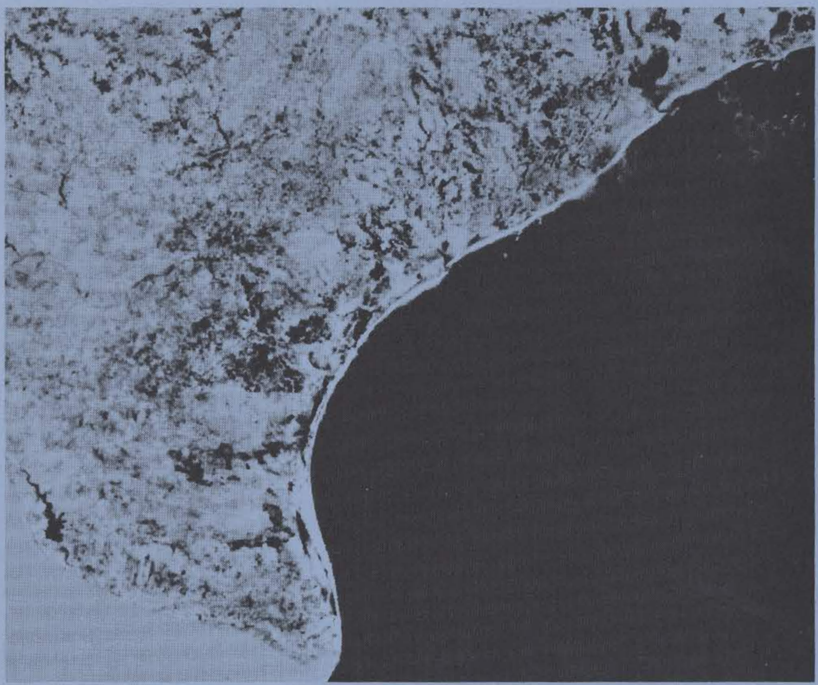
THE INFLUENCE OF FRESHWATER INFLOWS UPON THE MAJOR BAYS AND ESTUARIES OF THE TEXAS GULF COAST

EXECUTIVE SUMMARY



The preparation of this report was financed in part through funds made available by Senate Bill 137 of the 64th Texas Legislature.

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TEXAS DEPARTMENT OF WATER RESOURCES

Second Edition — September 1982

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ABSTRACT

The Texas Department of Water Resources was directed by Senate Bill 137, 64th Texas Legislature, to conduct comprehensive studies of the effects of freshwater inflow upon the bays and estuaries of Texas and to estimate the inflows needed to maintain a suitable ecological environment. This report describes the findings of studies on the relationships between freshwater inflow, salinity, and biological activity in the seven largest estuaries on the Texas coast. A method is described for relating the impact of freshwater inflows to estuarine conditions by the use of three key indicators: inundation frequency of riverine deltaic marsh complexes, mean monthly salinity, and annual commercial fisheries harvests. Using this methodology, estimates are given for the monthly and seasonal freshwater inflows needed to meet three alternative estuarine objectives: ecosystem subsistence, fisheries harvest maintenance, and fisheries harvest enhancement. Alternative means of providing freshwater inflows to the bays and estuaries are discussed.

TABLE OF CONTENTS

TABLE OF CONTENTS--Continued

TABLE OF CONTENTS--Continued

FIGURES

TABLES

SUMMARY

The coastal region of Texas is a valuable and diverse natural resource, having seven major and several smaller estuarine systems spread along approximately 370 linear miles (595 km) of Texas coastline. Freshwater inflow of sufficient quantity and quality is an important factor in marsh and bay productivities, and further, contributes to the near-shore productivity of the Gulf of Mexico. Freshwater inflows dilute the saline tidal waters and transport nutritive and sedimentary materials that maintain marsh environments and promote estuarine productivity.

In the past, Texas water planning efforts have been hindered by the lack of a comprehensive data base and a reliable set of techniques and criteria for measuring the response of estuarine ecosystems to the timing and volumes of freshwater inflows. This was particularly significant during the development of the 1968 Texas Water Plan and in more recent water planning work. Although several limited programs were underway in 1968, these were largely independent of each other and none of the programs were truly comprehensive. Therefore, a program was initiated by the Texas Water Development Board and is carried on by its successor agency, the Texas Department of Water Resources, to collect the data considered essential for analyses of the physical and water quality characteristics and ecosystems of Texas' bays and estuaries.

In 1975, the 64th Texas Legislature enacted Senate Bill 137, a mandate for "comprehensive studies of the effects of freshwater inflow upon the bays and estuaries of Texas." Reports published as a part of the effort were to address the relationship of freshwater inflow to the health of living estuarine resources (e.g., fish, shrimp, etc.) and to present methods of providing and maintaining a suitable ecological environment.

This report summarizes the findings of six reports on seven individual Texas bays and estuaries, including (1) the Sabine-Neches estuary, (2) the Trinity-San Jacinto estuary, (3) the Lavaca-Tres Palacios estuary (4) the Guadalupe estuary, (5) the Mission-Aransas estuary, (6) the Nueces estuary, and (7) the Laguna Madre estuary. These studies were done to fulfill the mandate of Senate Bill 137.

The objectives of these technical analyses were to describe and quantify the freshwater inflow/salinity/biological relationships of the estuarine environments and to estimate the annual and seasonal freshwater inflows associated with the production of finfish and shellfish at observed historic levels. Program studies draw from all available sources of information and consider the effects of freshwater inflows on nutrient supplies, habitat maintenance, and production of fishery resources (including economic aspects).

The economic outlook for the coastal areas adjacent to the seven estuarine systems analyzed is comparatively bright due to the growth potential of energy, petrochemical and related industries, and a broad base of manufacturing and service industries. The manufacturing base of the regions is projected to continue to broaden. This expansion is estimated to result in increased employment and earnings in the trade and service sectors. The economic base of the coastal area also contains large scale energy, agricultural, agribusiness, and commercial fishing operations.

Analyses have been performed to compute estimates of the quantities of sport and commercial fishing and the economic impacts of these fisheries upon the state and local economies. The sport fishing estimates are based on data obtained by the Texas Parks and Wildlife Department and the Texas Department of Water Resources. The commercial fishing estimates are based on data from U. S. Department of Commerce statistical series about the industry.

According to a study conducted in 1976-1977, direct annual expenditures for sport fishing is about $42.6 million.

Commercial fishery dockside landings are valued at $133.6 million annually. The combined commercial and sport fishing activities produce over $553 million in direct and indirect gross business and over $153 million in annual personal income in Texas. These values do not account for non-fishing related benefits to the recreation and tourism industry, as well as the general public, associated with the maintenance of "healthy" estuarine conditions. Comprehensive economic evaluations of estuaries have not been entirely successful since a large portion of an estuary's value may be related to natural functions and public benefits having little or no market value.

Many complicated interactions govern the biological productivity of Texas bays and estuaries other than the quantity of freshwater inflows. In order to estimate the influence of freshwater inflows on estuarine ecosystems, some assumptions must be made. A main premise underlying the assumptions of these studies is that the relationships and interactions between freshwater inflows and estuarine productivity can be indirectly examined through analysis of "key" indicators. One "key" indicator, the frequency of marsh inundation, is based on the recognition that coastal marsh areas associated with river deltas are inundated by periodic overbanking of river flows and that this flooding contributes basic nutrients to the estuary, with movement of these nutrients accomplished through the flooding process. In addition, marsh flooding contributes to the maintenance of "nursery" habitats for young growing organisms such as juvenile fish and shrimp. Salinity in estuarine water is a second significant indicator since important commercial estuarine- dependent organisms are critically dependent upon monthly salinity levels for viable growth and reproduction. The third "key" indicator utilized in analyzing freshwater inflow needs is the historical commercial fishery harvests. Annual harvest statistics coupled with associated seasonal freshwater inflows over the 1962 through 1976 period provide the best available data with which to estimate relationships between the timing and quantities of freshwater inflows and associated fishery harvest yields.

Sources of freshwater inflow to Texas estuaries are: (1) gaged inflow (as measured at the most downstream flow gage[1/] of each river system and includes wastewater discharges or return flows, reservoir spills and releases, and unregulated runoff), (2) ungaged runoff, and (3) direct precipitation on the estuary's surface. The measurement of each of these sources of freshwater inflow is necessary to develop analytical relationships between freshwater inflow and resulting changes in the estuarine environment. Gaged inflows are the most readily available and accurate inflow data since a number of appropriate located stations record daily streamflows; however, gaged records do require adjustment to reflect diversions and return flows downstream of streamgage locations.

Computations of ungaged inflow were made using soil moisture data and runoff coefficients developed from field surveys. Direct precipitation on an estuary is assumed to be an average of the daily precipitation recorded at weather stations in the coastal regions adjacent to each bay.

In this report, estimates of freshwater inflows needed for selected major estuarine systems are based on the quantity of river inflows from the major river basin drainage areas measured by streamgages necessary to: (1) inundate riverine deltaic marsh complexes; (2) provide desirable salinity gradients in primary estuarine habitat regions; and (3) maintain or enhance fishery harvests above the mean 1962 through 1976 harvest levels. The "gaged" estimates are in addition to freshwater inflows from ungaged areas within the major river basins and the coastal basins.

1/ Due to tidal influences, the most downstream streamgage is not located at the mouth of the river, and thus does not measure all of a river basin's flow contribution to an estuary.

The estimates of estuarine freshwater inflow needs are expressed in terms of the annual volume of water passing the most downstream river gaging station and represent the estimated volumes needed to satisfy the three alternative estuarine objectives described in the following paragraphs. Ungaged inflows from the coastal basins to the estuaries are largely unregulated and are assumed, for total inflow accounting, to be at their computed historical average monthly rates for the 1941-1976 period. The ungaged inflow contributions from the major river basins are estimated based upon statistical relationships derived from recorded data which relate monthly total basin inflow to the gaged basin inflow component of total inflow. The three alternatives were selected to demonstrate the methodology developed in this study and to illustrate a wide range of possible desired estuarine conditions under the assumption that the profitability of fishing remains relatively stable in relation to each alternative considered here. The alternatives selected are not the only ones possible, but reflect logical goals for the management of estuarine ecology.

The Subsistence Alternative (Alternative I) considers the marsh inundation and salinity characteristics of an estuary and establishes minimum monthly inflows for the basic purposes of nutrient transport, habitat maintenance, and salinity control.

The annual freshwater inflow need for the Fisheries Harvest Maintenance Alternative (Alternative II) is the least annual inflow, distributed appropriately on a monthly and seasonal basis, such that this level of inflow satisfies the Subsistence Alternative and also provides sufficient freshwater to support annual commercial harvests, for each of the major fisheries harvest components in each respective estuary, at no less than average annual levels over the period 1962 through 1976 -- a period for which reliable and comprehensive fisheries data are available.

A third Alternative, termed Fisheries Harvest Enhancement (Alternative III), was considered in order to provide estimates of monthly and seasonal freshwater inflows needed to satisfy the Subsistence Alternative and to increase, to the maximum extent possible, the harvest of a specific commercial fisheries harvest component (which differs with the estuary considered), where the total annual freshwater inflow is constrained in the analysis at a level not to exceed the mean annual historic inflow over the period 1941 through 1976.

The estimated annual gaged freshwater inflow needed, in addition to the ungaged inflow, for the Sabine-Neches and Trinity-San Jacinto estuaries under the three Alternatives[1/] stated above are less than the historical (1941-1976) mean annual gaged inflow to these estuaries (Figure 1). The gaged inflow needs for the estuaries along the drier central and southern portion of the Texas Gulf coast (the Lavaca-Tres Palacios, Guadalupe, Mission-Aransas, Nueces, and Laguna Madre estuaries) are lower than or equal to the 1941-1976 period average annual inflow for Alternatives II and III (Figure 1). Excluding the Sabine-Neches estuary, the estimated total annual gaged inflow needs are approximately 7.6, 9.1, and 9.3 million acre-feet (9.4, 11.2, and 11.5 billion m^3) for Alternatives I, II, and III, re-

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1/ Inflow estimates for the Sabine-Neches estuary were not derived for the Maintenance and Enhancement Alternatives since the relationships between recorded inflows and fisheries harvests could not be utilized with validity over a range of inflows consistent with the Subsistence Alternative constraints. Such fisheries harvest estimates were required in order to determine inflow needs for Alternatives II and III.

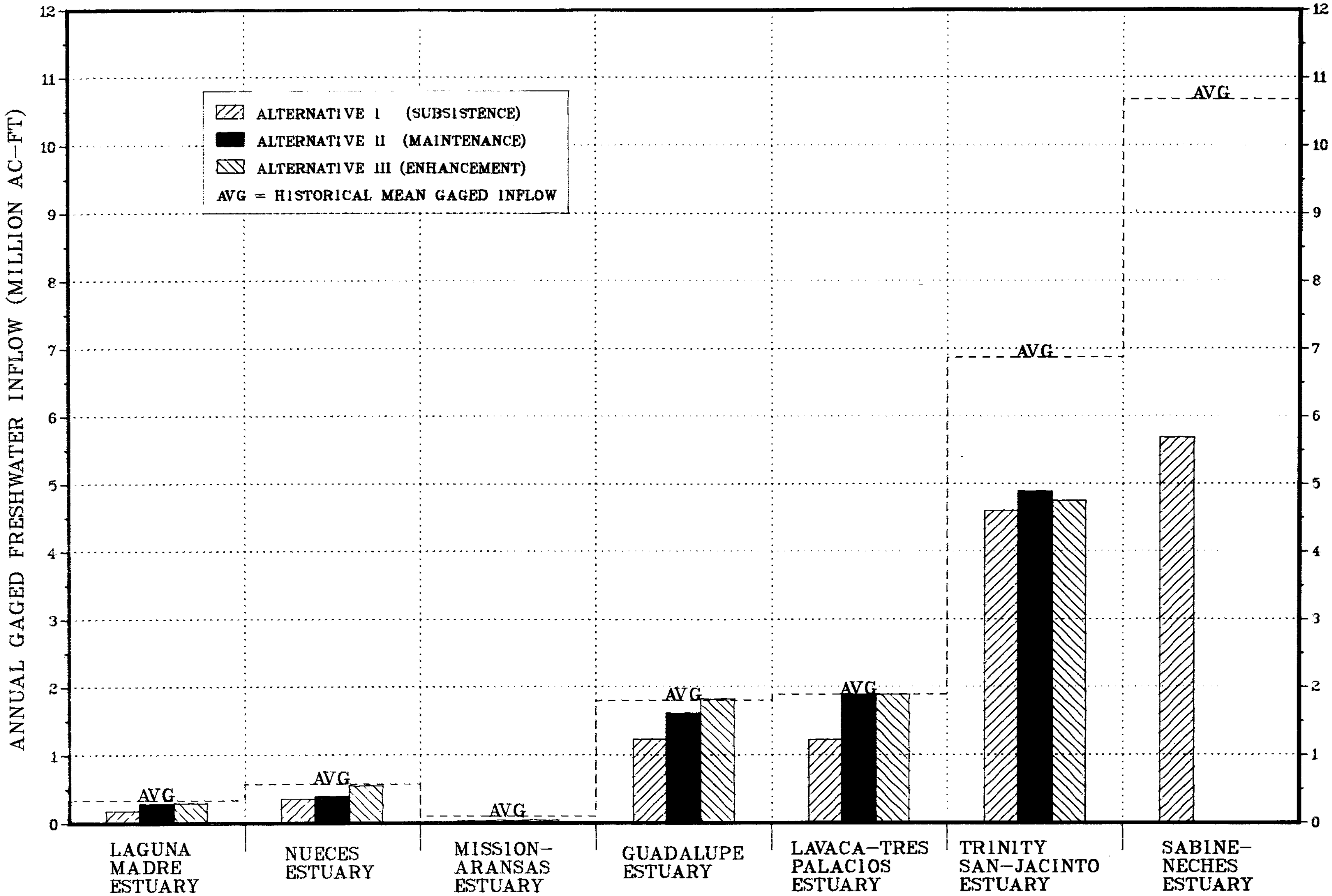

Figure 1. Estimated Annual Gaged Freshwater Inflow Needs and Mean Annual Gaged Historical Freshwater Inflows for Seven Texas Estuaries (1941-1976)

spectively.[1/] The inflow need of the Sabine-Neches estuary for the Subsistence Alternative amounts to approximately 5.7 million acre-feet (7.0 billion m^3) annually. The average 1941-1976 annual recorded gaged inflow to the seven estuaries was about 22.3 million acre-feet (27.5 billion m^3).

The estimated combined annual commercial finfish and shellfish harvests under the three Alternative freshwater inflow needs[2/] generally exceed the average recorded harvests for the 1962 through 1976 period (Figure 2). These estimated harvests indicate that fisheries and fishery harvests may potentially be improved with the proper seasonal distribution of available freshwater inflows.

1/ Total annual value of commercial fisheries, as measured at the landing site in 1976, is reported at $136.5 million. Sport fishing expenditures in the 1975 through 1977 period were estimated at $42.6 million annually. Total value of irrigated crops produced in Texas, as measured at the farm market point, was reported at $1.655 billion in 1976. It is estimated that irrigated agriculture used 13.0 million acre-feet of water in 1976.

2/ The fisheries harvest for the Trinity-San Jacinto estuary includes the shrimp harvest in the adjacent offshore Gulf fishing area from Sabine Pass to near Freeport and 100 miles offshore (Gulf Area No. 18), which averages about 10 million pounds (4.5 million kg) for the 1959 through 1976 period. The Laguna Madre fisheries harvest includes the 1959-1976 average shrimp harvest of 8.4 million pounds (3.8 million kg) from the adjacent Gulf Area No. 21 offshore of Padre Island. Commercial fishery harvests under the three Alternatives for the Sabine-Neches estuary could not be estimated with validity because the Subsistence Alternative monthly inflow regime determined by the desired estuarine salinity conditions was not entirely within the range of observed inflows over the 1962 through 1976 period for which inflow-commercial harvests relationships were derived.

Comparison of the annual freshwater inflow needs and the associated predicted commercial fishery harvests for the Lavaca-Tres Palacios estuary indicates that nearly equal volumes of freshwater may result in significantly different harvests. This condition reflects the importance to fisheries productivity of the seasonal timing of estuarine inflows. Generally, it was observed that spring inflows (April through June) were the most beneficial for fisheries productivity.

Relationships were also derived relating historical (1959-1976) Texas Gulf shrimp harvests to the total combined seasonal inflows of five major estuaries. The Sabine-Neches estuarine inflows were omitted to eliminate possible unknown influences from Louisiana. The inflows to the Laguna Madre were also not considered due to incomplete monthly inflow data. The shrimp harvest-inflow relationships indicate a strong influence on Texas offshore shrimp harvests by Texas estuarine inflows, particularly spring season inflows.

Texas estuarine systems are dynamic and have historically received a wide range of freshwater inflows from drought to wet or hurricane years. In fact, it is generally believed that a constant rate of freshwater inflows would be detrimental to the estuarine organisms which have adapted to the prevailing dynamic annual and seasonal cycles. For this reason, the estimates of freshwater inflow needs should be regarded as statistical long-term central tendencies (such as the average) of inflows needed to sustain the estuarine systems. Major events, such as hurricanes and uncontrolled floods, will continue to provide freshwater inflows that may greatly exceed the estimated needs.

Freshwater inflows needed to maintain an estuarine ecosystem can be provided from a combination of unregulated and regulated sources. In these analyses, it has been assumed for computation purposes that the estuarine inflow from local uncontrolled drainages in adjacent coastal basins will continue in the future at historical levels. Inflows from the major contributing river basins, however, will in many cases be

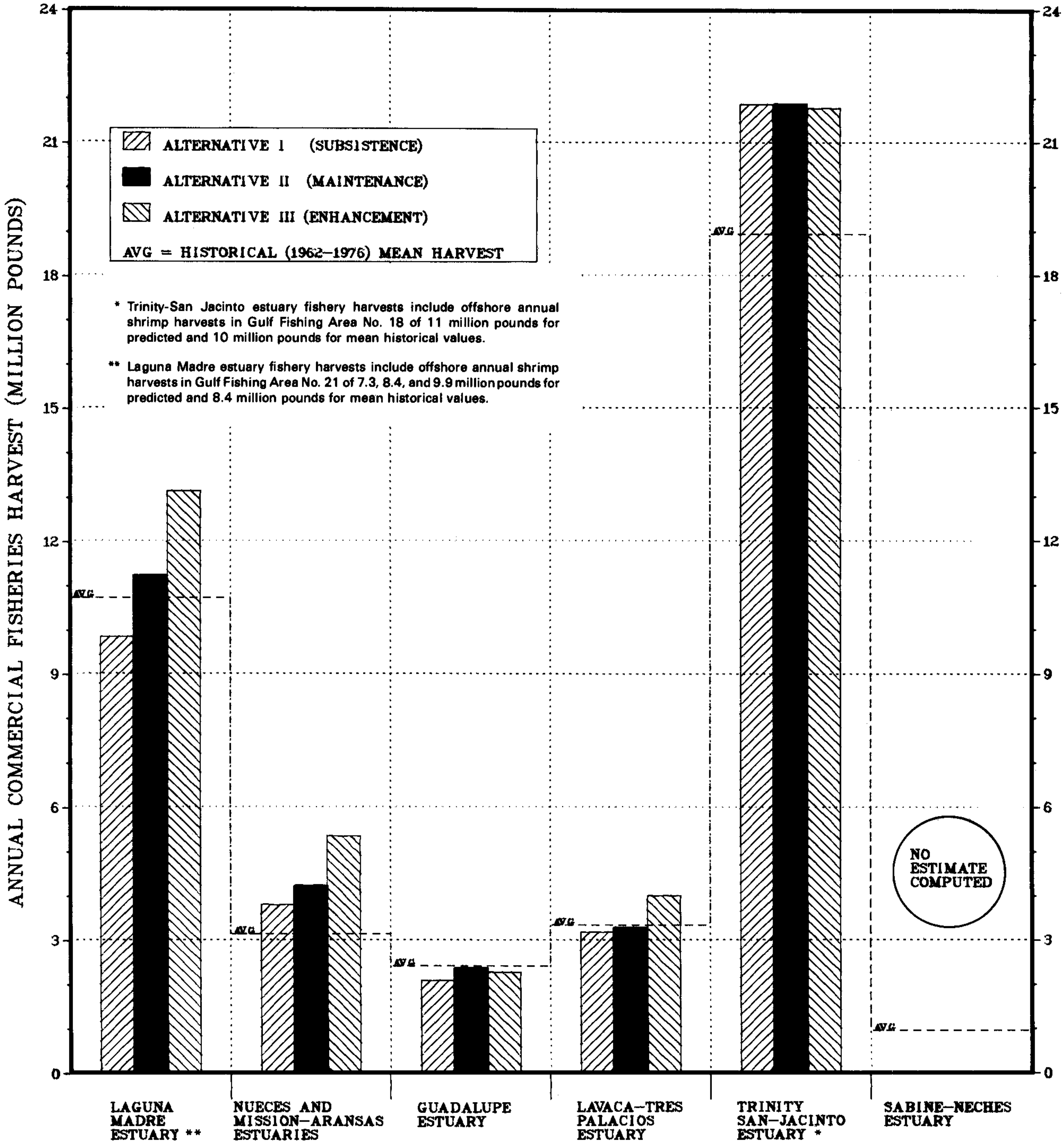

Figure 2. Estimated Annual Fisheries Harvests Under Three Alternative Freshwater Inflow Levels and Mean Annual Fisheries Harvests (1962-1976) for Seven Texas Estuaries

subject to significant alteration due to man's activities. Continued provision of freshwater inflow from the upstream river basin is subject to decisions based on institutional systems designed to manage the State's waters to the benefit of all of the citizens of the State.

