by Robert A. Morton et al. Their Geological Circular 76-4. 42 p. 1976. [557.64/T31G/776-4]

31. Texas, University at Austin, Center for Research in Water Resources. "Biogeochemical Cycling of Carbon, Nitrogen, and Phosphorus in Saltwater Marshes in Lavaca Bay, Texas," by Armstrong et al. 1975. v.p. CRWR-121. [333.9/T31CRWR/121]

32. Texas, University at Austin, Center for Research in Water Resources. "Establishment of Operational Guidelines for Texas Coastal Zone Management; Special Report I: Water Quality Modeling and Management Studies for Corpus Christi Bay: A Large Systems Approach," by B. R. Penumalli et al. 1975. 22 p. Their Technical Report CRWR-122. [333.9/T31CRWR/122]

33. Texas, University at Austin, Center for Research in Water Resources. "Exchange Rates for Carbon, Nitrogen, and Phosphorus in Colorado River Delta Marshes," by Neal E. Armstrong and Nadine Gordon. 1977. v.p. CRWR-153 [333.9/TelCRWR/153]

34. Texas, University at Austin, Center for Research in Water Resources. "Exchange Rates for Carbon, Nitrogen, and Phosphorus in Nueces and San Antonio Bay Marshes," by Neal E. Armstrong and Nadine V. Gordon. v.p. and appendix. 1977. Technical Report CRWR-152, EHE 77-05. [333.9/T31CRWR/152]

35. Texas, University at Austin, Center for Research in Water Resources. "Exchange of Carbon, Nitrogen, and Phosphorus in Lavaca Bay, Texas Marshes: Volume I, The Role of Sediments in Nutrient Exchange in the Lavaca Bay Brackish Marsh System," by N. E. Armstrong and B. A. Brown. (Report CRWR-147) v.p. 1976. [333.9/T31CRWR/147]

36. Texas, University at Austin, Center for Research in Water Resources. "Exchange of Carbon, Nitrogen, and Phosphorus in Lavaca Bay, Texas Marshes: Volume II. The Role of Plants in Nutrient Exchange in the Lavaca Bay Brackish Marsh System," by A. J. Dawson and N. E. Armstrong. (CRWR-129) Report to the Texas Water Development Board (IAC-74/74-1217). 115 p. 1975. [333.9/T31CRWR/129]

37. Texas, University Division of Natural Resources and Environment. "Establishment on Operational Guidelines for Texas Coastal Zone Management. Final Report on Estuarine Modeling," by George W. Murfee et al. v.p. 1974. Report to the National Science Foundation and Division of Planning Coordination, Office of the Governor of Texas. [333.917/T31CES/4]

38. Texas, University Division of Natural Resources and Environment. "Establishment of Operational Guidelines for Texas Coastal Zone Management. Final Report on Biological Uses Criteria," by Carl H. Oppenheimer et al. v.p. 1974. Report to the National Science Foundation and the Division of Planning Coordination, Office of the Governor of Texas. [333.917/T31CES/6]

39. Texas, University at Austin, Marine Science Institute at Port Aransas. "Analysis of

Freshwater Inflow Effects on Metabolic Stresses of Fish in Corpus Christi, San Antonio, and Matagorda Bays," by D. E. Wohlschlag (IAC-76/77-0632) 97 p. 1976.

40. Texas, University at Austin, Marine Science Institute at Port Aransas. "Analysis of Freshwater Inflow Effects on Metabolic Stresses of South Texas Bay and Estuarine Fishes: Continuation and Extension," by D. E. Wohlschlag (IAC-76/77-1690) 114 p. 1977.

41. Texas, University at Austin, Marine Science Institute. "A Benthos and Plankton Study of the Corpus Christi, Copano and Aransas Bay Systems; Annual Report to the Texas Water Development Board," by J. S. Holland et al. 1973. v.p. [574.92/T31B]

42. Texas, University at Austin, Marine Science Institute at Port Aransas. "Environmental Effects of Metabolic Scope and Swimming Performance of Some Estuarine Fishes," by J. M. Wakeman. 147 p. 1978.

43. Texas, University at Austin, Marine Science Institute at Port Aransas. "Nearshore Surface Currents, Southeastern Texas Gulf Coast," by R. L. Watson et al. *Contributions in Marine Science,* Vol. 15, pp. 133-143. 1970.