In addition to freshwater entering an estuary in the needed volume and at the appropriate time, it is also necessary that the inflows be relatively free of toxic pollutants and contain sufficient nutrient materials to insure continued reproduction and growth of estuarine organisms.

INTRODUCTION

Background

In 1975, the 64th Texas Legislature enacted Senate Bill 137 (Appendix 1), a mandate for comprehensive studies of "the effects of freshwater inflow upon the bays and estuaries of Texas." These studies were to address the relationship of freshwater inflow to the living estuarine resources (e.g., fish, shrimp, etc.) and to present methods of providing and maintaining a suitable ecological environment. This report presents the major findings and results of studies that have been conducted for seven major Texas bays and estuaries, including (1) the Sabine-Neches, (2) the Trinity-San Jacinto, (3) the Lavaca-Tres Palacios, (4) the Guadalupe, (5) the Mission-Aransas (6) the Nueces, and (7) the Laguna Madre estuaries (Figure 3). In the analyses of each estuarine system, physical, chemical, and biological factors are conceptually and empirically related. Many estuarine needs are directly related to freshwater inflow and associated quality constituents. In some cases, these needs may be exceeded in importance only by the availability of nutrients and the habitat conditions in the ecosystem.

Established public policy stated in the Texas Water Code (Section 1.003 as amended, Acts 1975) provides for the conservation and development of the State's natural resources, including "the maintenance of a proper ecological environment of the bays and estuaries of Texas and the health of living marine resources." Both Senate Concurrent Resolution 101 (63rd Legislature, 1973) and Senate Resolution 267 (64th Legislature, 1975) declare that "a sufficient inflow of freshwater is necessary to protect and maintain the ecological health of Texas estuaries and related living marine resources."

The development of the Texas Water Plan, adopted in 1969, pointed to the acute need for a comprehensive data base and a reliable set of techniques and criteria for measuring the response of estuarine ecosystems to varying amounts and regimes of freshwater inflows in order to understand this very complex "real world" problem. Although several limited programs were underway in 1968, these were largely independent of one another and none of the programs were truly comprehensive.

A program was therefore initiated by the Department, in cooperation with the Texas Parks and Wildlife Department, General Land Office and 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 U.S. Geological Survey, the official hydrologic data collection agency of the Federal government, 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 flow 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. Through this cooperative program with the U.S. Geological Survey, the Department is now collecting water quality and water circulation data in all estuarine systems of the Texas Coast.

Definition of an Estuary

The definition of an estuarine system has received considerable attention in recent years. One of the more useful definitions is that of "a semi-enclosed coastal body of water which has a free connection with the open sea and within which seawater is measurably diluted with freshwater derived from land drainage" (Dr. Donald Pritchard, Johns Hopkins University). This definition describes six of Texas' seven major estuarine systems. The remaining estuary, Laguna Madre, is also referred to as a lagoon, since its connection with the sea is not "free" and seawater may be concentrated to hypersaline

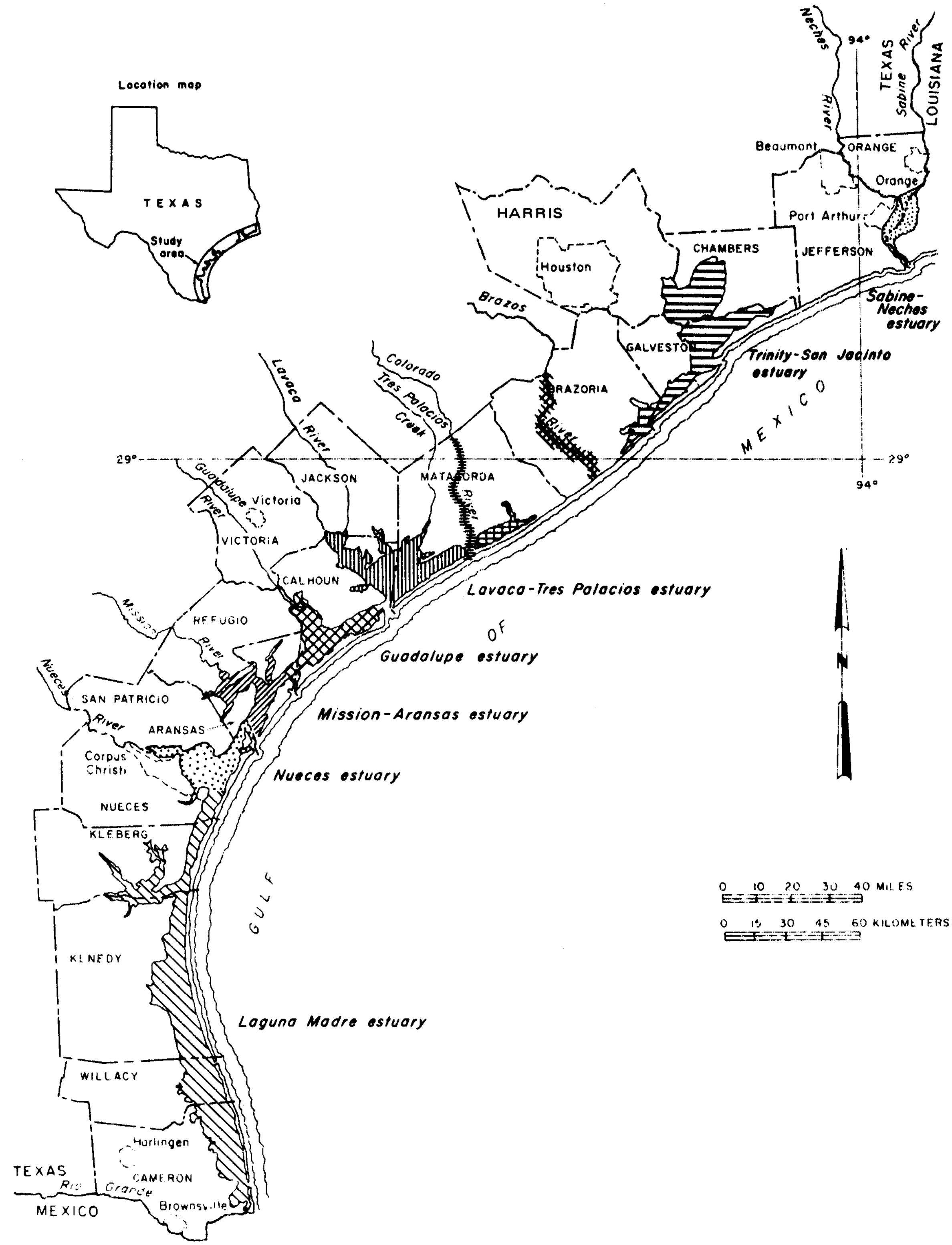

Figure 3. Locations of Texas Estuaries

Base from Official State Highway Map of Texas, 1971 conditions rather than diluted to brackish saline conditions by significant freshwater inflow.

Objectives

The purpose of the analyses reported upon herein is to describe and measure, in so far as possible, the freshwater inflow/salinity/biological relationships of the Texas estuarine environments. Results from all known studies plus field data collected specifically during the course of these studies have been used for the purpose of bringing together knowledge about the effects of freshwater inflows on nutrient exchange, habitat maintenance, and fisheries production, including the economic aspects. The Department and consultants through interagency and consultant contracts and cooperative studies with other State, federal, and local agencies, particularly the Texas Parks and Wildlife Department, General Land Office and Texas University developed a number of analytical techniques to quantitatively express:

1. inundation/dewatering processes of river delta marshes;
2. cycling and exchange of nutrients;
3. water movement and salinity patterns in the open bay systems; and
4. production of fisheries.

These analytical techniques were utilized to identify and quantify, insofar as possible, the relationships among the physical, hydrologic, chemical, and biological parameters which govern the productivity within these systems. Using data about each system, estimates have been made of the quantities of freshwater needed on a monthly basis for marsh inundation and nutrient transport, for proper salinity levels, and to support various levels of fisheries harvests.

Importance of Freshwater Inflows

Generally, Texas estuarine systems can withstand intensive use without appreciable deterioration; however, they are not all equally suited for all uses. Alteration of crucial ecosystem areas, such as the marshes and submerged seagrass beds, is potentially destructive and may impact not only these areas, but the entire ecosystem's energy flow, food chain, and living resource organism production as well. Freshwater inflow of sufficient quantity and quality is an important factor in marsh and bay productivities, and further, contributes to the near-shore productivity of the Gulf of Mexico. Freshwater inflows to Texas estuaries are principally rainfall-runoff from neighboring coastal areas and the flow of rivers and streams that empty into the estuaries. Freshwater inflows dilute the saline tidal waters and transport nutritive and sedimentary materials that promote productivity and maintain marsh environments. Seasonal inundation of the marshes and periodic flushing of the estuaries by freshwater inflows are crucial for these coastal systems. Periodic flushing removes pollutants, removes or limits some parasites, bacteria, and viruses harmful to the estuarine ecosystem, and increases the exchange of water, sediments, and biota with the near-shore Gulf environments.

These multiple and only partially understood relationships make it difficult to precisely determine the freshwater inflow needs of each Texas estuarine system, yet such determinations are necessary to balance competition between beneficial inland and coastal uses of Texas' freshwater resources, and to avoid long-term degradation of valuable fisheries resources.

Concurrent with the biological and hydrological studies of the six estuarine systems named earlier, data were collected and analyzed and estimates were made of the quantities of sport and commercial fishing and the economic impact of these fisheries upon the local and state economies. In addition, the economic impacts of sport and commercial fishing in the Laguna Madre estuary were estimated in order to develop a more thorough picture of the significance of these economic activities to the entire Texas Gulf Coast. The sport fishing estimates are based upon data obtained through surveys of a sample of fishing parties, conducted in cooperation with the Texas Parks and Wildlife Department. The commercial fishing estimates are based on data from published statistical series about the industry.

DESCRIPTION OF THE COASTAL ZONE

Physical Description

The Texas Coastal Zone borders the northwestern Gulf of Mexico (Figure 3). It forms a low-lying land mass which slopes gently toward the sea and is a landward extension of the shallow continental shelf which extends sixty miles or more into the Gulf of Mexico. The shore is characterized by shallow bays and lagoons behind barrier islands which front on the open sea. Extensive wetlands are interspersed among these bays and lagoons.

The coast extends generally northeast to southwest. The northeastern one-third is a forested area of high rainfall and high humidity. The southwestern one-third is semi-arid brush country, where rainfall and humidity are low.

Throughout the year the prevailing winds are from the south, especially during the hot summer months. Exceptions to this pattern, during which winds blow out of the north or northwest, occur mostly during the winters which are usually mild.

The dominant forces which shape the coast are the prevailing Gulf currents, which continually reshape the Gulf-ward shore of the mainland and the barrier islands; the rivers, which bring sediment and nutrients into the estuaries; and hurricanes and tropical storms which periodically disrupt the on-going processes and chaotically re-distribute the sediment. The astronomical tides, because of their narrow range (a few inches in the bays to a maximum of about two feet along the seaward shores), are a minor factor in shaping the coastline.

With respect to structure, a simple classification of the bays in Texas estuarine systems can be made by placing them into Primary, Secondary, and Tertiary bay categories (Figure 4). Gulf water passing through a tidal inlet mixes with estuarine water in the primary bay area. In Texas, the primary bay is often referred to as the "center" bay of each estuary (e.g., Galveston, Matagorda, San Antonio, and Corpus Christi Bays) and is usually of moderate (17 parts per thousand (ppt)) to high (35 ppt) salinity. A secondary bay is generally a semi-enclosed bay of brackish (9 ppt) to moderate salinity that contributes to and exchanges directly with the primary bay. A tertiary bay area may be considered as a semi-enclosed bay which contributes to and exchanges with a secondary bay, or as a lake or series of lakes in the headwaters of an estuarine system above a secondary bay. Proximity of tertiary bay areas to runoff and freshwater inflow from the contributing drainage basins normally results in fresh to brackish salinity.

Socio-Economic Description

The coastal area, consisting of the area from the Texas Gulf coastline to fifty miles inland, comprises about one-twentieth of the State's total area; and about one-fourth of the State's population. The economic significance of the resources associated with the major estuarine systems is reflected in the direct and indirect linkages of bay-supported resources to the local area economies. Trends in population and employment are presented for each of six study areas: (1) Sabine-Neches, (2) Trinity-San Jacinto (3) Lavaca-Tres Palacios, (4) Guadalupe, (5) Nueces-Mission-Aransas, and (6) Laguna Madre. The Nueces and Mission-Aransas estuaries were grouped into a single area for socio-economic analysis since the two estuaries act physically more as a single estuarine system and share a common outlet to the Gulf of Mexico -- Aransas Pass. The individual areas consist of the following counties: Orange and Jefferson (Sabine-Neches); Brazoria, Chambers, Galveston, and Harris (Trinity-San Jacinto); Calhoun, Jackson, Matagorda, and Victoria (Lavaca-Tres Palacios); Refugio, Aransas, Calhoun, and Victoria (Guadalupe); Aransas, Nueces, San Patricio, and Refugio (Nueces and Mission-Aransas); and Kleberg, Kenedy, Willacy, and Cameron (Laguna Madre).

Population

In 1975, the population of the coastal area was 3,253,200. The Trinity-San

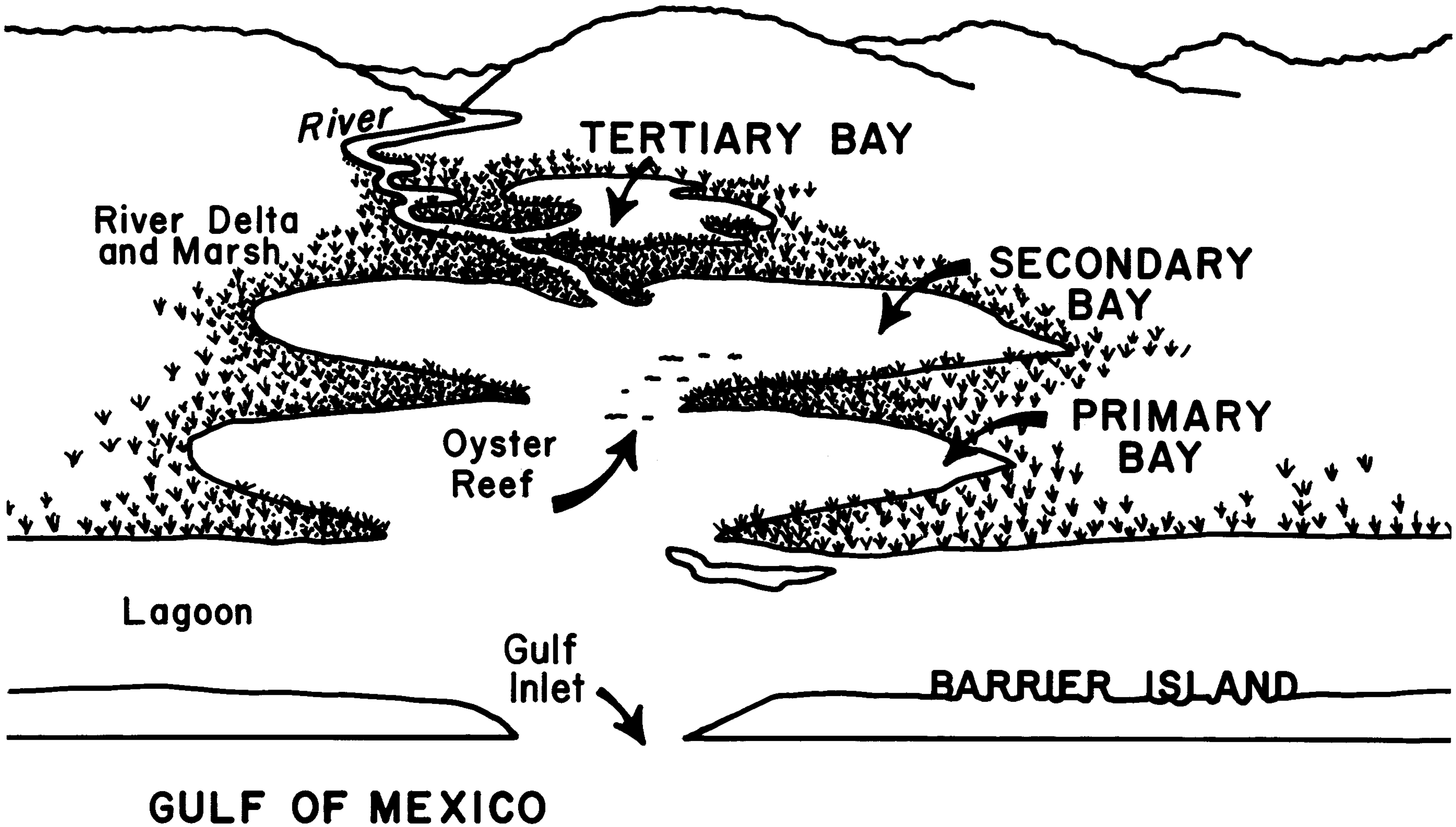

Figure 4. General Structural Classification of Bays in a Texas Estuary

Jacinto study area, which includes Brazoria, Chambers, Galveston and Harris Counties, accounted for 70 percent of the total. Forecasts for the period 1975 to 2030 indicate that the aggregate population of the coastal area can be expected to increase 1.8 percent per annum to the year 2030 (Appendix V). The Trinity-San Jacinto region is projected to remain the most populated, growing to 76 percent of the total population in 2030. The Laguna Madre region has the highest projected growth rate, 2.0 percent per annum from 1970 to 2030. The Trinity-San Jacinto, Guadalupe, Nueces-Mission-Aransas, Lavaca-Tres Palacios and Sabine-Neches estuary areas are expected to gain population at average annual rates of 1.9, 1.5, 1.4, 1.2 and 0.7 percent, respectively, over the same time period.

The population of the coastal area experienced collectively an annual growth of 1.9 percent between 1970 and 1975, which is above the statewide figure of 1.7 percent for the same period. However, only Laguna Madre portion and the Trinity-San Jacinto portion of the six regions had annual growth rates (2.9 and 2.3 percent, respectively) higher than the statewide average. The Guadalupe, Nueces-Mission-Aransas, Lavaca-Tres Palacios and Sabine-Neches study areas grew at more modest annual rates of 1.1, 0.9, 0.8 and 0.2 percent, respectively.

Employment

In 1970, an estimated 1,131,405 persons were employed in the six study areas, and over 73 percent of these worked in the Trinity-San Jacinto region. In two other regions, Sabine-Neches and Nueces-Mission-Aransas, employment exceeded 100 thousand, and in the Laguna Madre, Lavaca-Tres Palacios, and Guadalupe study areas employment levels were between 30 and 55 thousand.

Seventy-seven percent of the region's employed labor force is distributed among eight major industrial sectors (Appendix V). Workers employed by wholesale and retail trade establishments, the largest employment sector, account for more than 22 percent of the regions' labor force. Manufacturing is also a major employer in the study areas, accounting for 226 thousand workers and 20 percent of the labor force.

Industry

The "basic" industries in the areas are manufacturing, agriculture-fisheries, and mining. These sectors account for 25 percent of all employment in the study areas. In addition to the basic sectors are the service sectors: wholesale and retail trade, and professional service sectors provide goods and services to the basic industries as well as to the general public and are, in varying degrees, dependent upon them.

The most significant basic sector, in terms of total earnings as well as employment, is manufacturing (Appendix V). The major portion of manufacturing activity is centered in the Trinity-San Jacinto and Sabine-Neches areas and is concentrated in the production of chemicals, petrochemicals, petroleum refining, machinery, equipment, and primary metals.

The ports and harbors along the Texas Gulf Coast from the Sabine River to the Port of Brownsville are important factors in the coastal and statewide economies. Annually, more than 200 million in the coastal and statewide short-tons of commerce are handled by Texas ports. Principal foreign imports received through these ports are crude petroleum, chemicals, and iron ore with agricultural commodities such as wheat, rice, corn, and cotton as well as petrochemicals comprising the major export products.

In addition to providing transportation linkages between world markets, these maritime harbors have access to other Texas ports as well as ports on the Mississippi River via the Intracoastal Canal. The portion of the Intracoastal Canal extending from the Sabine River to the Port of Brownsville provides waterborne transportation for more than 62 million short-tons of commence annually.

The significance of these Texas ports has played a major role in the economic development of regional economies. In addition to providing basic low cost transportation for raw materials and finished products, these ports are also an important source of direct and indirect employment for the coastal economies.

The mineral wealth of the coastal area is also a key factor in the diversity and strength of these regional economies. In 1976, these estuarine study areas produced over $3.2 billion of petroleum, natural gas and natural gas liquids, stone, clay, sand and gravel, salt, cement, lime, magnesium and sulphur. These mineral products supply raw materials for the petroleum refining and petrochemical industries and other manufacturers, as well as inputs for the construction sector of the area economies.

Agriculture

The coastal area had almost $430 million in receipts from crop production in 1977. Major regional crops are grain sorghum, rice, soybeans, cotton, citrus and corn. Livestock and livestock product receipts in 1977 were over $118 million, for a total regional agricultural output of over $548 million that year.

Economic Importance of the Sport and Commercial Fisheries

It is estimated that 1.123 million fishing parties visited the seven estuaries annually during the 1976-1977 study period (Appendix V). From this quantity of sport fishing visitation, expenditures for travel, food, lodging, bait and other items by sport fishing parties were estimated at $42.6 million (Appendix V). Annual business activity resulting from sport and commercial fishing was estimated as follows:

1. Annual expenditures for sport fishing were $42.62 million of which over 89 percent accrued to the local area economies. Commercial fishing was valued at $133.6 million annually.
2. The annual statewide impact from sport fishing in the seven major estuarine estuary systems was estimated at $137.6 million (1976 dollars).
3. The proportion of gross business impact that occurred within the local regions was 57 percent, but a significant amount of gross receipts (42 percent) accrued to the rest of the Texas economy because the materials and services for fishing-related businesses are supplied throughout the State.
4. Commercial fishing resulted in over $416.2 million in statewise gross business volume, of which about 63 percent accrued within the estuary regions.
5. An estimated $39.1 million and $114.5 million in personal income resulted annually from sport and commercial fishing, respectively.
6. Total State tax and license revenues associated with sport fishing activities were estimated at about $1.4 million, including 57 percent collected within the regions. Local tax revenues totaled $2.2 million, with a larger percent (63.4) remaining in the local economies.
7. The total tax revenue impacts for commercial fishing were $3.8 million and $5.3 million for state and local governments, respectively. More tax revenues remained in the regions from commercial fishing than those stimulated by sport fishing -- 64 percent for state and 80 percent for local revenues.
8. An estimated 4,581 full-time equivalent jobs resulted from sport fishing business; the regions' share was about 69 percent, over 3,200 jobs. The annual commercial fishing impact on employment statewide was estimated to be over 10,339 jobs, mostly concentrated within the regions with about 20 percent of the total employment located elsewhere in Texas.

The results of this study demonstrate that the economic importance of the sport and commercial fishing activities in the six estuary regions extends beyond the coastal areas. On the average, for each dollar spent on variable sport fishing activities, an additional $2.23 in gross sales occurs throughout the State. For each dollar of commercial fishing harvest, an estimated $2.12 in additional gross business results. Combined, the fishing activities produce over $553 million in direct and indirect gross business and over $153 million in annual personal income in Texas.

FRESHWATER INFLOW NEEDS

Introduction

Many complicated interactions govern the biological productivity of Texas bays and estuaries other than the quantity of freshwater inflows. However, freshwater inflows and their associated nutrients and sediments are recognized as one of the primary factors in estuarine productivity. In order to estimate freshwater inflows necessary to sustain Texas estuarine ecosystems, some assumptions must be made. The main premise underlying these assumptions is that the relationships and interactions between freshwater inflows and estuarine productivity can be indirectly examined through analysis of "key" indicators. A more extensive discussion of the underlying physical, chemical and biological relationships in an estuary is provided in Appendix VI.

One "key" indicator, the frequency of marsh inundation, is based on the recognition that coastal marsh areas associated with river deltas are inundated by periodic overbanking of river flows. Timing and extent of the inundation and dewatering processes are influenced by seasonal tidal conditions and constitute a natural environmental function of the estuary in terms of waste assimilation, nutrient cycling, and maintenance of "nursery" habitats for young growing organisms such as juvenile fish and shrimp. The frequency of flood flow durations and their water volumes, in conjunction with the area of adjacent marsh habitats, gives an indication of the history of previous inundation events and an indication of the extent of this natural process. Analysis of this information provides an estimate of the freshwater inundation requirements necessary to sustain system inundation at historical levels.

Another "key" indicator is salinity and involves the development of freshwater inflow-salinity relationships for an estuarine system. This task is accomplished by formulating relationships between observed salinity levels and known river inflow quantities. The resulting inflow-salinity relationships are then applied to evaluate antecedent inflow requirements to maintain a specified salinity range at specific locations in the estuary. Further, the specified salinity range can be changed to meet general physiological salt-tolerance criteria of predominant estuarine-dependent organisms during critical months or seasons of the year. However, it is emphasized that meeting salinity criteria may not necessarily meet all vital ecosystem needs.

The final "key" indicator presently used in the assessment of freshwater inflow needs to maintain Texas bays and estuaries is based on historical commercial fishery harvests. Analysis of harvest statistics in relation to associated river inflows provides guidelines for the determination of timing and quantities of freshwater inflows essential to maintain fishery yields.

The total amount of freshwater entering Texas estuarine systems is the sum of gaged inflows, ungaged inflows, and precipitation on the estuary (Table 1). The gaged inflows are those inflows from major rivers and streams measured at the streamgaging station closest to the estuaries. Ungaged inflows are unmeasured runoff entering the estuary and can only be estimated from rainfall and runoff relationships. The net quantity of freshwater inflow for an estuarine system is the sum of the gaged inflow, return flows entering downstream of the gages and direct precipitation on and the surface of the estuary, less the evaporation from the estuary.

Analyzing the Estuarine Complex

The development of environmental modeling techniques has improved the capability of analysts to make evaluations of specified development alternatives and their impact on aquatic ecosystems. Due to the complexity of aquatic ecosystems and their importance in water resources plan-

Table 1. Average Annual Freshwater Inflows, 1941-1976, to Selected Major Texas Estuarine Systems a/

Estuary	Gaged Flows a/	Estimated Ungaged Inflows b/	Return Flows	River Diversions	Estimated Combined Inflows c/	Estimated Precipitation On Estuary	Estimated Bay Evaporation	Net Freshwater Inflows d/
	(thousands of acre-feet)							
Sabine-Neches	11,184	1,950	375	507	13,002	221	165	13,058
Trinity-San Jacinto	7,087	2,537	365	217	9,772	1,569	1,382	9,959
Lavaca-Tres Palacios	1,893	967	75	0	2,935	864	1,171	2,628
Guadalupe	1,808	460	0	0	2,268	444	648	2,063
Mission-Aransas	104	276	6	0	386	332	564	154
Nueces	628	78	30	54	682	270	539	413
Laguna Madre	335	308	46	0	689	1,300	2,757	-768
Annual Totals	23,039	6,576	897	778	29,734	5,000	7,226	27,507

a/ Denotes recorded streamflow of major rivers at the most downstream U. S. Geological Survey streamgaging station, without diversions below the gage removed.
b/ Denotes runoff from contiguous coastal tributaries not included in gaged runoff.
c/ The sum of gaged flow and ungaged inflows, plus the return flows minus the river diversions downstream of the most downstream river gaging stations.
d/ Includes gaged and ungaged inflows, diversions and return flows, and bay precipitation and evaporation components.

ning, mathematical techniques have been developed and are being used for assessment of alternative projects and programs.

Any desired objective for the biological resource of an estuary must ultimately include a value judgement concerning competing interests. Where seasonal salinity needs are competitive among estuarine-dependent species (e.g., one species prefers low salinities in the spring and another prefers high salinities in the same season), a management decision may be required to specify a preference to one or more species' needs. Such a decision could be made on the basis of which organism has been more characteristic of the estuary of interest. Additionally, needs for freshwater in the contributing river basins must ultimately be weighed against the freshwater needs of the estuary.

Method of Estimating Freshwater Inflow Needs. In order to estimate the freshwater inflow needs of an estuary, mathematical techniques are applied to combine the large number of relationships and constraints, such that all of the information can be used in consideration of competing factors. The methodology utilized in the development and application of relationships is illustrated in Appendix II. The relationships and constraints considered include:

(1) equations relating annual commercial fisheries harvests over the period 1962-1976 to inflows in up to five "seasonal" intervals,
(2) equations relating monthly salinities to monthly freshwater inflows, and
(3) upper and lower bounds, on a monthly basis, for the salinities required to maintain a viable salinity gradient for selected aquatic organisms.

The constraints listed above are incorporated into a special computational procedure[1/] to determine the monthly freshwater inflows needed to meet specified marsh inundation, salinity, and fisheries production objectives.

The results of the application of the methodology provide estimates of the seasonal or monthly freshwater inflows needed to meet selected objectives, which in this case are expressed in terms of criteria for marsh inundation, salinity, and fisheries harvests. The commercial harvests that are predicted under such a regime of freshwater inflows are compared with the average historical commercial harvests for the years 1962-1976 to estimate changes in biological productivity.

Assessment of Alternatives

The freshwater inflow needs of each estuary are assessed for three alternative objectives termed (1) Subsistence, (2) Maintenance of commercial fisheries harvests, and (3) Enhancement of selected commercial fisheries harvests. These alternatives were selected to demonstrate the methodology developed in this study and to illustrate a wide range of potentially desirable estuarine conditions. These three alternatives are most certainly not the only ones possible. However, they demonstrate a wide range of variations in bay productivity (as assumed to be generally measured by commercial fisheries harvests) resulting from varying seasonal and annual levels of freshwater inflows.

The Subsistence Alternative considers the marsh inundation and salinity characteristics of an estuary, and the freshwater inflow needs for this Alternative are the estimates of the minimum monthly inflows for the basic purposes of nutrient transport, habitat maintenance, and salinity control. The volumes of water considered necessary for the marsh inundation events,

1/ The procedure involves the formulation and solution of a mathematical programming model.

from those rivers which flood significant marsh areas, correspond to the volumes of water in recorded floods with peak flow rates equal to the median peak flow rate of all flood events recorded on streamgage records. The historic median peak flow rate is selected as best representing a typical peak flood discharge, since the median peak flow (as distinguished from the average peak flow) is the peak flow event that is the midpoint of all peak flows observed (i.e., 50 percent of the recorded peak flows are less than the median and 50 percent are greater). The annual frequency of needed marsh inundation events is specified at the same frequency as that observed for flood events over the period of accurate streamgage records, with the events seasonally distributed such that they occur in those months which biological information indicates are the most beneficial to the aquatic organisms in the estuary. Monthly inflows for salinity control are established for areas near the major inflow points of freshwater based on (1) relationships between historical gaged inflows and observed salinity levels and (2) ranges of allowable salinities, incorporating observed median historic (1941-1976) monthly salinities and salinity viability limits for important aquatic organisms. Again, the median monthly salinity is taken as a level typical of the salinity conditions.

The Fisheries Harvest Maintenance Alternative requires monthly and seasonal inflows which satisfy the Subsistence Alternative and which also are at levels sufficient to support annual commercial fisheries harvests for the major harvest categories in an estuary at levels no less than reported average annual catches from 1962 through 1976 -- the only period for which reliable and comprehensive fisheries data are available. The fisheries harvests are predicted using relationships estimated between seasonal inflows and commercial harvests over the period 1962-1976. The major harvest categories considered reflect the most predominant fishery species in an estuary, and in these analyses include individual harvests of spotted seatrout, red drum, white shrimp, blue crabs and bay oysters.

A third alternative, termed Fisheries Harvest Enhancement, was considered to evaluate the monthly and seasonal inflows needed to satisfy the Subsistence Alternative and to improve the harvest of a specific commercial fisheries harvest category (which differs among estuaries), but with the constraint that the total freshwater inflow would not exceed the mean annual historic inflow over the period 1941-1976. The annual inflow available for harvest enhancement need not necessarily be limited to the mean historic freshwater inflow, as was done in this analysis, since the freshwater inflows for increasing the harvest of a particular fisheries species may only be limited by salinity bounds. However, it is logical to ask the question as to the greatest increased harvest, for a specific fisheries group, that might be expected to occur, given the most efficient or "best" seasonal redistribution of as much as the annual mean historic freshwater inflow to an estuary.

The fisheries analyses underlying the assessment of the Alternatives stated above do not consider the response of offshore commercial harvests in the Gulf of Mexico to estuarine freshwater inflows, with the exception of the Alternatives considered for the Trinity-San Jacinto and Laguna Madre estuaries. However, relationships were developed relating the response of offshore commercial shrimp harvests to the combined seasonal inflows into the Trinity-San Jacinto, Lavaca-Tres Palacios, Guadalupe, Mission-Aransas, and Nueces estuaries. These relationships are described following the discussions of the freshwater inflow needs for each estuary.

In the following sections, estimates are presented of the freshwater inflow needs for each of the Alternatives described above for each of the six major Texas estuarine systems analyzed. Since water resources development most directly affects the gaged river inflows, the gaged inflow component is emphasized in estimating freshwater inflow needs.

Estimates of Freshwater Inflow Needs

Sabine-Neches Estuarine System

The Sabine and Neches Rivers are the major rivers discharging into the Sabine-Neches estuary (Figure 5). The combined freshwater inflow[1/] for the Sabine-Neches estuarine system averaged nearly 13.0 million acre-feet (16.0 billion m^3) per year during the 1941 through 1976 period of record (Appendix III). Ungaged inflows averaged approximately 2.0 million acre-feet (2.97 billion m^3) and gaged river inflows accounted for an average of about 10.7 million acre-feet (13.2 billion m^3) (Table 1).

Wetlands near the mouths of the Neches and Sabine Rivers contribute nutrients to Sabine Lake. These nutrients are carried into the estuary by both tidal and riverine flooding. Information developed by the National Weather Service indicates that flooding occurs on the Sabine River at the stream gaging station near Ruliff and the Neches River gaging station at Evadale when flows exceed 17,000 ft^3/sec (481 m^3/sec) and 7,600 ft^3/sec (215 m^3/sec), respectively.

Based on the 1925 through 1976 record of gaged flows, a median of three flood events on the Neches River at Evadale and two events on the Sabine River near Ruliff would be needed annually to provide the same frequency of inundation which has occurred during the recorded historical period. The peak discharge of each of these floods corresponds to the historical median peak discharge for flood events in each basin: 28,000 ft^3/sec (793 m^3/sec) for the Sabine River near Ruliff and 18,000 ft^3/sec (510 m^3/sec) for the Neches River at Evadale. The total volume of gaged inflow for each of the flood events on the Sabine is estimated at 802,000 acre-feet (989 million m^3), and on the Neches at 480,300 acre-feet (592 million m^3).

A river inflow-salinity relationship was developed using the mathematical relationship between the sum of the Sabine River flow near Ruliff and the Neches River flow at Evadale, and the salinity of upper Sabine Lake near the Sabine-Neches canal. The Subsistence Alternative estimate of the gaged river inflows necessary to sustain monthly salinities within a range of desirable salinities and maintain historical marsh inundation frequency totals about 5.69 million acre-feet (7.0 billion m^3) annually (Table 2) or 5.01 million acre-feet (6.18 billion m^3) less than the average annual gaged inflow for the period, 1941 through 1976. This annual volume of freshwater inflow was exceeded in all but ten of the years from 1941 through 1976. The annual inflow from the ungaged portions of the Sabine and Neches River Basins is estimated at 1.83 million acre-feet (2.26 billion m^3).

The freshwater inflow needs for the two additional Alternatives (Fisheries Harvest Maintenance and Fisheries Harvest Enhancement) could not be evaluated for this estuary since the fisheries harvest equations derived for this estuary were not valid for the range of possible flows consistent with the Subsistence Alternative. The salinities presented in Table 2, if met, would constitute a shift in the salinity regime of Sabine Lake from the existing intermediate fresh-brackish salinity regime to a more truly estuarine environment. This change in the salinity regime would be expected to increase the species diversity and productivity in Sabine Lake as illustrated in Figure VI-3 of Appendix VI, presuming an absence of toxic materials and assuming that existing marsh habitats are maintained. However, the magnitude of any possible change in estuarine productivity cannot be accurately assessed from existing data reflecting past conditions in the estuary. The Sabine-Neches estuary was the only estuary of the six estuaries studied for which it was not possible to compute estimates of freshwater inflow needs for all of the three Alternatives discussed earlier.

1/ Combined inflow includes gaged and ungaged inflow, diversions, and return flows, but excludes direct precipiation on and evaporation from the estuary's surface.

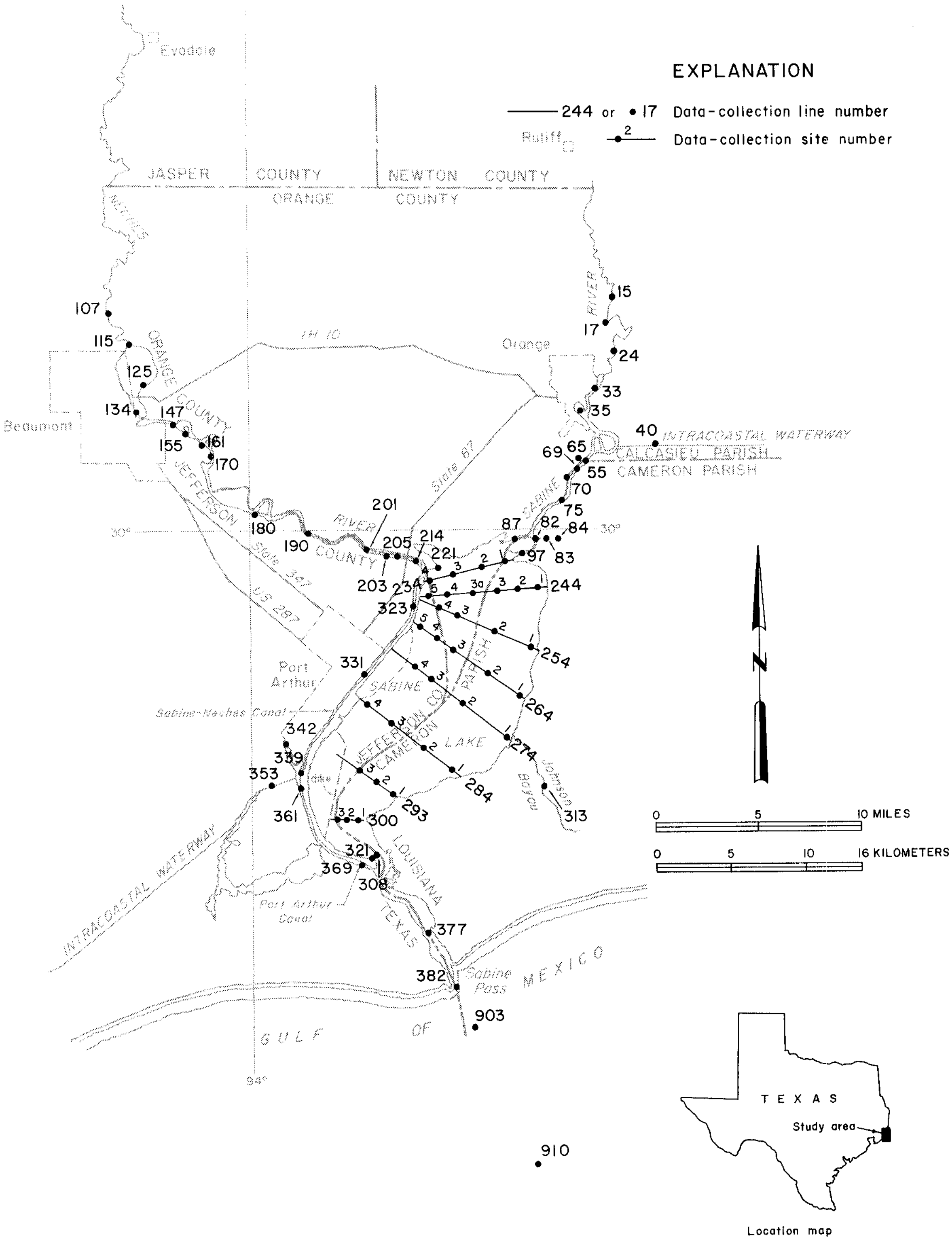

Figure 5. Sabine-Neches Estuarine System

925

Table 2. Gaged River Inflow needs of the Sabine-Neches Estuarine System for the Subsistence Alternative a/

Month	Predicted Salinity b/ (parts per thousand)	Estimated Gaged River Inflows (thousand acre-feet)
January	10.0	350.7
February	10.0	361.7
March	10.0	340.4
April	5.0	535.4
May	1.6	1,282.3
June	4.0	477.5
July	10.0	204.3
August	11.0	178.5
September	15.0	132.2
October	4.0	1,282.3
November	14.0	189.1
December	10.0	352.0
Annual		5,686.4

a/ Combined gaged streamflow of Sabine River near Ruliff and Neches River at Evadale.

b/ Based upon monthly regression equations relating salinity in upper Sabine Lake (Figure 5, line site 244, sample site 4) to gaged inflows.

Trinity-San Jacinto Estuarine System

The Trinity and the San Jacinto River Basins discharge into the Trinity-San Jacinto estuary (Figure 6). The combined freshwater inflow to the Trinity-San Jacinto estuarine system averaged about 9.8 million acre-feet (12.1 billion m^3) per year during the 1941 through 1976 period of record (Appendix III). Ungaged inflows averaged almost 2.6 million acre-feet (3.2 billion m^3) annually (Table 1), gaged Trinity River inflows accounted for an average of 5.2 million acre-feet (6.4 billion m^3) annually, and gaged San Jacinto River inflows averaged 1.6 million acre-feet (2.0 billion m^3) annually. Return flows, primarily from the City of Houston, averaged approximately 365 thousand acre-feet (450 million m^3) annually.

The Trinity-San Jacinto estuary receives freshwater inflows from two major rivers: the Trinity and San Jacinto. Each river has a deltaic marsh system at its junction with the estuary. Marsh inundation needs for the San Jacinto delta were not developed due to the relatively limited areal extent of the marsh complex. However, the large wetland complex in the Trinity River delta, extending over 49,880 acres (20,200 hectares), warranted the estimation of marsh inundation needs for that deltaic system. The average "bank full" capacity of the river channel through the delta is estimated to be 20,000 ft^3/sec (566 m^3/sec) under normal tidal conditions. Based on the gaged flows in the Trinity River at Romayor during the 1927 through 1976 period, a median of three flood events would be needed annually to provide the same frequency of marsh inundation which has occurred historically. Using the median peak flow of the recorded flood events, the peak daily discharge of each of these flood events is 29,500 ft^3/sec (835 m^3/sec), with the total volume of freshwater inflow of 750,000 acre-feet (925 million m^3) for each such event.

Statistical relationships were developed for the salinity levels in upper Trinity Bay based upon the gaged flow of the Trinity River at Romayor -- the most downstream gaging station on the river. Analysis of inflows sufficient to provide salinities within acceptable bounds to sustain the viability of various estuarine-dependent fishery species, and to provide marsh inundation, yields an estimate of approximately 3.17 million acre-feet (3.91 billion m^3) annually of gaged inflows from the Trinity River Basin for the Subsistence Alternative (Table 3). Estimated gaged inflow needs from the Trinity River to maintain commercial fisheries harvests of the estuary at levels equal to or greater than the average for the 1962 through 1976 period amounts to 3.19 million acre-feet (3.93 billion m^3) per year for the Fisheries Harvest Maintenance Alternative (Table 3). The Fisheries Harvest Enhancement Alternative, which considers maximizing the offshore commercial shrimp harvest for the offshore fishing area (designated as Gulf Area No. 18) adjacent to the estuary, would require an estimated 3.18 million acre-feet (3.9 billion m^3), or slightly less than that needed for the Maintenance Alternative, of gaged inflow annually from the Trinity River Basin (Table 3). The estimated annual inflow from the ungaged portion of the Trinity River Basin totals approximately 414 thousand acre-feet (510 million m^3) for each of the above three Alternatives.