44. Texas, University at Austin, Marine Science Institute. "A Pilot Study to Analyze Effects of Freshwater Inflows and Metabolic Stresses for Important Fish Species in Corpus Christi Bay, Texas," by D. E. Wohlschlag. 1975. 49 p. [574.526/T31P]

45. Texas, University at Austin, Marine Science Institute at Port Aransas. "Salinity Stress and Swimming Performance of Spotted Seatrout," by John M. Wakeman and Donald E. Wohlschlag. 15 p. 1977.

46. Texas, University at Austin. "Marsh Production: A Summary of the Literature," by C. S. Keefe. *Contributions in Marine Science,* Vol. 16, pp. 163-181. 1972.

47. Texas, University at Houston Sc. of Public Health. "An Investigation of Tertiary Estuary Productivity and Nutrient Optimization in Texas Coastal Waters. Report to Texas Water Development Board," by Ernst M. Davis, 355 p. Houston, Texas: 1973. [574.526/T314I]

48. Texas Water Development Board. "Coastal Data System User Documentation; Vol. I, Storage Reference Manual; Vol. II, Retrieval Reference Manual." 1973 (revised 1977).

49. Texas Water Development Board. "Continuing Water Resources Planning and Development for Texas." 2 Vol. v.p. Austin, Texas: 1977.

50. Texas Department of Water Resources. "Mathematical Simulation Capabilities in Water Resources Systems Analysis." (LP-16) 62 p. Austin, Texas: 1978.

51. Texas Water Development Board. "Pilot Field and Analytical Studies of the Corpus Christi Ship Channel and Contiguous Waters," by Roy W. Hann et al. 106 p. 1972.

52. Texas Water Quality Board. "Texas Water Quality Standards." 79 p. Austin, Texas: February 1976.

53. Texas Water Quality Board. "Water Quality Segment Report for Segment No. 2484, Corpus Christi Inner Harbor," by Steve Warshaw. 29 p. (Report No. WQS-10) Austin, Texas: 1975 [628.168/T31WQS/10]

54. U.S. Coastal Engineering Research Center. "Monitoring of Foredunes on Padre Island." 69 p. (Miscellaneous Report 77-8) 1977.

55. U.S. Corps of Engineers. "Corpus Christi Beach, Texas (Restoration Project)." 56 p. Revised Final Environmental Statement. Galveston, Texas: 1975.

56. U.S. Corps of Engineers. "Corpus Christi Ship Channel, Texas." 6 p. Final Environmental Impact Statement. Galveston, Texas: 1971 [EIS/C815P]

57. U.S. Corps of Engineers. "Corpus Christi Ship Channel, Texas (45-Foot Project)." 10 p. Final Environmental Statement. Galveston, Texas: 1971.

58. U.S. Corps of Engineers. "Hydraulics and Dynamics of New Corpus Christi Pass, Texas: A Case History, 1972-1973." 126 p. Waterways Experiment Station Report. Galveston, Texas: 1977 [USCE-GE/77-8]

59. U.S. Corps of Engineers. "Hydraulics and Dynamics of New Corpus Christi Pass: A Case History, 1973-1975." 175 p. (Report No. 76-9) Galveston, Texas: 1976. [USCE-GE/76-9]

60. U.S. Corps of Engineers. "Maintenance Dredging, Corpus Christi Ship Channel, Texas; Final Environmental Impact Statement." 83 p. Galveston, Texas: 1975 [USCE-G/C81M]

61. U.S. Corps of Engineers. "Survey Report on Corpus Christi Beach, Texas - Restoration Project." 31 p. Galveston, Texas: 1969.

62. U.S. Geological Survey. "Water Resources Data for Texas, 1966-1976." Austin, Texas.

63. U.S. National Oceanic and Atmospheric Administration. "Cooperative Gulf of Mexico Estuarine Inventory and Study - Texas: Area Description," by Richard A. Diener. 129 p. NOAA Technical Report NMFS CIRC-393. Seattle, Washington: September, 1975.

64. Water Resources Engineers, Inc. "RIVTID, Simulation of Flood-Flow Hydrodynamics in River/Tidal Systems: Program Documentation and User's Manual," by R. J. Brandes and R. B. Wise. v.p. Austin, Texas: 1973.