The annual volume of estimated gaged inflow needed from the Trinity River Basin for each of the three Alternatives represents approximately 61 percent of the average annual gage inflow over the 1941 through 1976 period. The recorded gaged annual inflow from the Trinity River exceeded the estimated annual inflow needs in 25 of the 36 years from 1941 through 1976.

River inflow-salinity relationships were also developed based upon the San Jacinto River flows at the most downstream streamgages in the basin, to estimate salinity responses in upper Galveston Bay near Morgan Point -- the Texas Department of Water Resources (TDWR) salinity measuring station in Galveston Bay closest to the mouth of the San Jacinto River. Based upon

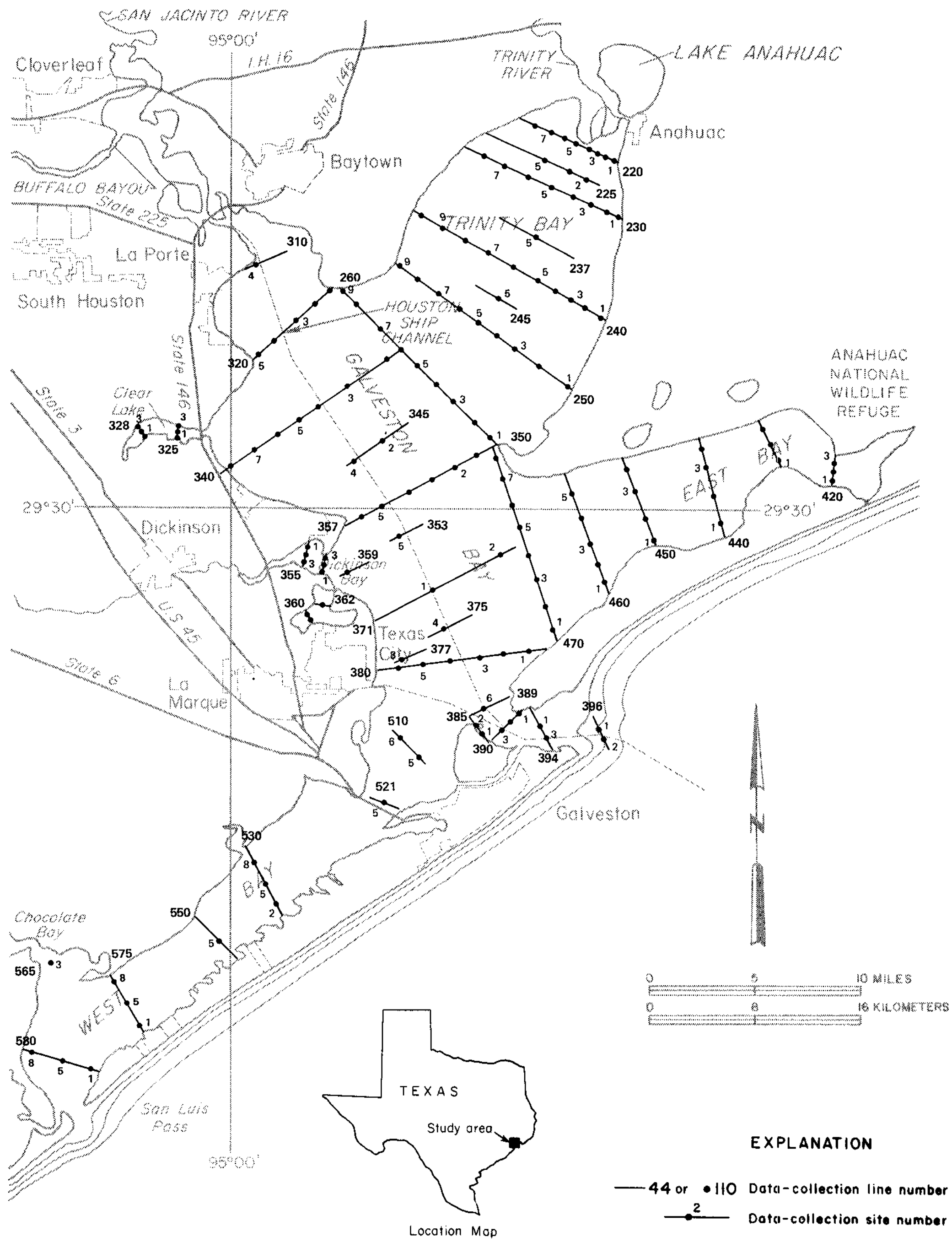

Figure 6. Trinity-San Jacinto Estuarine System

Table 3. Gaged River Inflow Needs of the Trinity-San Jacinto Estuary Under Three Alternative Levels of Fisheries Productivity a/

Month	Trinity River Basin b/						San Jacinto River Basin c/					
	Ecosystem Subsistence d/		Fisheries Harvest Maintenance e/		Shrimp Harvest Enhancement f/		Ecosystem Subsistence d/		Fisheries Harvest Maintenance e/		Shrimp Harvest Enhancement f/	
	Gaged Inflow (1000 ac-ft)	Salinity (ppt)	Gaged Inflow (1000 ac-ft)	Salinity (ppt)	Gaged Inflow (1000 ac-ft)	Salinity (ppt)	Gaged Inflow (1000 ac-ft)	Salinity (ppt)	Gaged Inflow (1000 ac-ft)	Salinity (ppt)	Gaged Inflow (1000 ac-ft)	Salinity (ppt)
January	96.1	10.0	96.1	10.0	96.1	10.0	181.5	13.0	181.5	13.0	181.5	13.0
February	97.1	10.0	97.1	10.0	97.1	10.0	153.0	13.0	153.0	13.0	153.0	13.0
March	81.4	10.0	81.4	10.0	81.4	10.0	110.6	14.0	110.6	14.0	110.6	14.0
April	691.2	3.0	691.2	3.0	691.2	3.0	154.5	14.0	154.5	14.0	154.5	14.0
May	702.2	3.0	702.2	3.0	702.2	3.0	197.0	12.0	197.0	12.0	197.0	12.0
June	429.9	3.0	429.9	3.0	429.9	3.0	124.1	13.0	124.1	13.0	124.1	13.0
July	56.5	10.0	56.5	10.0	56.5	10.0	85.4	17.0	85.4	17.0	182.5	12.1
August	59.0	11.0	59.0	11.0	69.4	10.0	84.4	16.0	84.4	16.0	117.5	14.2
September	70.2	13.0	70.2	13.0	70.2	13.0	98.0	17.0	98.0	17.0	98.0	17.0
October	670.2	5.3	670.2	5.3	670.2	5.3	57.0	18.0	57.0	18.0	57.0	18.0
November	94.8	11.0	114.2	10.0	94.8	11.0	52.9	21.0	230.5	12.4	52.9	18.0
December	119.1	10.0	119.1	10.0	119.1	10.0	139.0	15.0	224.4	12.3	139.0	21.0
Annual	3,167.7		3,187.1		3,178.1		1,437.4		1,700.4		1,570.6	

a/ All inflows are mean monthly values

b/ These values computed using regression equations relating monthly river basin inflow to the estuary with monthly gaged inflows at USGS Station on the Trinity River at Romayor, with historic diversions between the stream gage and the estuary removed Salinities are predicted values in Trinity Bay

c/ These values computed using regression equations relating monthly river basin inflow to the estuary with monthly gaged inflows at USGS Stations #08074000, 08074500, 08075500, 08076000, and 08076500. Salinities are predicted values in upper Galveston Bay near near Morgan Point

d/ The predicted annual commercial fisheries harvest for this Alternative is 501 thousand pounds of finfish and 21,369 thousand pounds of shellfish.

e/ The predicted annual commercial fisheries harvest for this Alternative is 556 thousand pounds of finfish and 21,326 thousand pounds of shellfish.

f/ The predicted annual commercial fisheries harvest for this Alternative is 414 thousand pounds of finfish and 21,368 thousand pounds of shellfish.

these relationships, an estimated 1.44 million acre-feet (1.78 billion m^3) per year of gaged inflow from the San Jacinto Basin, plus 666 thousand acre-feet (821 million m^3) of inflow from ungaged areas of the basin, to the Galveston Bay portion of this estuarine system is needed to sustain desired salinity limits (Subsistence Alternative) (Table 3). Based upon relationships established between commercial fisheries harvest data and seasonal inflows for the period 1962 through 1976, estimated gaged river inflows of 1.7 million acre-feet (2.1 billion m^3) per year are needed from the San Jacinto River Basin, in addition to 693 thousand acre-feet (886 million m^3) annual of ungaged inflow from the basin, to meet salinity and marsh inundation needs and maintain annual commercial fisheries harvests at no less than average historic levels for the 1962-1976 period (Harvest Maintenance Alternative) (Table 3). The estimated gaged freshwater inflows from the San Jacinto River Basin for meeting the Fisheries Harvest Enhancement Alternative, of maximizing the shrimp production of the adjacent offshore area (Gulf Area No. 18) to the estuary, equals the annual inflow limit set at the average (1941-1976) annual gaged basin inflow. This inflow volume is slightly less than 1.6 million acre-feet (2.0 billion m^3) (Table 3). Ungaged inflows from the basin are estimated at 693 thousand acre-feet (833 million m^3). The constraints of the Harvest Enhancement Alternative limits the annual inflow to no more than the 1941 through 1976 period average; since this limit was reached, it is believed, but not verified, that additional gaged inflow from the basin might increase the shrimp harvest. The maximum amount of additional inflow depends upon the lower salinity limits and has not been computed.

The estimated annual gaged inflow needs from the San Jacinto River Basin for the three Alternatives (Subsistence, Maintenance, and Enhancement) are 88, 106 and 100 percent, respectively, of the 1941 through 1976 mean annual gaged inflow from the basin. The number of years in the 36 year period of 1941 through 1976, for which the annual gaged inflow exceeded the estimated annual need were 17, 15, and 15 years, respectively, for the Subsistence, Maintenance, and Enhancement Alternatives.

Predicted total annual commercial fisheries harvests for the Trinity-San Jacinto estuary, including offshore shrimp harvests for Gulf Area No. 18 (the area roughly from Sabine Pass to Freeport and up to 100 miles offshore), amounts to approximately 21.9, 21.9, and 21.8 million pounds (9.93, 9.93, and 9.89 million kg) for the Subsistence, Maintenance, and Enhancement Alternatives, respectively. The freshwater inflow needs given for the three Alternatives may not be sufficient to achieve the predicted fisheries productivity if the water quality conditions in the estuary are further deteriorated by massive wastewater discharges entering the system from the Houston-Galveston area.

Lavaca-Tres Palacios Estuarine System

The Lavaca, Navidad and Colorado Rivers are the major contributing sources of freshwater inflow to the Lavaca-Tres Palacios estuary (Figure 7). The combined freshwater inflows to the Lavaca-Tres Palacios estuarine system averaged 2.9 million acre-feet (3.6 billion m^3) per year during the 1941 through 1976 period of record (Appendix III). Ungaged inflows averaged almost 0.97 million acre-feet (1.2 billion m^3) annually and gaged river inflows, including contributions from the Colorado River, accounted for an average of nearly 1.9 million acre-feet (2.3 billion m^3) annually (Table 1).

Because of the diking of the river banks along the lower Colorado River, marsh inundation of the Colorado River delta does not occur during river flooding. However, flooding of the Lavaca and Navidad Rivers does result in inundation of the Lavaca River delta. Thus, gaged flows from these rivers are considered in marsh inundation analysis. From 1941 through 1976, the average annual inflow of the Lavaca and Navidad Rivers to Lavaca Bay was 0.74 million acre-feet (913 million m^3). The average "bank-full" capacity of the river

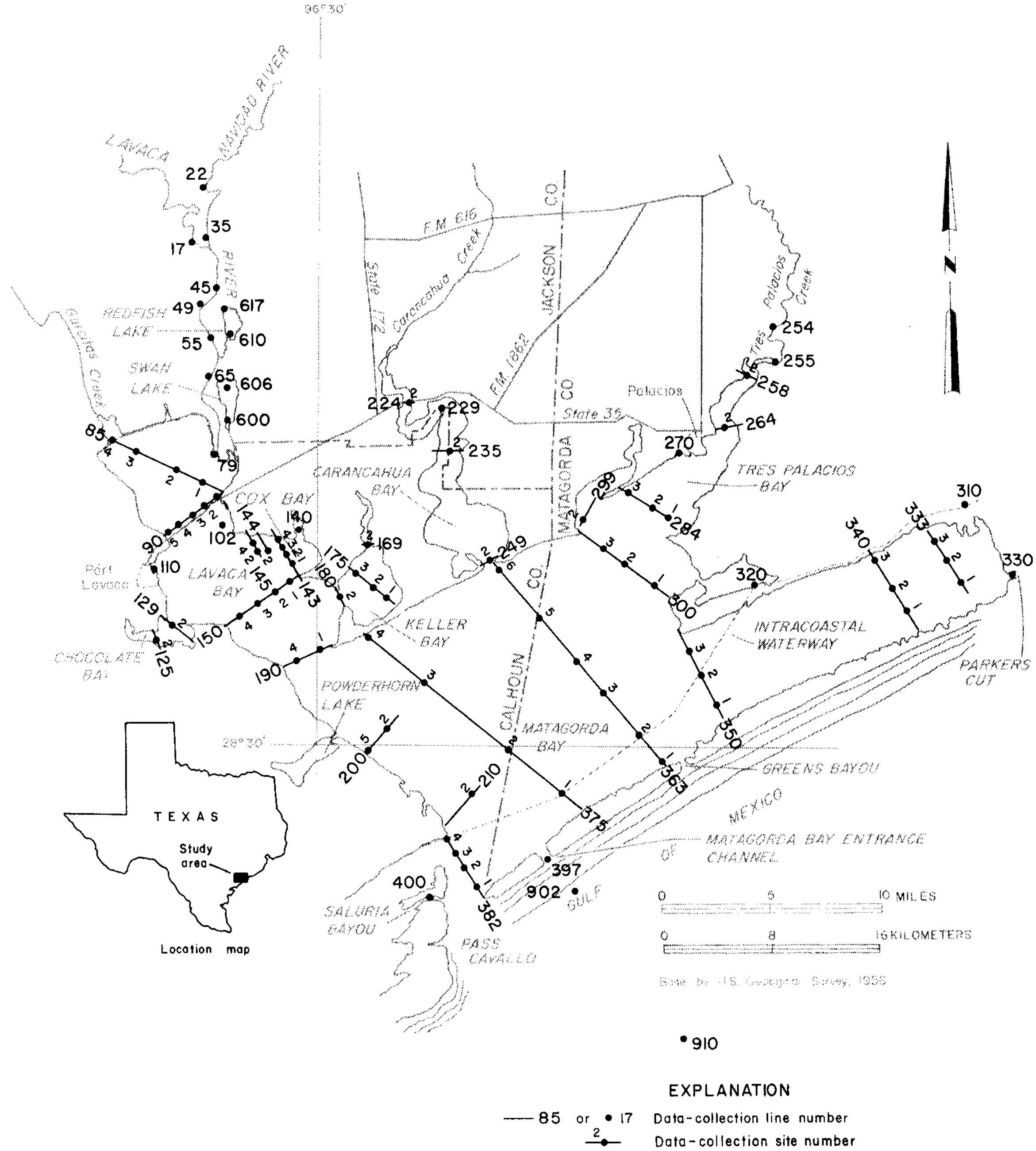

Figure 7. Lavaca-Tres Palacios Estuarine System

channel through the Lavaca delta is about 5,000 cubic feet per second (ft^3/sec) (142 m^3/sec). Based on the inflow records, it is estimated that a median of three flood events per year would provide inundation of the deltaic marsh complex with the same frequency which has occurred historically. The peak discharge of these flood events would be about 11,320 ft^3/sec (321 m^3/sec) and 10,370 ft^3/sec (294 m^3/sec) in the spring and fall, respectively, with total volumes of freshwater inflow at approximately 70,000 and 60,000 acre-feet (86 and 74 million m^3), respectively.

River inflow-salinity relationships were developed based on the Navidad River flows at the streamgage near Ganado and Lavaca River flows at the gaging station near Edna for a salinity response estimate in upper Lavaca Bay. Combining inundation and salinity conditions for the Subsistence Alternative yields a 0.35 million acre-feet (432 million m^3) per year estimate of gaged Lavaca River Basin inflows needed for the Lavaca Bay portion of this estuarine system (Table 4). Ungaged inflows from the basin are estimated at 72.0 thousand acre-feet (88.8 million m^3) annually. In meeting the Fisheries Maintenance Alternative, a gaged river inflow from the Lavaca River Basin of slightly more than 0.61 million acre-feet (752 million m^3) per year, in addition to the estimated 126 thousand acre-feet (155 million m^3) per year of ungaged inflow, is estimated to satisfy the salinity and marsh inundation needs and to maintain annual commercial fisheries harvests at levels greater than the mean harvests for the 1962-1976 period (Table 4). For the Harvest Enhancement Alternative, the gaged inflows from the Lavaca River Basin needed to maximize the annual commercial shellfish harvest of the estuary are estimated to be equal to the maximum annual inflow for this Alternative set at the average (1941-1976) annual gaged inflow. The estimated inflows from the ungaged portion of the basin total 126 thousand acre-feet (155 million m^3) yearly. This inflow volume equals 0.614 million acre-feet (757 million m^3) from the basin (Table 4). Since the inflow bound was reached it is believed but not verified that additional freshwater inflow (consistent with inundation and salinity limits) could increase the predicted shellfish harvest.

The annual gaged inflow needs from the Lavaca River Basin for the Subsistence, Maintenance, and Enhancement Alternatives correspond to 57, 99.9 and 100 percent, respectively, of the mean annual 1941 through 1976 period gaged inflows. The annual inflow needs were exceeded in 24, 16 and 16 of the years in the period 1941 through 1976 for the respective Alternatives above.

River inflow-salinity relationships were developed based upon Colorado River flows at the Bay City gaging station and salinities in the eastern arm of Matagorda Bay near Tiger Island Cut. Salinity analysis yields an 882.3 thousand acre-feet (1.08 billion m^3) per year estimate of gaged inflows to the eastern arm of Matagorda Bay portion of this estuarine system in order to sustain basic salinity gradients specified by the Subsistence Alternative (Table 4). The actual gaged flow at the last downstream gage on the Colorado River at Bay City of 1.11 million acre-feet (1.37 billion m^3) is estimated to supply the needed inflow of 882 thousand acre-feet (1.09 billion m^3) into the estuary, since the Colorado River delta has channels leading both to Matagorda Bay and to the Gulf and a portion of the gaged flow passes directly into the Gulf. For the Fisheries Maintenance Alternative, gaged river inflow needs of almost 1.27 million acre-feet (1.57 billion m^3) per year from the Colorado River Basin (corresponding to 1.8 million acre-feet or 2.2 billion m^3 of flow at the Bay City gage) are estimated to meet salinity and inundation needs and maintain the major commercial fisheries harvests categories at no less than their average historical levels for the 1962-1976 period (Table 4). For the Harvest Enhancement Alternative it is also established that maximizing the shellfish production in the estuary requires volumes of water from

Table 4. Gaged River Inflow Needs of the Lavaca-Tres Palacios Estuary Under Three Alternative Levels of Fisheries Productivity a/

	Lavaca River Basin b/						Colorado River Basin c/								
	Ecosystem Subsistence d/		Fisheries Harvest Maintenance e/		Shellfish Harvest Enhancement f/		Ecosystem Subsistence d/			Fisheries Harvest Maintenance e/			Shellfish Harvest Enhancement f/		
Month	Gaged Inflow (1000 ac-ft)	Salinity (ppt)	Gaged Inflow (1000 ac-ft)	Salinity (ppt)	Gaged Inflow (1000 ac-ft)	Salinity (ppt)	Gaged Flow (1000 ac-ft)	Gaged Inflow (1000 ac-ft)	Salinity (ppt)	Gaged Flow (1000 ac-ft)	Gaged Inflow (1000 ac-ft)	Salinity (ppt)	Gaged Flow (1000 ac-ft)	Gaged Inflow (1000 ac-ft)	Salinity (ppt)
January	21.8	13.0	21.8	13.0	21.8	13.0	88.1	70.0	19.0	88.1	70.0	19.0	88.1	70.0	19.0
February	26.8	12.0	26.8	12.0	26.8	12.0	99.2	73.0	19.0	99.2	73.0	19.0	92.1	73.0	19.0
March	17.0	12.0	17.0	12.0	17.0	12.0	76.4	62.3	19.0	76.4	62.3	19.0	76.4	62.3	19.0
April	59.0	9.2	71.7	8.5	106.4	7.2	101.1	80.3	20.0	133.2	100.5	18.6	101.1	80.3	20.0
May	56.1	8.8	104.8	6.8	154.3	5.8	139.7	106.3	19.0	188.0	135.0	17.7	139.7	106.3	19.0
June	32.0	9.0	106.4	5.6	153.8	4.8	105.4	82.3	19.0	160.8	116.0	17.3	105.4	82.3	19.0
July	15.6	11.0	18.4	10.0	15.6	11.0	53.4	45.5	21.0	53.4	46.5	21.0	162.5	98.4	14.3
August	10.4	17.0	35.1	10.0	10.4	17.0	49.1	45.2	24.0	49.1	45.2	24.0	109.7	77.8	17.1
September	24.2	13.0	97.1	7.3	24.2	13.0	147.7	109.8	20.0	147.7	109.8	20.0	147.7	109.8	20.0
October	48.8	8.4	77.8	6.9	48.8	8.4	91.6	75.0	20.0	91.6	75.0	20.0	91.6	75.0	20.0
November	17.6	13.0	17.6	13.0	17.6	13.0	79.5	65.0	19.0	387.7	230.7	13.5	383.7	228.7	13.5
December	17.5	14.0	17.6	14.0	17.5	14.0	82.2	66.6	19.0	322.3	209.6	13.6	325.1	211.1	13.6
Annual	346.8		612.1		614.2		1,113.4	882.3		1,797.5	1,273.6		1,830.2	1,275.0	

a/ All inflows are mean monthly values.

b/ These values computed using regression equations relating monthly river basin inflow to the estuary with monthly gaged inflows at USGS Stations #0816400 (Edna) and #08164500 (Ganado). Salinities are predicted values in upper Lavaca Bay.

c/ These values computed using regression equations relating monthly river basin inflow to the estuary with monthly gaged inflows at USGS Station #08162500 (Bay City). The gage flow values represent the monthly flow at Bay City required to give the gaged inflow value in the corresponding month, since a portion of the flow at the Bay City gage passes directly to the Gulf of Mexico. Salinities are predicted values in the eastern end of Matagorda Bay near Tiger Island Cut.

d/ The predicted annual commercial fisheries harvest for this Alternative is 285 thousand pounds of finfish and 2,894 thousand pounds of shellfish.

e/ The predicted annual commercial fisheries harvest for this Alternative is 364 thousand pounds of finfish and 2,927 thousand pounds of shellfish.

f/ The predicted annual commercial fisheries harvest for this Alternative is 285 thousand pounds of finsifh and 3,719 thousand pounds of shellfish.

the Colorado River Basin equal to the annual inflow limit set at the average (1941-1976) annual gaged inflow. This inflow volume is 1.28 million acrefeet (1.58 billion m^3) (Table 4). Since the upper limit on annual freshwater inflow was met, it is believed, but not fully verified, that additional inflow from the basin (consistent with salinity and inundation bounds) could increase the annual shellfish harvest.

The estimated gaged annual inflow needs from the Colorado River Basin for the Subsistence, Maintenance, and Enhancement Alternatives represent approximately 67, 99.9, and 100 percent of the mean annual inflow for the years 1941 through 1976. The annual inflow during these years exceeded the estimated annual need for each of the above Alternatives in 21, 16 and 16 of the 36 years, respectively.

The predicted total annual commercial fisheries harvests for the Lavaca-Tres Palacios estuary amount to approximately 3.18, 3.29, and 4.0 million pounds (1.44, 1.49, and 1.8 million kg) for freshwater inflow needs specified for the Subsistence, Maintenance, and Enhancement Alternatives, respectively.

Guadalupe Estuarine System

The Guadalupe and San Antonio Rivers are the major rivers discharging into the Guadalupe estuary (Figure 8). The combined freshwater inflow for the Guadalupe estuarine system averaged 2.27 million acre-feet (2.80 billion m^3) per year during the 1941 through 1976 period of record (Appendix III). Ungaged inflows averaged 0.46 million acre-feet (567 million m^3) annually and gaged river inflows accounted for an average of 1.8 million acre-feet (2.2 billion m^3) annually (Table 1).

The Guadalupe River delta is one of the most hydraulically complex marsh areas on the Texas Coast. Ten bayous and channels, including the main channel for the Guadalupe River, supply freshwater inflows to approximately 4,500 acres (2,370 hectares) of marsh located south of State Highway 35 between the Victoria Barge Canal and the community of Tivoli. Inundation of this deltaic marsh complex begins when the combined flow rate of the ten bayous and channels reaches about 4,000 ft^3/sec (113 m^3/sec). Based on the 1941 through 1976 inflow records, it is estimated that a median of three flood events would be necessary to sufficiently inundate the marsh complex with the same frequency which has occurred historically. The peak discharge of these flood events would be about 12,500 ft^3/sec (354 m^3/sec), and the total volume of freshwater inflow associated with each event approximately 125,000 acre-feet (154 million m^3).

A river inflow-salinity relationship was developed based on the Guadalupe River flows at the Victoria gaging station and San Antonio River flows at the Goliad gaging station for a salinity response in the middle of San Antonio Bay. Gaged freshwater inflows to meet marsh inundation and salinity needs for the Subsistence Alternative are estimated at 1.24 million acre-feet (1.53 billion m^3) per year from the Guadalupe River Basin, in addition to 250 thousand acre-feet (308 million m^3) per year of ungaged inflow from the basin, for this estuarine system (Table 5). The predicted total annual commercial fisheries harvest for the estuary under this Alternative amounts to almost 2.09 million pounds (.948 million kg). The estimated annual inflows to maintain commercial fishery harvests in the estuary (Harvest Maintenance Alternative) at no less than the average 1962 through 1976 harvests total 1.62 million acre-feet (2.0 billion m^3), with an additional 317 thousand acre-feet (391 million m^3) needed from ungaged portions of the basin (Table 5). Approximately 2.37 million pounds (1.08 million kg) annually of finfish and shellfish commercial harvest in the estuary is predicted under these freshwater inflows. It is also established that the Fisheries Harvest Enhancement Alternative objective of maximizing the shrimp production in the estuary requires volumes of water from the Guadalupe River Basin equal to the annual inflow limit set at the average annual gaged inflow for the

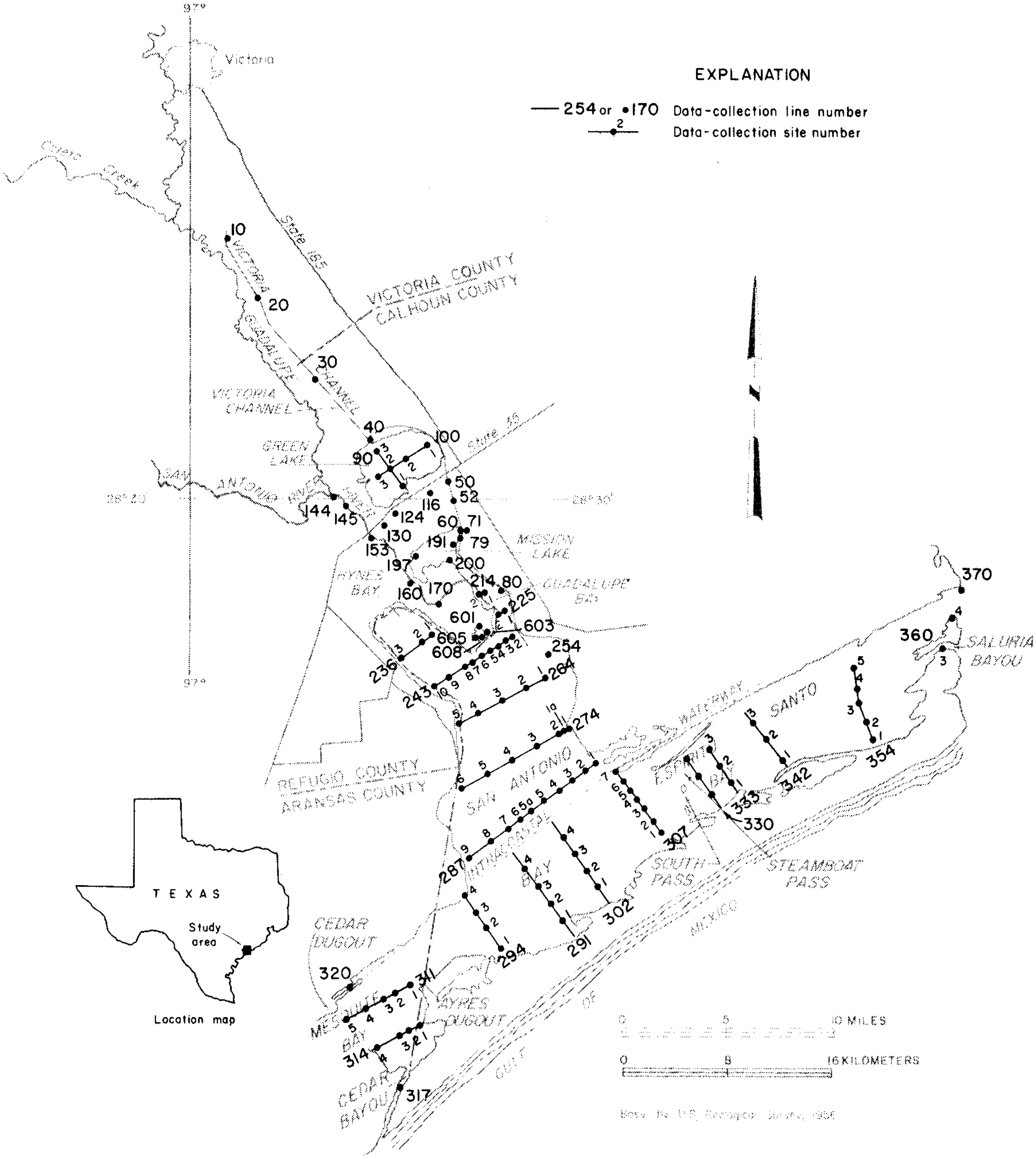

Figure 8. Guadalupe Estuarine System

Table 5. Gaged River Inflow Needs of the Guadalupe Estuary Under Three Alternative Levels of Fisheries Productivity a/

Month	Guadalupe River Basin b/					
	Ecosystem Subsistence c/		Fisheries Harvest Maintenance d/		Shrimp Harvest Enhancement e/	
	Gaged Flow (1000 ac-ft)	Salinity (ppt)	Gaged Flow (1000 ac-ft)	Salinity (ppt)	Gaged Flow (1000 ac-ft)	Salinity (ppt)
January	86.4	20.0	116.4	16.6	279.6	10.0
February	96.2	18.0	136.9	13.5	196.8	10.0
March	80.3	18.0	111.6	13.5	156.5	10.0
April	134.1	15.0	162.2	13.3	152.4	13.8
May	138.1	12.0	255.8	6.7	240.6	7.1
June	104.0	12.9	193.5	7.9	182.1	8.3
July	57.6	20.0	57.6	20.0	57.6	20.0
August	80.6	20.0	80.6	20.0	80.6	20.0
September	207.8	15.0	207.8	15.0	207.8	15.0
October	104.0	14.7	104.0	14.7	118.1	13.1
November	76.9	18.0	101.4	14.1	76.9	18.0
December	76.5	20.0	91.9	16.9	76.5	20.0
Annual	1,240.7		1,619.7		1,825.5	

a/ All inflows are mean monthly values.

b/ These values computed using regression equations relating monthly river basin inflow to the estuary with monthly gaged flows at USGS Stations on the Guadalupe River at Victoria and San Antonio River near Goliad.

c/ The predicted annual commercial fisheries harvests for this Alternative are 104 thousand pounds of finfish and 1,983 thousand pounds of shellfish.

d/ The predicted annual commercial fisheries harvests for this Alternative are 211 thousand pounds of finfish and 2,162 thousand pounds of shellfish.

e/ The predicted annual commercial fisheries harvests for this Alternative are 110 thousand pounds of finfish and 2,162 thousand pounds of shellfish.

period 1941-1976. The gaged inflow need is approximately 1.8 million acre-feet (2.2 billion m^3) from the basin (Table 5), with the resulting estuarine annual commercial harvest of finfish and shellfish predicted at 2.27 million pounds (1.03 million kg). The ungaged inflow is estimated at 353 thousand acre-feet (435 million m^3) annually from the Guadalupe River Basin. Since the estimated inflow need equals the upper limit on inflow analyzed in this study, it is likely that additional freshwater inflow (consistent with salinity and marsh inundation limits) will increase the predicted shrimp harvest.

The estimated annual gaged inflow need for Subsistence, Maintenance, and Enhancement Alternatives corresponds to 69, 90, and 101 percent, respectively, of the mean annual gaged inflow from 1941 through 1976. The annual estimated need was less than the historical gaged inflow in 14, 18 and 21 of the 36 years in the 1941 through 1976 period for the above Alternatives, respectively.

Mission-Aransas Estuarine System

The Mission and Aransas River Basins are the major river systems contributing freshwater inflow into the Mission-Aransas estuary (Figure 9). The combined freshwater inflow for the Mission-Aransas estuarine system averaged 386 thousand acre-feet (476 million m^3) per year during the 1941 through 1976 period of record (Appendix III). Ungaged inflows averaged 276 thousand acre-feet (340 million m^3) annually and gaged river inflows accounted for an average of 104 thousand acre-feet (128 million m^3) annually (Table I).

The river deltas of the Mission and Aransas Rivers are of limited areal extent and, therefore, were not considered of sufficient significance to warrant extensive analysis to estimate freshwater needed for marsh inundation.

River inflow-salinity relationships were developed based on the Mission River flows at Refugio, the most downstream gaging station, for the salinity response in upper Copano Bay. Estimates for the gaged inflows to sustain the desired salinity limits for the Subsistence Alternative yields a 15.4 thousand acre-feet (19 million m^3) annual gaged inflow volume (Table 6). The inflows needed annually, from the gaged portion of the Mission River (Table 6), to maintain the average 1962 through 1976 commercial fisheries harvests (Fisheries Harvest Maintenance Alternative) for the combined Mission-Aransas and Nueces estuaries totals 19.4 thousand acre-feet (24 million m^3). For the Harvest Enhancement Alternative, it is established that maximizing the finfish production in the Mission-Aransas and Nueces estuaries requires volumes of water from the contributing areas of the estuary equal to the annual inflow limit set at the average (1941-1976) annual inflows of 386 thousand acre-feet (476 million m^3) from the basin, with an annual gaged inflow need of 42.7 thousand acre-feet (53 million m^3) from the Mission River basin (Table 6). Since the estimated freshwater inflow need equals the upper limit on inflow, it is likely that additional inflow (consistent with salinity limits) will increase the annual finfish harvest.

The estimated annual gaged inflow needs from the Mission River Basin for the Subsistence, Maintenance, and Enhancement Alternatives correspond to 18, 23, and 51 percent, respectively, of the mean annual 1941 through 1976 gaged flow from the basin. In 29 of the 36 years from 1941 through 1976, the historical annual gaged inflow exceeded the annual gaged inflow needs of the first two Alternatives above, while in 21 of the years, the annual need for the Enhancement Alternative was exceeded by the recorded gaged inflow.

Nueces Estuarine System

The Nueces River is the primary source of freshwater inflow to the Nueces estuary (Figure 10). The combined gaged and ungaged freshwater inflow for the Nueces estuarine system averaged 682 thousand

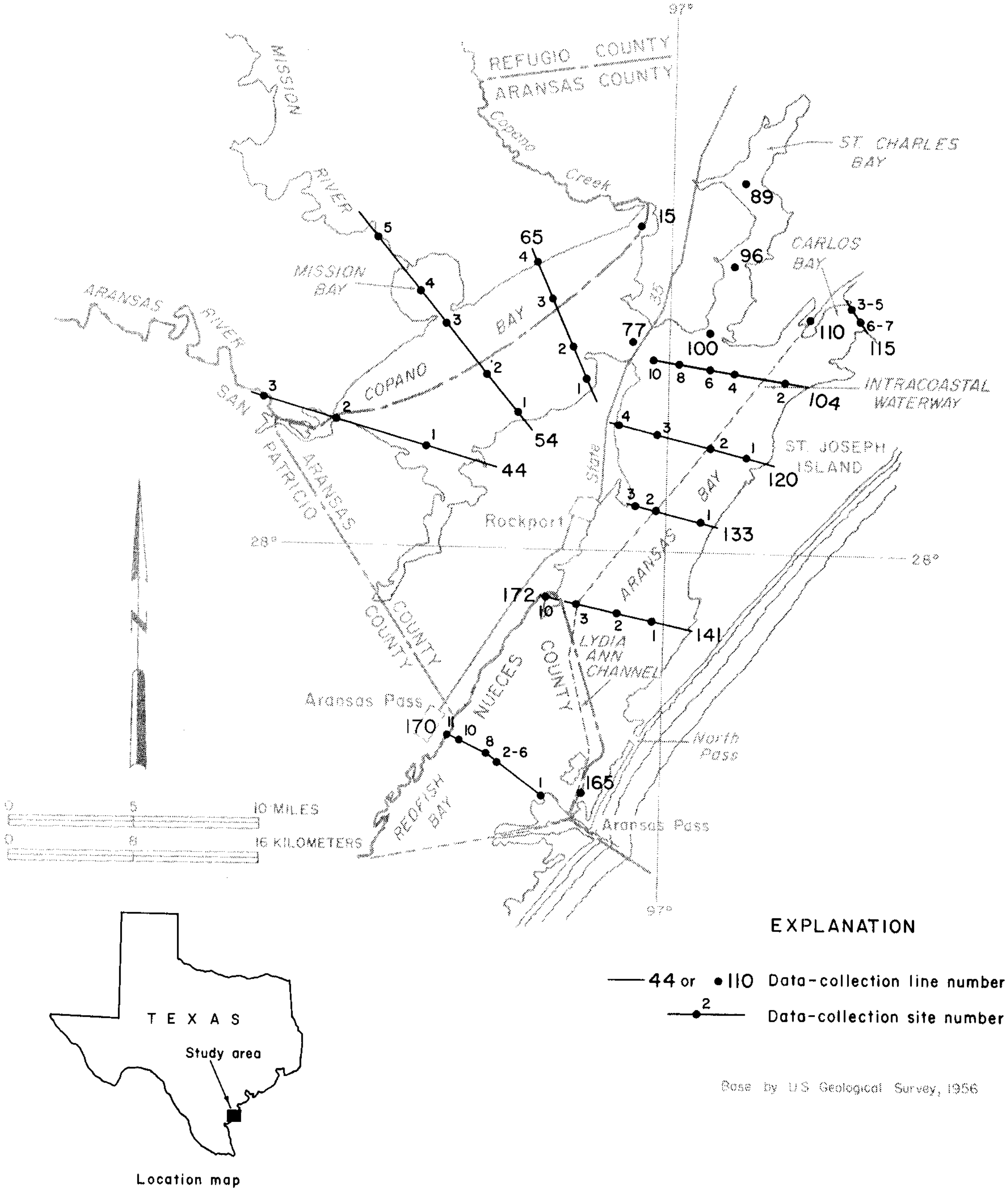

Figure 9. Mission-Aransas Estuarine System

Table 6. Gaged River Inflow Needs of the Mission-Aransas Estuary Under Three Alternative Levels of Fisheries Productivity a/

Month	Mission River Basin b/					
	Ecosystem Subsistence c/		Fisheries Harvest Maintenance d/		Finfish Harvest Enhancement e/	
	Gaged Flow (1000 ac-ft)	Salinity (ppt)	Gaged Flow (1000 ac-ft)	Salinity (ppt)	Gaged Flow (1000 ac-ft)	Salinity (ppt)
January	.7	16.0	.7	16.0	.7	16.0
February	1.2	15.0	1.2	15.0	1.2	15.0
March	.9	15.0	.9	15.0	.9	15.0
April	1.5	15.0	1.5	15.0	3.9	12.5
May	2.9	12.0	2.9	12.0	9.9	8.1
June	1.8	11.0	1.8	11.0	6.3	7.6
July	.8	15.0	2.8	10.0	2.8	10.0
August	.8	18.0	1.8	15.0	9.1	10.0
September	1.9	14.0	1.9	14.0	1.9	14.0
October	1.2	13.0	1.2	13.0	1.2	13.0
November	.9	14.0	.9	14.0	1.9	10.0
December	.9	15.0	1.8	11.9	2.9	10.0
Annual	15.5		19.4		42.7	

a/ All inflows are mean monthly values

b/ These values computed using regression equations relating monthly river basin inflow to the estuary with monthly gaged inflows at USGS Station on the Mission River at Refugio.

c/ The predicted annual combined commercial fisheries harvests for the Mission-Aransas and Nueces estuaries for this Alternative are 858 thousand pounds of finfish and 2,937 thousand pounds of shellfish.

d/ The predicted annual combined commercial fisheries harvests for the Mission-Aransas and Nueces estuaries for this Alternative are 1,087 thousand pounds of finfish and 3,143 thousand pounds of shellfish.

e/ The predicted annual combined commercial fisheries harvests for the Mission-Aransas and Nueces estuaries for this Alternative are 1,663 thousand pounds of finfish and 3,683 thousand pounds of shellfish.

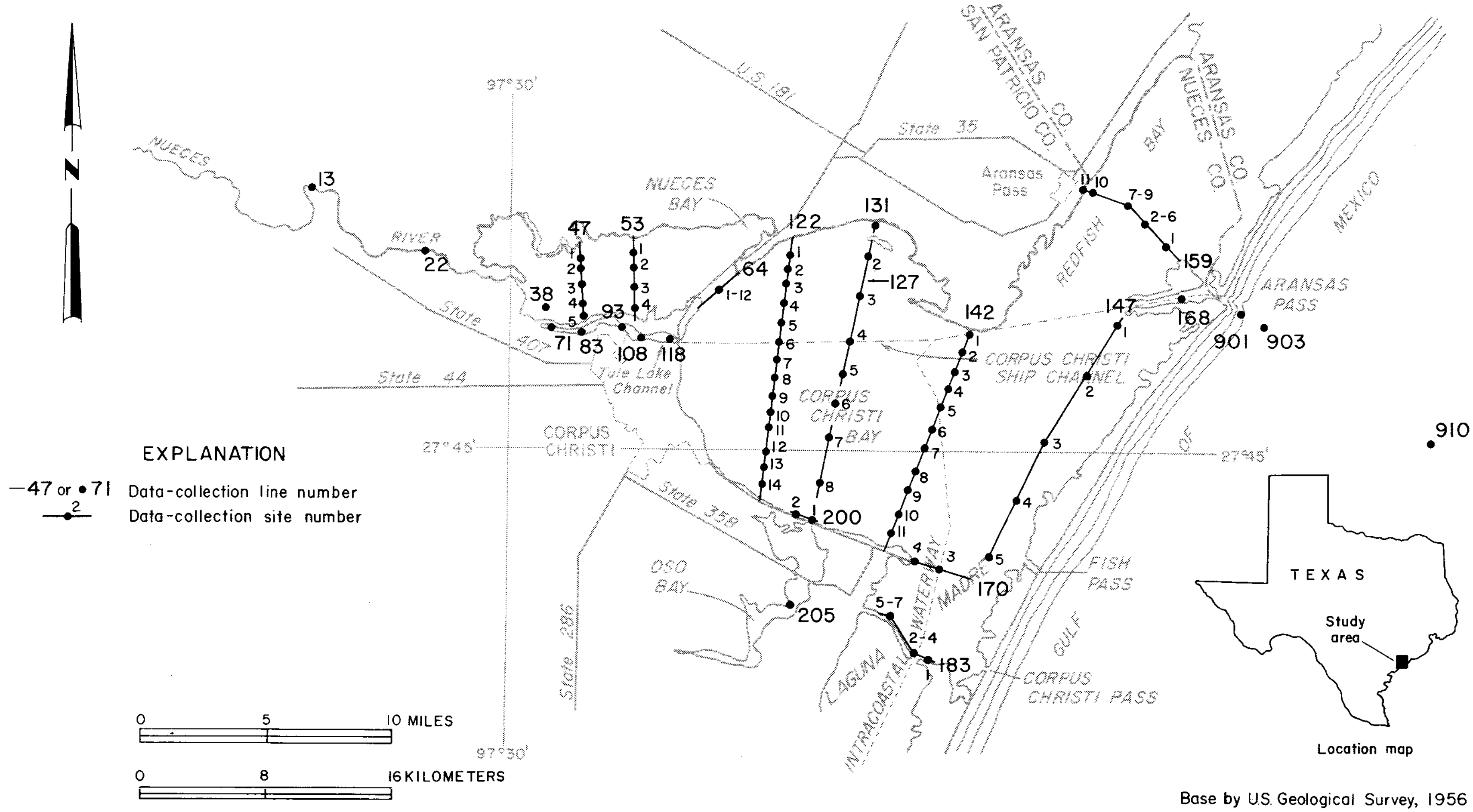

Figure 10. Nueces Estuarine System

acre-feet (841 million m^3) per year during the 1941 through 1976 period of record (Appendix III). Ungaged inflows averaged 78 thousand acre-feet (96 million m^3) annually and gaged river inflows accounted for an average of 575 thousand acre-feet (709 million m^3) per year (Table 1).

The Nueces River delta is a marsh complex containing approximately 9,500 acres (5,000 hectares) of marsh between zero and five feet above mean sea level. The average "bank full" capacity of the Nueces River immediately downstream from the Calallen Diversion Dam (the last control structure above the river mouth) is about 5,000 ft^3/sec (142 m^3/sec). Based on the historic inflow records, it is estimated that a median of two flood events annually (one in May and one in September) is necessary to sufficiently inundate the deltaic marsh with historic frequency. Crest discharge of each May flood event would be about 8,500 ft^3 sec (241 m^3/sec), with a total volume of freshwater inflow of approximately 79,000 acre-feet (97 million m^3). The peak discharge of the fall flood event would be 11,000 ft^3/sec (312 m^3/sec), with a total volume of 139,000 acre-feet (171 million m^3).

A river inflow-salinity relationship was developed based on the Nueces River flows recorded at the Mathis gaging station for the purpose of estimating salinity response in upper Nueces Bay. An annual inflow of 356 thousand acre-feet (439 million m^3) per year of gaged inflows is estimated as needed to sustain inundation processes and desired salinity regimes for this estuarine system (Subsistence Alternative) (Table 7). Based upon relationships derived between 1962 through 1976 commercial fishery harvests and seasonal inflows, a 397 thousand acrefeet (490 million m^3) per year estimate of gaged Nueces River inflows (Table 7) is necessary to meet the objective of the Fisheries Harvest Maintenance Alternative of maintaining fishery harvests of the Nueces and Mission-Aransas estuaries at no less than mean historical levels (1962-1976 period) as well as meeting salinity bounds and inundation needs. It is also estimated that the Fisheries Harvest Enhancement Alternative objective of maximizing finfish production in the Nueces and Mission-Aransas estuaries requires volumes of water from the Nueces River Basin equal to the annual inflow set at the average 1941 through 1976 annual inflow of 604 thousand acre-feet (745 million m^3) from the basin, with the annual gaged inflow from the basin being 550 thousand acre-feet (678 million m^3) (Table 7). Additional inflow from the Nueces River Basin might increase the estimated finfish harvest (consistent with marsh inundation and salinity limits); however, the quantity of inflow that would maximize the finfish harvest has not been computed.

The estimated gaged annual inflow needs to the estuary from the Nueces River Basin for the three Alternatives (Subsistence, Maintenance, and Enhancement) correspond to inflow rates equal to 62, 69, and 96 percent, respectively, of the 1941 through 1976 historical mean annual gaged inflow. In 17 of the 36 years from 1941 through 1976, the recorded annual gaged inflow exceed the gaged annual inflow need of the Subsistence Alternative; while in 15 and 13 of the years in the same period, the annual gaged inflow was greater than the estimated need for the Maintenance and Enhancement Alternative, respectively.

Combined predicted annual commercial finfish and shellfish harvests for the Nueces and Mission-Aransas estuaries total about 3.8, 4.2, and 5.3 million pounds (1.7, 1.9, and 2.4 million kg) under the monthly freshwater inflows specified for the Subsistence, Maintenance and Enhancement Alternatives, respectively.

Laguna Madre Estuarine System

The Laguna Madre estuarine system (Figure 11) receives freshwater inflow only from adjacent ungaged drainage areas. There are no major river basins which drain directly into this vast lagoon, although the Rio Grande has limited influence on the

Table 7. Gaged River Inflow Needs of the Nueces Estuary Under Three Alternative Levels of Fisheries Productivity a/

Month	Nueces River Basin b/					
	Ecosystem Subsistence c/		Fisheries Harvest Maintenance d/		Finfish Harvest Enhancement e/	
	Gaged Inflow (1000) ac-ft)	Salinity (ppt)	Gaged Inflow (1000) ac-ft)	Salinity (ppt)	Gaged Inflow (1000) ac-ft)	Salinity (ppt)
January	6.5	27.0	6.5	27.0	6.5	27.0
February	7.2	26.0	7.2	26.0	7.2	26.0
March	7.9	25.0	7.9	25.0	7.9	25.0
April	21.5	20.0	21.5	20.0	21.5	20.0
May	72.8	13.9	72.8	13.9	66.7	13.9
June	30.5	14.0	30.5	14.0	50.1	12.3
July	19.8	16.0	34.5	13.9	84.2	11.0
August	12.2	20.0	20.4	16.9	50.6	12.5
September	129.2	12.2	129.2	12.2	129.2	12.2
October	30.8	15.0	30.8	15.0	30.8	15.0
November	11.2	18.0	27.2	12.2	42.9	10.0
December	6.2	25.0	8.1	22.3	52.5	10.0
Annual	355.8		396.6		550.1	

a/ All inflows are mean monthly values.
b/ These values computed using regression equations relating monthly river basin inflow to the estuary with monthly gaged inflows at the USGS Station on the Mission River at Refugio.
c/ The predicted annual combined commercial fisheries harvests for the Mission-Aransas and Nueces estuaries for this Alternative are 858 thousand pounds of finfish and 2,937 thousand pounds of shellfish.
d/ The predicted annual combined commercial fisheries harvests for the Mission-Aransas and Nueces estuaries for this Alternative are 1,087 thousand pounds of finfish and 3,143 thousand pounds of shellfish.
e/ The predicted annual combined commercial fisheries harvests for the Mission-Aransas and Nueces estuaries for this Alternative are 1,663 thousand pounds of finfish and 3,683 thousand pounds of shellfish.

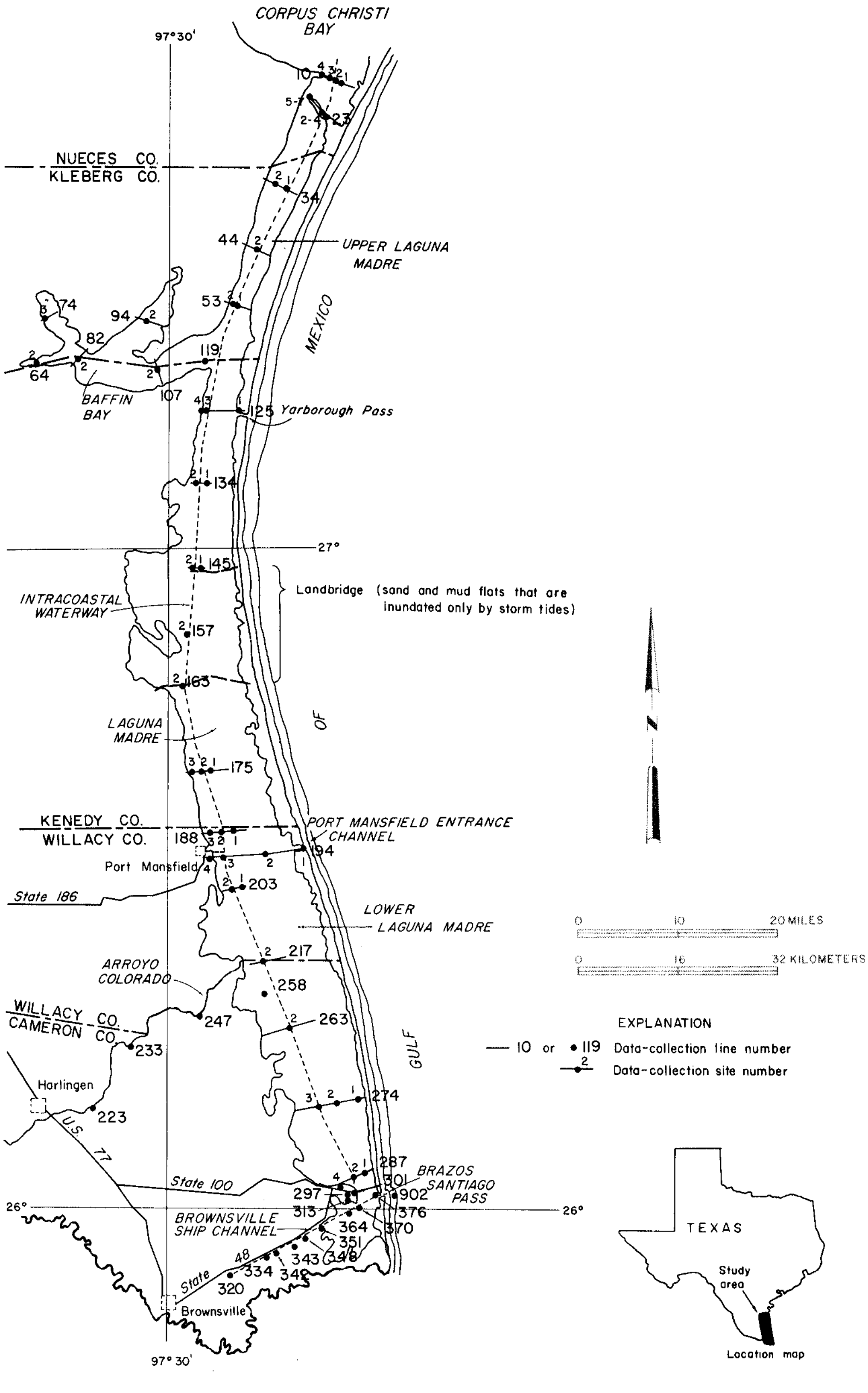

Figure 11. Laguna Madre Estuarine System

system. The Rio Grande provides some freshwater indirectly through the passage of mixed river and Gulf waters into the estuary via Brazos Santiago Pass, and through the routing of excess floodwaters and municipal, agricultural, and manufacturing wastewater discharges into the Rio Grande Floodway and the Arroyo Colorado which empty into the lower Laguna Madre. Nevertheless, the Laguna Madre estuarine system ranks first on the Texas Coast in annual finfish harvest.

The combined freshwater inflow for the Laguna Madre estuary averaged 689 thousand acre-feet (850 million m^3) per year during the 1941 through 1976 period of record (Appendix III). Ungaged inflows averaged 308 thousand acre-feet (380 million m^3) annually and gaged inflows from San Fernando Creek, Los Olmos Creek, Arroyo Colorado, and the North Floodway averaged some 335 thousand acre-feet (413 million m^3) (Table 1). Ungaged return flows from municipal, manufacturing, and irrigation purposes in the lower Rio Grande Valley averaged some 46 thousand acre-feet (56.7 million m^3) annually of inflow contribution.

The river deltas in lower Laguna Madre and Baffin Bay are of limited areal extent and are thus not considered of sufficient significance to warrant extensive analysis to estimate the freshwater needed for marsh inundation.

River inflow-salinity relationships were developed based on the total gaged flows of San Fernando (at Alice) and Los Olmos Creeks (near Falfurrias) for the salinity response in upper (western) Baffin Bay. Monthly relationships were also estimated for the gaged flow of the Arroyo Colorado and the salinity in lower Laguna Madre at the intersection of the Arroyo Colorado and the Gulf Intracoastal Waterway. Estimates for the annual gaged inflows to sustain the desired salinity limits for the Subsistence Alternative yield 4.2 thousand acre-feet (5.2 million m^3) and 177.7 thousand acre-feet (219.2 million m^3) of gaged inflow into Baffin Bay and lower Laguna Madre, respectively (Table 8). The inflows needed annually from the gaged portion of the drainage area of Baffin Bay and lower Laguna Madre (Table 8) to maintain the average 1962 through 1976 commercial fisheries harvest (Fisheries Harvest Maintenance Alternative) totals 5.9 thousand acre-feet (7.3 million m^3) and 278.8 thousand acre-feet (344 million m^3), respectively. For the Harvest Enhancement Alternative, it is estimated that maximizing the finfish commercial harvest in the Laguna Madre estuary requires volumes of water from the contributing areas of the estuary equal to the annual inflow limit set at the average 1941-1946 annual inflows of 689 thousand acre-feet (850 million m^3), with the annual gaged inflow need of 8.8 thousand acre-feet (10.9 million m^3), from the Baffin Bay drainage area (Table 8) and 283 thousand acre-feet (349 million m^3) from the lower Laguna Madre drainage basin.

The estimated annual gaged inflow needs from the Baffin Bay drainage area for the Subsistence, Maintenance, and Enhancement Alternatives correspond to 20, 28, and 42 percent, respectively, of the mean annual 1941 through 1976 gaged flow from the contributing area. In 18 of the 36 years from 1941 through 1976 the historical annual gaged inflow exceeded the annual gaged inflow needs of the first Alternative above, while in 17 and 15 of the years the annual needs for the Maintenance and Enhancement Alternatives, respectively, were exceeded by the recorded gaged inflow.

The estimated annual gaged inflow needs from the lower Laguna Madre drainage area for the Subsistence, Maintenance, and Enhancement Alternatives correspond to 56, 88, and 90 percent, respectively, of the mean annual 1941 through 1976 gaged flow from the contributing basin. In 16 of the 36 years from 1941 through 1976 the historical annual gaged inflow exceeded the annual gaged inflow needs of the last two Alternatives above, while in 23 of the years, the annual need for the Subsistence Alternative was exceeded by the recorded gaged inflow.

The predicted total annual commercial fisheries harvests for the Laguna Madre estuary amount to approximately 9.8, 11.6,

Table 8. Gaged River Inflow Needs of the Laguna Madre Estuary Under Three Alternative Levels of Fisheries Productivity a/

Month	Baffin Bay and Upper Laguna Madre b/						Lower Laguna Madre c/					
	Ecosystem Subsistence d/		Fisheries Harvest Maintenance e/		Finfish Harvest Enhancement f/		Ecosystem Subsistence d/		Fisheries Harvest Maintenance e/		Finfish Harvest Enhancement f/	
	Gaged Inflow (1000 ac-ft)	Salinity (ppt)	Gaged Inflow (1000 ac-ft)	Salinity (ppt)	Gaged Inflow (1000 ac-ft)	Salinity (ppt)	Gaged Inflow (1000 ac-ft)	Salinity (ppt)	Gaged Inflow (1000 ac-ft)	Salinity (ppt)	Gaged Inflow (1000 ac-ft)	Salinity (ppt)
January	.13	33.0	.08	33.1	.13	33.0	10.35	42.0	10.35	42.0	26.15	26.2
February	.08	33.5	.11	35.0	.26	24.0	10.52	38.0	10.52	38.0	23.18	29.1
March	.25	29.0	.23	29.0	.07	29.0	11.55	40.0	11.55	40.0	18.93	31.0
April	.08	26.3	.39	18.7	.88	14.2	15.69	35.0	15.69	35.0	15.69	35.0
May	.48	28.0	1.29	18.8	2.74	13.9	16.54	34.0	16.54	34.0	16.54	34.0
June	.61	16.8	.55	13.7	1.24	10.0	16.40	33.0	23.38	29.2	16.40	33.0
July	.36	14.0	1.02	11.6	1.05	10.0	12.65	37.0	17.25	32.5	12.65	37.0
August	.58	14.0	.57	10.7	.78	10.0	10.99	39.0	19.86	32.7	10.99	39.0
September	.97	15.0	.97	15.0	.98	14.2	25.96	29.0	68.59	19.8	62.50	20.5
October	.16	13.0	.20	12.7	.41	11.5	19.48	31.0	57.50	19.3	52.40	20.1
November	.46	15.0	.42	15.0	.21	15.0	13.86	36.0	13.86	36.0	13.86	36.0
December	.07	15.0	.11	15.0	.07	24.0	13.73	37.0	13.73	37.0	13.73	37.0
Annual	4.23		5.94		8.82		177.72		278.83		283.01	

a/ The upper and lower portions of the estuary are separated by the "land cut." All inflows are mean monthly values.
These values computed using regression equations relating monthly stream inflow to the upper estuary with total monthly gaged flows at the USGS Stations on San Fernando Creek at Alice #08211900 and on Los Almos Creek near Falfurrias #08212400. Salinities are predicted values in west Baffin Bay.

c/ These values computed using regression equations relating monthly stream inflow to the lower estuary with total monthly gaged flows at the USGS Stations on the Arroyo Colorado near Harlingen #08470400 and on the North Floodway near Sebastian #08470200. Salinities are predicted values at the intersection of the Arroyo Colorado and the Gulf Intracoastal Waterway.

d/ The predicted annual commercial fisheries harvest for this Alternative is 2,397 thousand pounds of finfish and 7,443 thousand pounds of shellfish.

e/ The predicted annual commercial fisheries harvest for this Alternative is 2,728 thousand pounds of finfish and 8,505 thousand pounds of shellfish.

f/ The predicted annual commercial fisheries harvest for this Alternative is 3,091 thousand pounds of finfish and 10,045 thousand pounds of shellfish.

and 13.1 million pounds (4.4, 5.3, and 5.9 million kg) for the freshwater inflow needs specified for the Subsistence, Maintenance and Enhancement Alternatives, respectively. These harvest estimates include the shrimp harvest from the adjacent offshore area (Gulf Area No. 21).

Influence of Freshwater Inflow from Texas on Texas Offshore Shrimp Harvests

The previous sections have described the responses of estuarine fisheries to the volume and seasonal timing of freshwater inflows to seven major Texas estuaries. Although estuarine fisheries are environmentally and economically important, the offshore fisheries harvests in the Gulf of Mexico yields more pounds annually of commercial catch than inshore (estuarine) harvests. This is particularly true with commercial shrimp harvests since about 60 percent of the white shrimp landings and 95 percent of the brown and pink shrimp landings made in Texas are contributed from areas in the adjacent Gulf of Mexico. Thus, it is important to relate the quantity of offshore fisheries production to seasonal freshwater inflows.

Eighteen years (1959-1976) of offshore shrimp harvest, offshore commercial fishing effort (number of fishing trips per year), and associated total gaged and ungaged freshwater inflows to the major contributing estuaries were analyzed. Shrimp harvest and fishing effort data for the Texas Gulf Coast from ten miles west of Sabine Pass to the mouth of the Rio Grande are used. Seasonal inflows to each estuary include inflow from all contributing river and coastal drainage basins. The sum of the inflows to the Trinity-San Jacinto, Lavaca-Tres Palacios, Guadalupe, Mission Aransas, and Nueces estuaries produces a seasonal inflow data base that reflects both the wet and dry climatic cycles experienced by Texas. The Sabine-Neches estuary is omitted since it presently exhibits a low level of shrimp production and has an associated offshore fishing zone (Gulf Area No. 17) for which a significant portion lies offshore from Louisiana, and thus is most likely influenced significantly by inflows from Louisiana.

The analysis mentioned above results in a significant harvest relationship (equation) for each of three shrimp harvest components: (1) white shrimp, (2) brown and pink shrimp, and (3) all shrimp. The best significant equation explains 70 percent of the annual variations in the harvests of all shrimp. Shrimp harvests are found to increase with increases in fishing effort and spring (April-June) inflow, and decreases with increasing winter (January-March) and summer (JulyAugust) inflows. Other seasonal inflows do not relate significantly to offshore shrimp harvests, except for autumn (SeptemberOctober) inflow which is predicted to decrease the brown and pink shrimp harvest with increasing inflow. During the 18 year interval analyzed, the average annual harvest of white, brown, and pink shrimp in the Texas Gulf was 49.4 million pounds, caught by an average 21,216 fishing trips per year. Similarly, the average inflow of correlating seasons was 2.9 million acre-feet (3.6 billion m^3) in winter, 4.2 million acre-feet (5.2 billion m^3) in spring, 1.3 million acre-feet (1.6 billion m^3) in summer, and 2.0 million acre-feet (2.5 billion m^3) in autumn. Late fall (November-December) season inflows averaged 1.7 million acre-feet (2.1 billion m^3).

Interpretation of Estimated Freshwater Inflow Needs

Estimated freshwater inflow needs given for selected major estuarine systems in this report are based on the quantity of river inflows from the drainage areas measured by streamgages necessary to: (1) inundate riverine deltaic marsh complexes: (2) provide desirable salinity gradients in primary estuarine habitat regions; and (3) maintain or enhance fishery yields (Table 9). Additional water is also contributed from ungaged areas. The estimates are expressed in terms of the annual quantity of water passing the most downstream river gaging station and are the quantities estimated to be needed to sustain, maintain

Table 9. Historical Gaged River Inflows, Commercial Fisheries Harvests, Alternative Estimated Inflow Needs, and Estimated Commercial Fisheries Harvests for Seven Major Texas Estuarine Systems (Amounts are in thousands of acre-feet)

Estuarine System	Major River(s)	Minimum Monthly and Minimum Annual Gaged Inflows	Maximum Monthly and Maximum Annual Gaged Inflows	Average Historic Gaged River Inflows 1941-1976	Estimated Annual Gaged River Inflow Needs			Average Annual Estuarine Commercial Harvest (1962-1976) (1,000 lbs)		Estimated Annual Commercial Harvest (1,000 lbs) under Alternative Inflow Needs					
										Finfish			Shellfish		
					a/	b/	c/	Finfish	Shellfish	a/	b/	c/	a/	b/	c/
Sabine-Neches	Neches and Sabine Rivers	31 (Oct. 1956) 2,483 (1967)	7,493 (May 1953) 24,202 (1946)	10,677	5,686	d/	d/	20	927	d/	d/	d/	d/	d/	d/
Trinity-San Jacinto	Trinity and San Jacinto Rivers	13 (Oct. 1956) 1,054 (1956)	4,788 (Apr. 1945) 15,305 (1973)	6,870	4,605	4,888	4,749	347	18,588 g/	501	556	414	21,369 g/	21,326 g/	21,368 g/
Lavaca-Tres Palacios	Lavaca, Navidad, and Colorado Rivers	16 (Nov. 1956) 323 (1954)	1,102 (Jun. 1973) 2,655 (1960)	1,893	1,229 e/	1,886 e/	1,889 e/	300	3,034	285	364	285	2,894	2,927	3,719
Guadalupe	San Antonio and Guadalupe Rivers	6 (Jun. 1956) 235 (1956)	1,546 (Sep. 1967) 4,584 (1973)	1,808	1,241	1,620	1,826	237	2,162	104	211	110	1,983	2,162	2,162
Mission-Aransas	Mission and Aransas Rivers	0.1 (Dec. 1956) 3 (1950)	458 (Sep. 1967) 524 (1967)	104	16 f/	19 f/	43 f/	869 h/	2,255 h/	858 h/	1,087 h/	1,663 h/	2,937 h/	3,143 h/	3,683 h/
Nueces	Nueces River	0 (Apr. 1955) 10 (1962)	1,479 (Sep. 1967) 2,537 (1971)	575	356	397	550								
Laguna Madre	Arroyo Colorado North Floodway	0 (Aug. 1958) 41 (1952)	898 (Oct. 1958) 1,941 (1958)	335	182	285	292	2,204	8,512 j/	2,397	2,728	3,091	7,443 j/	8,505 j/	10,045 j/
Annual Totals				22,262	13,315	9,095	9,349	3,977	35,478 g/j/	4,145 i/	4,946 i/	5,563 i/	36,626 i/j/	38,063 i/j/	40,977 i/j/

a/ Based on salinity and inundation needs.
b/ Based on salinity and inundation needs and maintaining commercial fishery harvest levels at no less than mean historical levels (1962-1976) for major commercial fisheries components in each estuary.
c/ Based on salinity and marsh inundation needs, and enhancing a major commercial fisheries harvest category.
d/ Monthly inflows needs could not be used with validity to predict fisheries harvests, thus freshwater inflows for the estuary could not be computed for Alternatives b/ and c/.
e/ Includes the flow at the Bay City streamgage that actually enters the estuary. The remaining portion of the gaged flow goes directly into the Gulf of Mexico.
f/ Gaged inflow need represents only gaged inflow of the Mission River, which averaged 84 thousand acre-feet over the 1941-1976 period.
g/ Includes the estimated harvest of shrimp in Offshore Gulf Area No. 18.
h/ Combines the harvest from the Nueces and Mission-Aransas estuaries.
i/ Does not include the Sabine-Neches estuary harvests, but includes with the Shellfish the estimated shrimp harvest in Offshore Gulf Area No. 18.
j/ Includes historical or estimated harvest of shrimp in Offshore Gulf Area No. 21.

or enhance the primary ecosystem habitat and fisheries productivity. However, Texas estuarine systems are dynamic and have historically received a wide range of freshwater inflows from drought to wet or hurricane years. In fact it is generally believed that a constant rate of freshwater inflows would be detrimental to the estuarine organisms which have adapted to the prevailing dynamic seasonal cycles. For this reason, the estimates of freshwater inflow requirements should be regarded as statistical long-term central tendencies of inflows needed to maintain the estuarine systems. Major events, such as hurricances and uncontrolled floods, will continue to provide freshwater inflows that may greatly exceed the estimated needs.

The estimated freshwater inflow needed for each of the Alternatives represent the long-term central tendencies in the inflow needed to meet the stated objectives of each Alternative. The exact specification of this central tendency is open to interpretation. The long-term central tendency could be viewed as an average, median (i.e., a condition exceeded one-half of the time), or some other desired inflow condition. The historic frequency of the inflows determined under the three Alternatives has not been naturally satisfied on a uniform basis, either monthly or annually. In reality, the biologic communities in the estuaries have had to adapt to natural hydrologic variations which have resulted in intervals of freshwater inflow significantly below the levels computed to be adequate to maintain the communities that is, in some cases estuarine communities have been depressed or even destroyed by extreme hydrologic conditions.

Therefore, the question arises as to what statistical basis of frequency the freshwater inflow exceeding the estimated need for an estuary should be provided. There is no clearcut answer since it depends upon the conditions desired in the estuary. Should the monthly and seasonal freshwater inflow needs be defined as those quantities to be exceeded on the average, then any period of inflows having average monthly and seasonal levels greater than those quantities would satisfy the estimated freshwater inflow needs. It might therefore be possible to physically retain water from the contributing basins in months of excess and still maintain the estimated levels of freshwater inflows needed. However, such a policy would not only reduce the average estuarine inflow but would most likely cause an increase in the frequency of low inflow events to an estuary. Thus, in so far as an estuary is concerned, droughts would be more extreme and of longer duration, as reflected by estuarine inflows, under this specification of the needed level of freshwater inflow than would have occurred historically.

If the estimated level of freshwater inflow needs were required to be met or exceeded 50 percent of the time (the median), then it would probably be necessary in many months to provide additional inflow at levels greater than would have occurred over a repetition of historical inflows. This condition would lead to enhancement of the estuary and would probably diminish the extent and the magnitude of drought events for the estuary but at the expense of upstream water needs of the State.

Should it be desired that the frequency of meeting the freshwater inflow needs corresponds to the historic frequency of inflow events, then any modification of the inflows would require that there be no greater frequency of flows below the freshwater inflow needs than observed over a designated period of years. This assumes that the operation of any new water resources project for withdrawal of water in contributing river basins would be evaluated under a repetition of the base period of hydrology, so that the difference between the inflows would be due to the project alone.

It appears that the most satisfactory interpretation of the freshwater inflow needs, with the view of maintaining the existing marine organisms, would be to interpret the freshwater needs as being flows needed by the estuary with approximately the same frequency as historically entered the estuary. However, a drawback to such an interpretation would be the possibility that the frequency of very low flows could be increased by construction of a water development project, even though operation of the project might result in estuarine inflows exceeding the estimated freshwater inflow needs with the same frequency as has occurred historically. Such a situation could be overcome by applying an additional qualification to the frequency of the freshwater inflow needs, whereby the frequency of the very low inflows (such as those exceeded 90 percent of the time) be no less than that which has occurred over the historical period.

Techniques for Meeting Freshwater Inflow Needs

The freshwater inflows needed to maintain an estuarine ecology can be provided from both unregulated and regulated sources. Estuarine inflows from the runoff of uncontrolled drainage areas in the major river basins downstream of the last streamgage and the coastal basins, and direct precipitation on the estuary will most likely continue in the future at historical levels, except in those areas where major water diversions or storage projects will be located. Inflows from the major contributing river basins, however, will in some areas be subject to significant alteration due to man's activities. A compilation and evaluation of existing permits, claims and certified filings on record at the Texas Department of Water Resources indicate that should diversions closely approach or equal rates and volumes presently authorized under existing permits and claims presently recognized and upheld by the Texas Water Commission, such diversions could equal or exceed the total annual runoff within several major river systems during some years, particularly during drought periods. At the present time, total annual water use (diversions) does not yet approach authorized diversion levels in most river basins, as evidenced both mandatory and voluntary comprehensive water use reporting information systems administered by the Department. However, with completion of major new surface-water development and delivery systems, freshwater inflows to some bay systems may be reduced and/or points of re-entry (in the form of return flows) may be significantly altered.

Freshwater Inflow Management

Freshwater runoff from the regulated watersheds of the upstream river basins may be managed in several ways to insure the passage of necessary flows to the estuaries. These include the granting of water rights for surface-water diversion and/or storage consistent with the freshwater inflow needs of the estuary.

Water Rights Allocation. The implementation of actions to meet these freshwater inflow needs is subject to decisions of the Texas Water Commission, through the existing State water management program and could most easily be accomplished by evaluating future applications for the appropriation of State waters on the basis of their estimated effect on the inflows to the estuaries during a specified base historic hydrologic period. Should a requested permit result in an estimated significant depletion of inflows, either on a monthly or an annual basis, to the estuary below the volume and frequency desired, then a permit which might be issued might be conditioned to comply with the estimated estuarine freshwater inflow needs. Thus, the permit granting the storage and/or diversion of State waters might be issued only if it were consistent with the estimated freshwater inflow needs. Cumulative depletions in streamflow occurring through the granting of numerous individual permits could be taken into account by modifying the historic hydrology to reflect permits currently in force. It might be appropriate to apply a "Grandfather" clause to all existing or permitted water diversion or storage rights since retroactive application of actions to meet estimated freshwater inflow needs would bring about conflict with legally valid contracts and commitments. However, all future water rights requests could be assessed on the basis of their additional impact on freshwater inflow to the estuary as is provided for in the Texas Water Code.

Adjudication of surface-water rights in Texas is an extremely important factor in addressing questions related to estuarine maintenance, since adjudication relates to the quantity of water permitted for diversion and use for other purposes. In 1967, the Texas Legislature enacted the Water Rights Adjudication Act Section 11.301 et seq. of the Texas Water Code. The declared purpose of the Act was to require a recordation with the Texas Water Commission of claims of water rights which were unrecorded, to limit the exercise of those claims to actual use, and provide for the adjudication and administration of water rights. Pursuant to the Act, all persons wishing to be recognized who were claiming water other than under permits or certified filings were required to file a claim with the Commission by September 1, 1969. Such a claim is to be recognized only if valid under existing law and only to the extent of the maximum actual application of water for beneficial use without waste during any calendar year from 1963 to 1967, inclusive. Riparian users were allowed to file an additional claim on or before July 1, 1971 to establish a right based on use from 1969 to 1970, inclusive.

The adjudication process is complex and lengthy, and in basin segments where preliminary determinations are challenged is subject to final determination in the courts. Currently, the adjudication program in the State is approximately 83 percent complete and although the adjudication program has been accelerated, several years will be required to complete the remaining unadjudicated basins.

Recognition of the freshwater needs of the estuaries, allocation and possibly ultimately a direct appropriation of State water to meet these needs, and equitable adjudication of water rights and claims are intertwined--a fact which must be recognized by all those involved in identifying coastal issues and resolving coastal problems.

Operation of Upstream Reservoirs in Contributing Basins. The control of surface-waters through impoundment and release from large storage reservoirs is a potential source of supplementary waters for the Texas estuaries. Increased attention should be given to the possibilities of providing storage capacity in future reservoir projects specifically for allocation to estuarine inflows, with releases timed to provide the most benefit to the estuary. Development of new institutional arrangements whereby repayment criteria for such allocated storage are determined and associated costs repaid will be necessary. Potential transbasin diversions to convey "surplus" freshwater from "water-rich" hydrologic systems to water-deficient estuaries will also have to be studied and costs will have to be computed. Additionally, structural measures and channel modifications which might enhance marsh inundation processes using less freshwater will have to be evaluated. These are all a part of the continuing planning process to meet the present and future water needs of Texas.

Elimination of Water Pollutants

The presence of toxic pollutants in freshwater inflows can have a detrimental effect upon productivity of an estuarine ecosystem by surpressing biological activity. Historically, pollutants have been discharged into rivers and streams and have locally contaminated some areas of the coastal estuaries. Imposition of wastewater discharge and streamflow water quality standards by State and Federal agencies has had and will continue to have a significant impact in reducing pollutants entering estuarine waters. Presence of toxic pollutants in Texas estuaries will continue for the foreseeable future in some areas as compounds previously deposited in sediments become resuspended in the water column when hurricanes or severe storms cause abnormally strong currents. This report does not include a comprehensive assessment of water pollution problems in Texas estuaries, as other ongoing programs of the Department of Water Resources address such problems and the results of such efforts can be used along with the results of these studies in administering Texas water resources.

Land Management

The uses of watershed areas are of particular importance to the contribution of nutrient materials from the land areas surrounding Texas estuaries. In coastal areas, significant contributions of nutrients are provided to the estuary by direct runoff. Removal of marsh grasses in coastal areas through overgrazing and through drainage improvement practices is currently taking place, particularly on the upper Texas coast, and may result in substantial reductions in the volume of nutrients contributed to the estuaries. This report does not consider land management techniques in detail, although land management is an alternative technique in coastal zone management planning.

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APPENDIX I

Text of Senate Bill 137,
64th Texas Legislature (1975)

WATER CODE—BAYS AND ESTUARIES—ECOLOGICAL ENVIRONMENT

CHAPTER 344

S. B. No. 137

An Act amending the Water Code as follows: declaring as public policy of the state the maintenance of the ecological environment of the bays and estuaries in the conservation and development of the state's natural resources; directing the Texas Water Rights Commission in the consideration of any permit to store, take, or divert water to assess the effects thereof upon the bays and estuaries of Texas; directing the Texas Water Development Board to investigate the effects of fresh water inflows upon bays and estuaries of Texas and to complete comprehensive studies regarding the development of methods of providing and maintaining the ecological environment thereof; directing the Texas Water Rights Commission, the Texas Water Quality Board, the General Land Office, the Parks and Wildlife Department, and the Coastal and Marine Council to assist and cooperate in the conduct of such studies and investigations; repealing laws in conflict; making appropriations; and declaring an emergency.

Be it enacted by the Legislature of the State of Texas:

Section 1. Section 1.003 of Chapter 1, Water Code, is amended [16] to read as follows:

"Sec. 1.003. Public Policy

"It is the public policy of the state to provide for the conservation and development of the state's natural resources, including:

"(1) the control, storage, preservation, and distribution of the state's storm and floodwaters and the waters of its rivers and streams for irrigation, power, and other useful purposes;

"(2) the reclamation and irrigation of the state's arid, semiarid, and other land needing irrigation;

"(3) the reclamation and drainage of the state's overflowed land and other land needing drainage;

"(4) the conservation and development of its forest, water, and hydroelectric power;

"(5) the navigation of the state's inland and coastal waters; and

"(6) the maintenance of a proper ecological environment of the bays and estuaries of Texas and the health of related living marine resources."

Sec. 2. Subchapter D of Chapter 5, Water Code, as amended, is amended by adding [17] Section 5.145 to read as follows:

"Sec. 5.145. Effects of Permit on Bays and Estuaries

"In its consideration of an application for a permit to store, take, or divert water, the commission shall assess the effects, if any, of the issuance of such permit upon the bays and estuaries of Texas."

Sec. 3. Section 11.062 of Chapter 11, Water Code, as amended, is amended [18] to read as follows:

"Sec. 11.062. Studies, Investigations, Surveys

"(a) The staff shall make studies, investigations, and surveys of the occurrence, quantity, quality, and availability of the surface water and groundwater of this state. For these purposes the staff shall collect, receive, analyze, and process basic data concerning the water resources of the state.

16. V.T.C.A. Water Code, § 1.003.
17. V.T.C.A. Water Code, § 5.145.
18. V.T.C.A. Water Code, § 11.062.

1 Tex.Sess L. '75 Bd.Vol —64

"(b) The staff shall:

"(1) determine suitable locations for future water facilities including reservoir sites;

"(2) locate land best suited for irrigation;

"(3) make estimates of the cost of proposed irrigation works and the improvement of reservoir sites;

"(4) examine and survey reservoir sites; and

"(5) investigate the effects of fresh water inflows upon the bays and estuaries of Texas.

"(c) The staff shall keep full and proper records of its work, observations, data, and calculations, all of which are the property of the state.

"(d) In performing its duties under this section, the staff shall assist the commission in carrying out the purposes and policies stated in Section 6.054 of this code."

Sec. 4. Subchapter D of Chapter 11, Water Code, as amended, is amended by adding [19] Section 11.108.

"Sec. 11.108. Studies of Bays and Estuaries

"The board shall carry out comprehensive studies of the effects of fresh water inflows upon the bays and estuaries of Texas, which studies shall include the development of methods of providing and maintaining the ecological environment thereof suitable to their living marine resources. The studies shall be completed and the results published by December 31, 1979. The Texas Water Rights Commission, the Texas Water Quality Board, the General Land Office, the Parks and Wildlife Department, and the Texas Coastal and Marine Council are authorized and directed to assist and cooperate in all possible ways with the board in this undertaking."

Sec. 5.[20] There is hereby appropriated to the Texas Water Development Board $250,000 for fiscal year 1976 and any unexpended balances for fiscal year 1977 in addition to funds appropriated to the board in the General Appropriations Act for bay and estuary studies and fresh water inflow needs of those systems.

Sec. 6.[20] Any law in conflict with the provisions of this Act is specifically repealed to the extent the same is in conflict.

Sec. 7. The fact that the absence of regulatory authority over the quantities of fresh water inflows into the bays and estuaries of Texas has the possibility of degradation of the ecological environment creates an emergency and an imperative public necessity that the constitutional rule requiring bills to be read on three separate days in each house be suspended, and this rule is hereby suspended, and that this Act take effect and be in force from and after its passage, and it is so enacted.

Passed the senate on March 25, 1975, by a viva-voce vote; May 30, 1975, senate refused to concur in house amendments and requested appointment of Conference Committee; May 31, 1975, house granted request of the senate; June 2, 1975, senate adopted Conference Report: Yeas 31, Nays 0; passed subject to the provisions of Article III, Section 49a of the constitution; passed the house, with amendments, on May 29, 1975: Yeas 136, Nays 5, 6 present not voting; May 31, 1975, house granted request of the senate for appointment of Conference Committee; June 2, 1975, house adopted Conference Report: Yeas 118, Nays 15, 2 present not voting; passed subject to the provisions of Article III, Section 49a of the constitution.

Approved June 19, 1975.

Effective June 19, 1975.

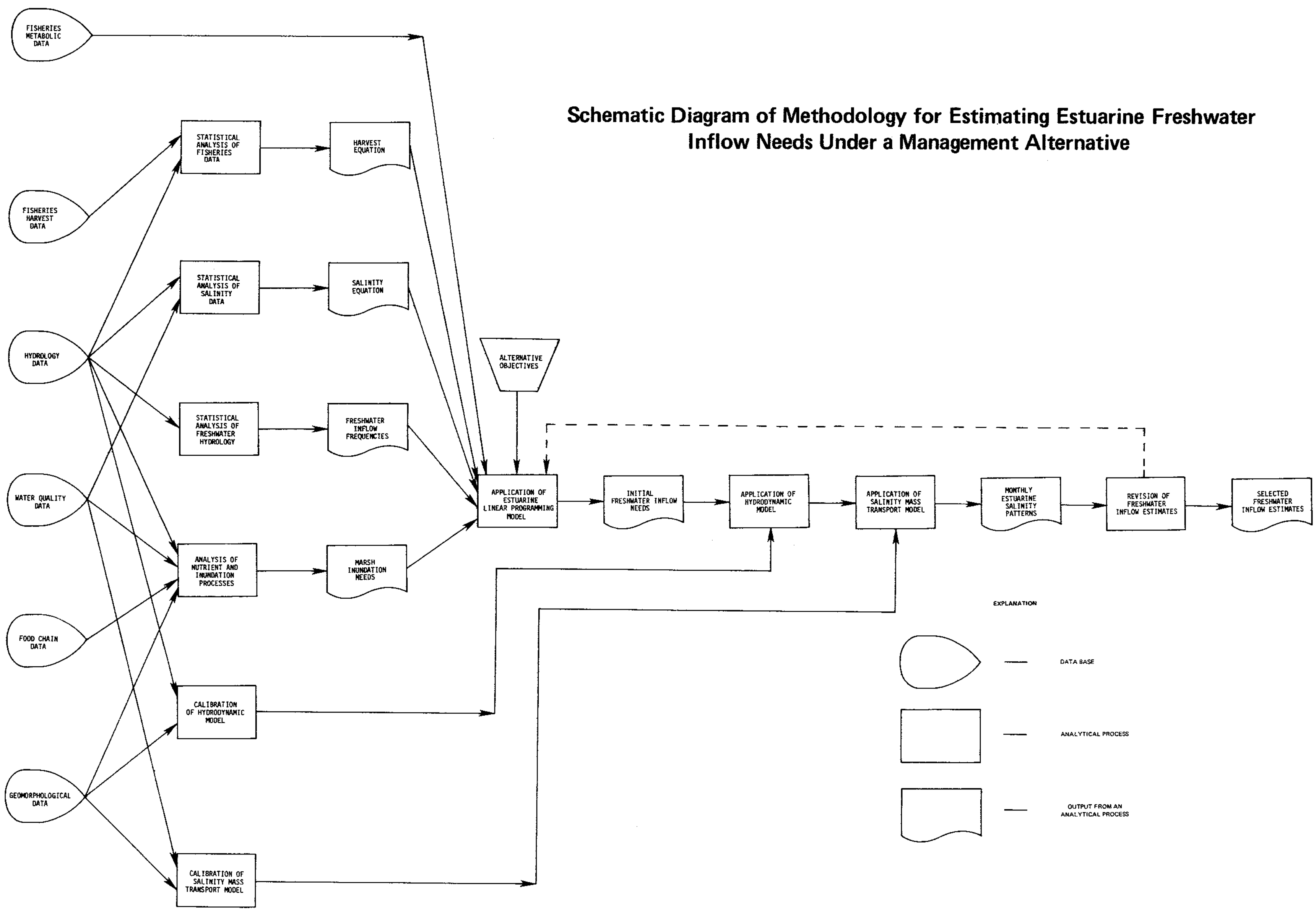
19. V.T.C.A. Water Code, § 11.108.

20. V.T.C.A. Water Code, § 11.108 note.

APPENDIX II

Schematic Diagram of Methodology for Estimating Estuarine Freshwater Inflows Needed to Meet Specific Objectives

Schematic Diagram of Methodology for Estimating Estuarine Freshwater Inflow Needs Under a Management Alternative



APPENDIX III

Combined Inflow Hydrographs and
Monthly Inflow Frequency Distribution
for the Seven Estuaries.

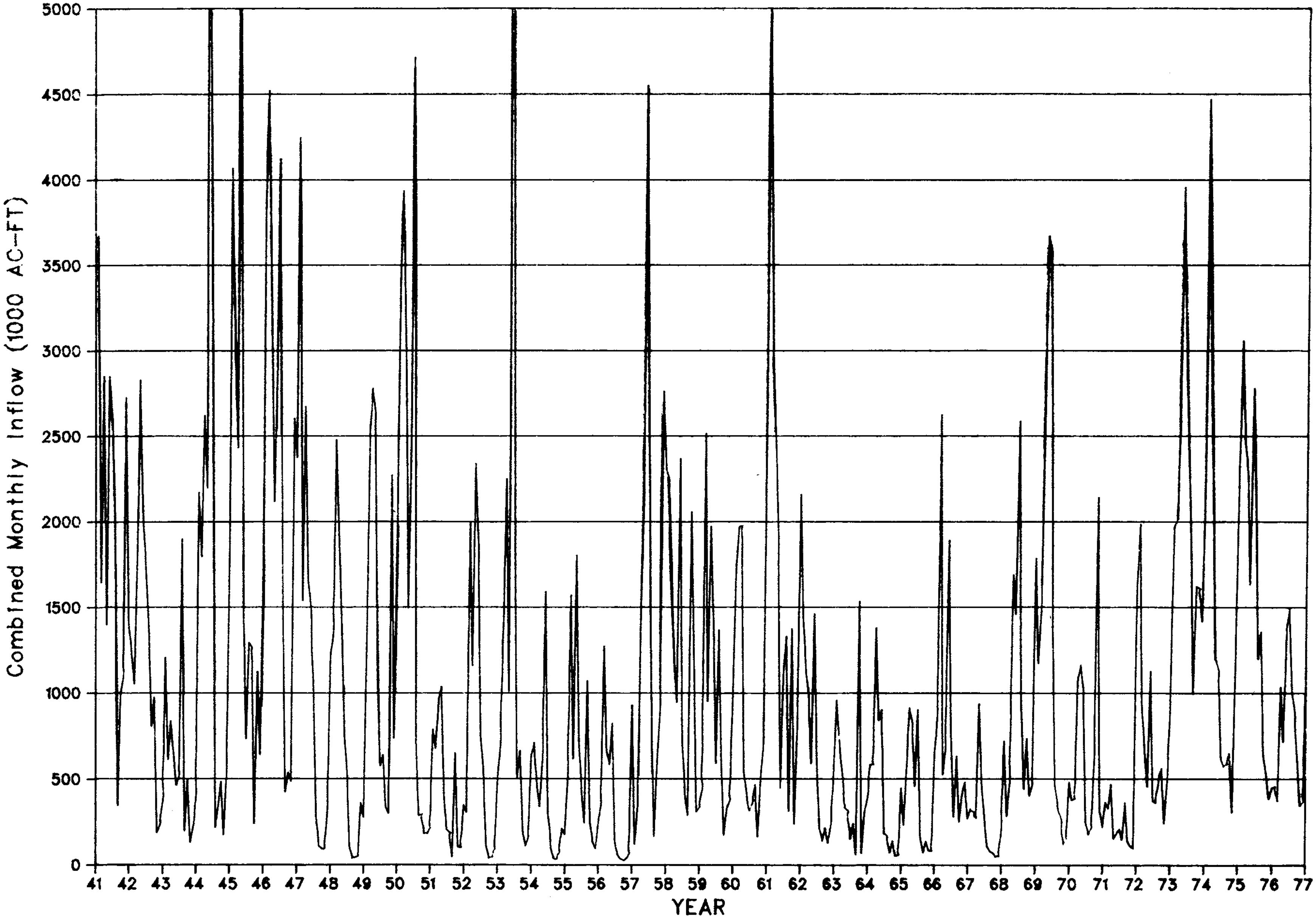


Figure III-1. Combined Monthly Inflow to the Sabine-Neches Estuary, 1941-1976

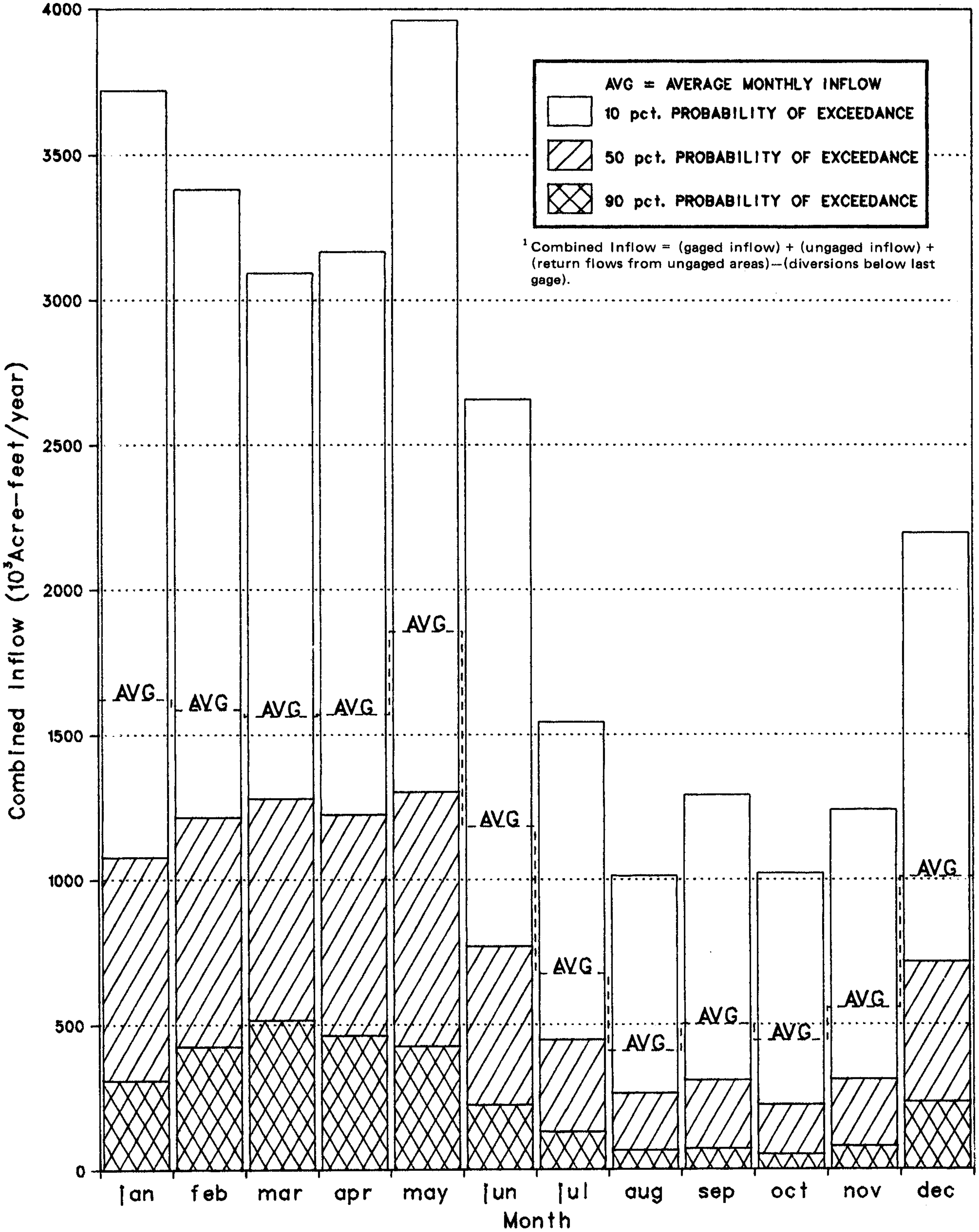


Figure III-2. Monthly Distribution of Combined Inflow,[1] Sabine-Neches Estuary, 1941-1976

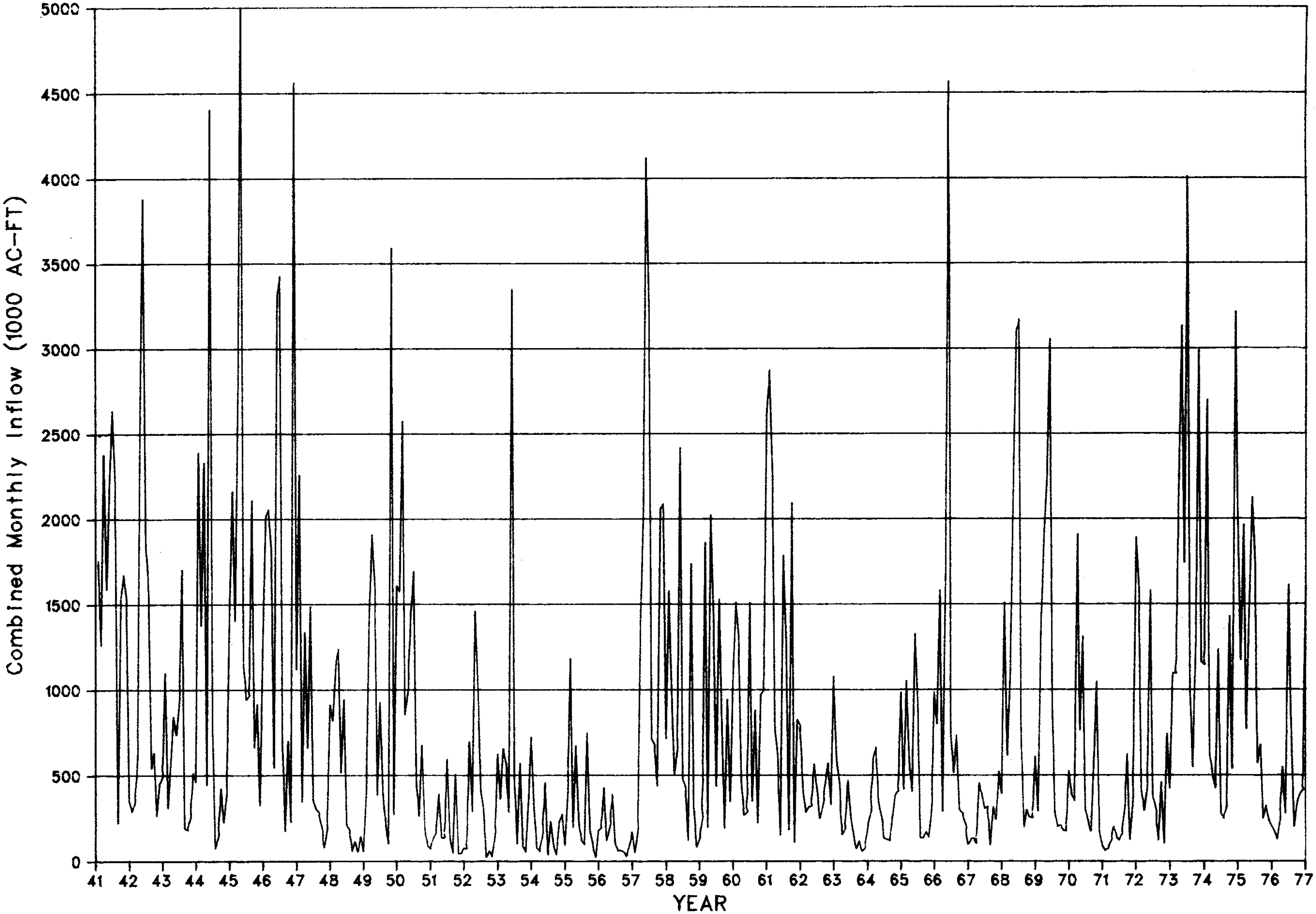


Figure III-3. Combined Monthly Inflow to the Trinity-San Jacinto Estuary, 1941-1976

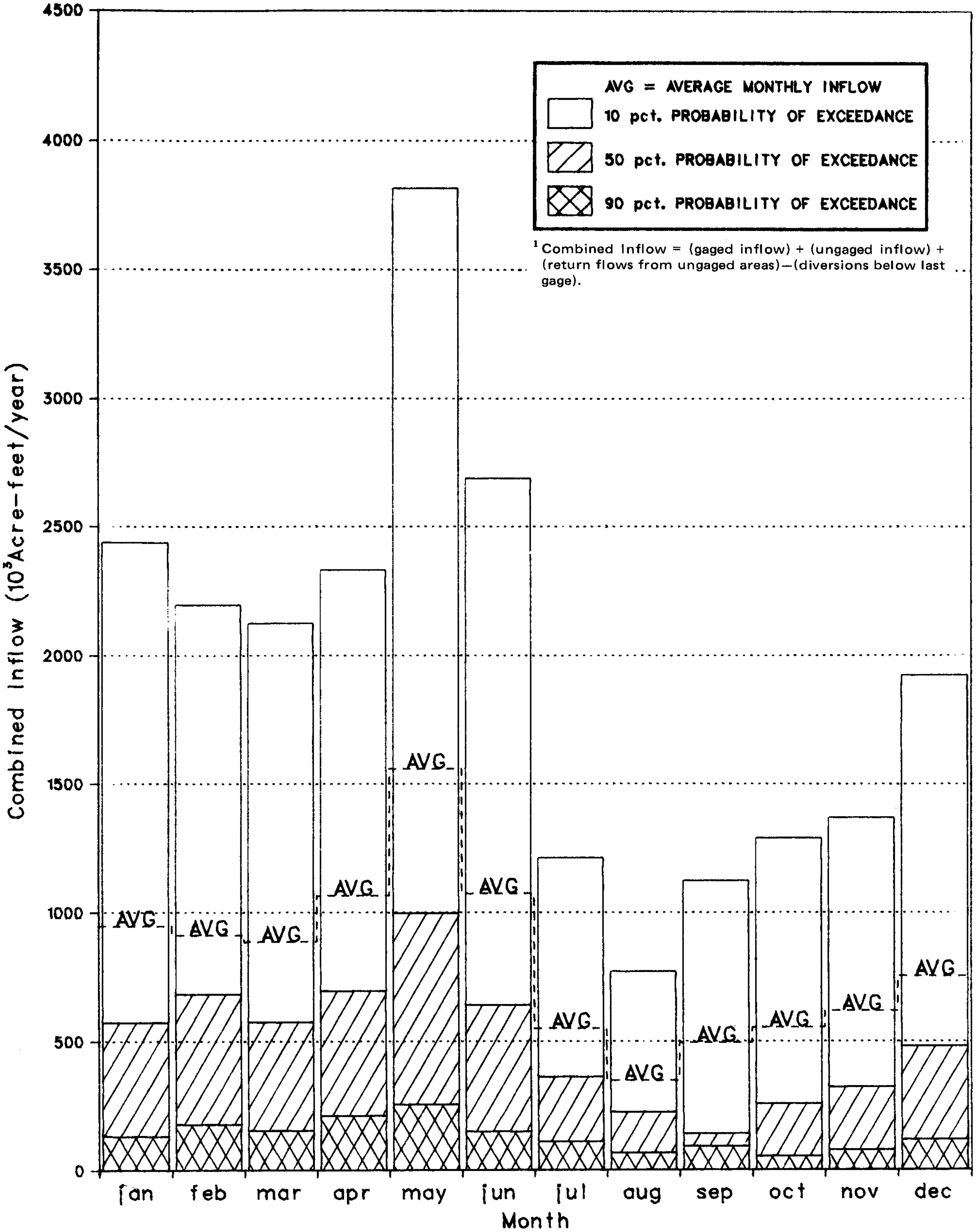


Figure III-4. Monthly Distribution of Combined Inflow,[1] Trinity-San Jacinto Estuary, 1941-1976

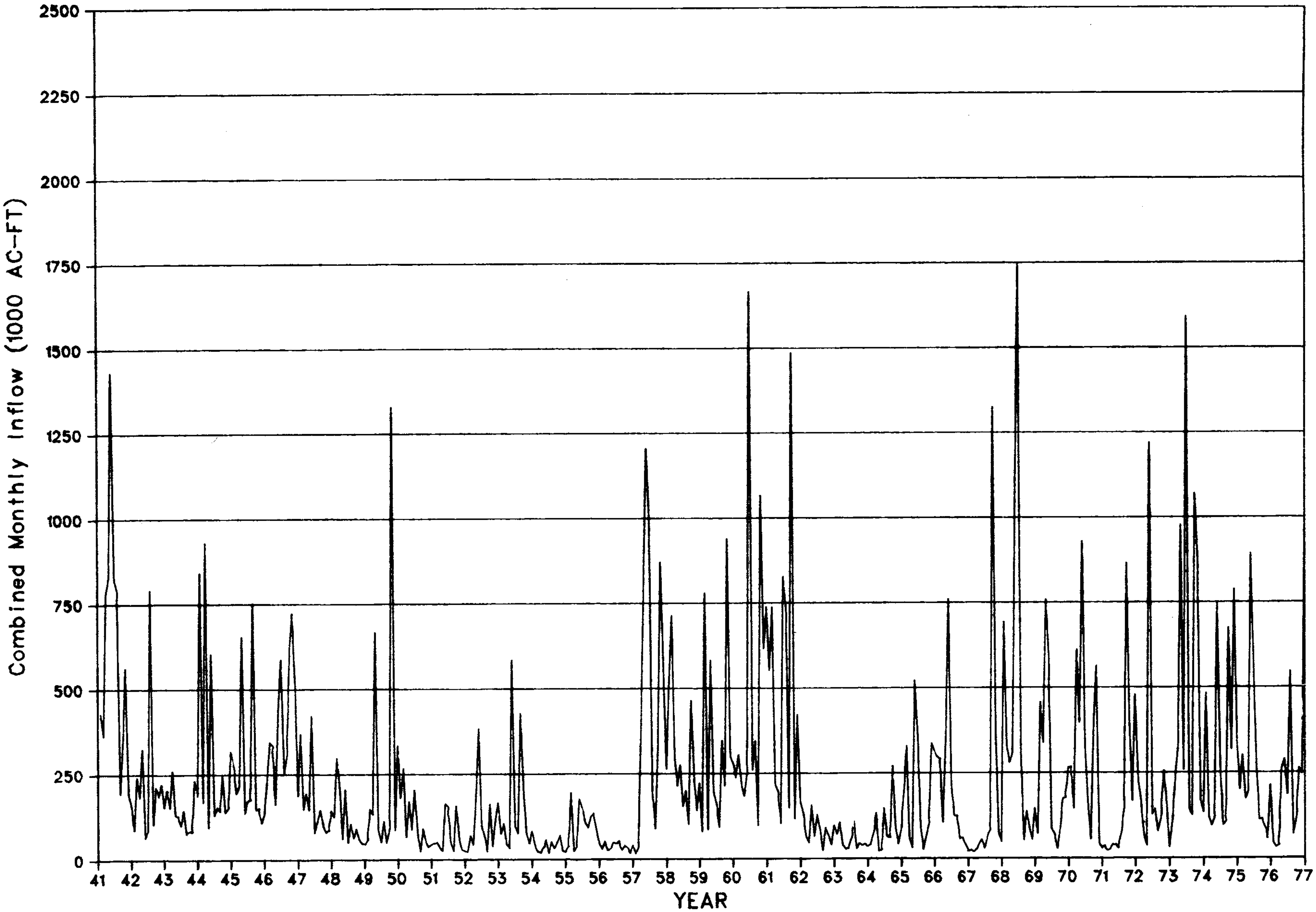


Figure III-5. Combined Monthly Inflow to the Lavaca-Tres Palacios Estuary, 1941-1976

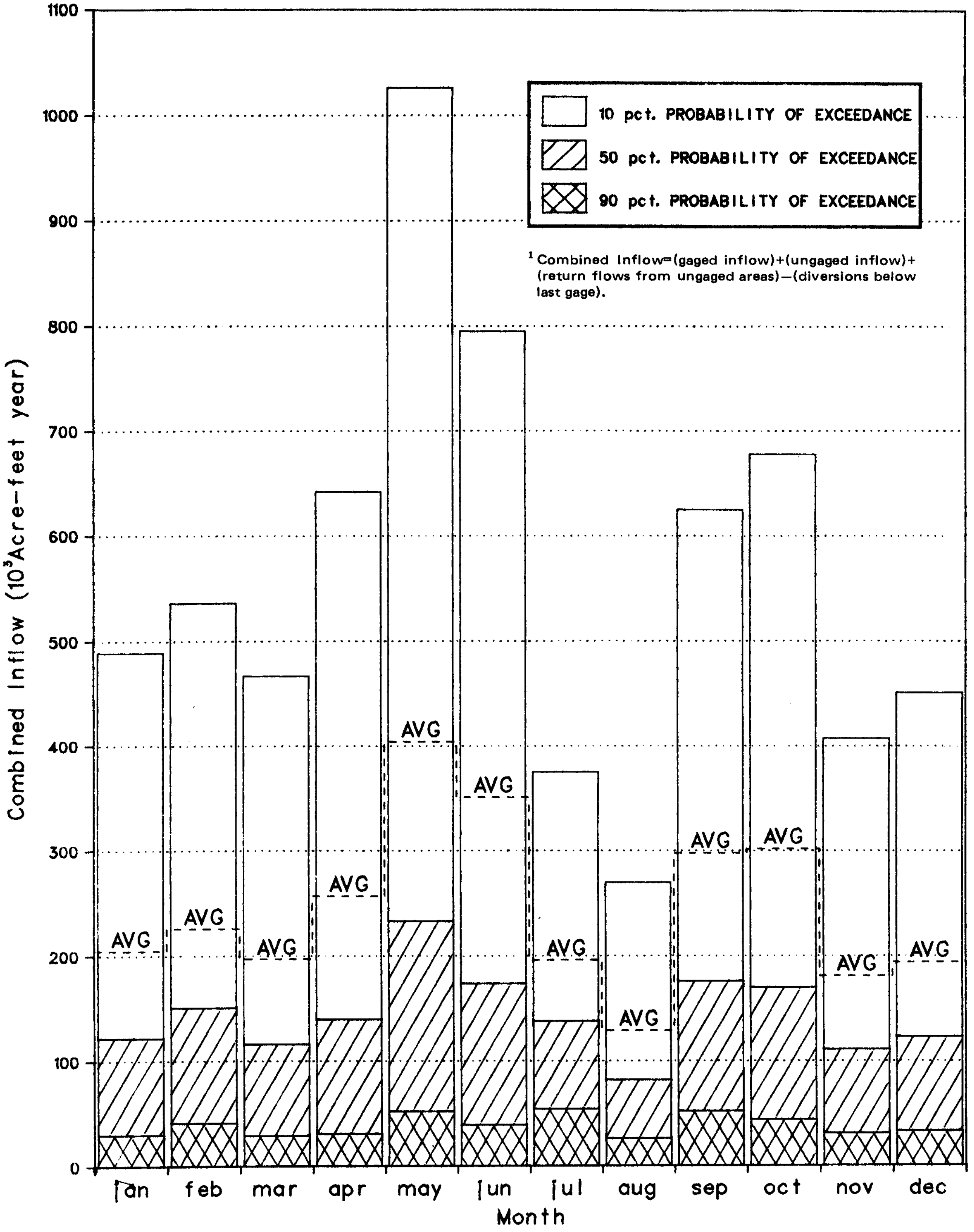


Figure III-6. Monthly Distribution of Combined Inflow,[1] Lavaca-Tres Palacios Estuary, 1941-1976

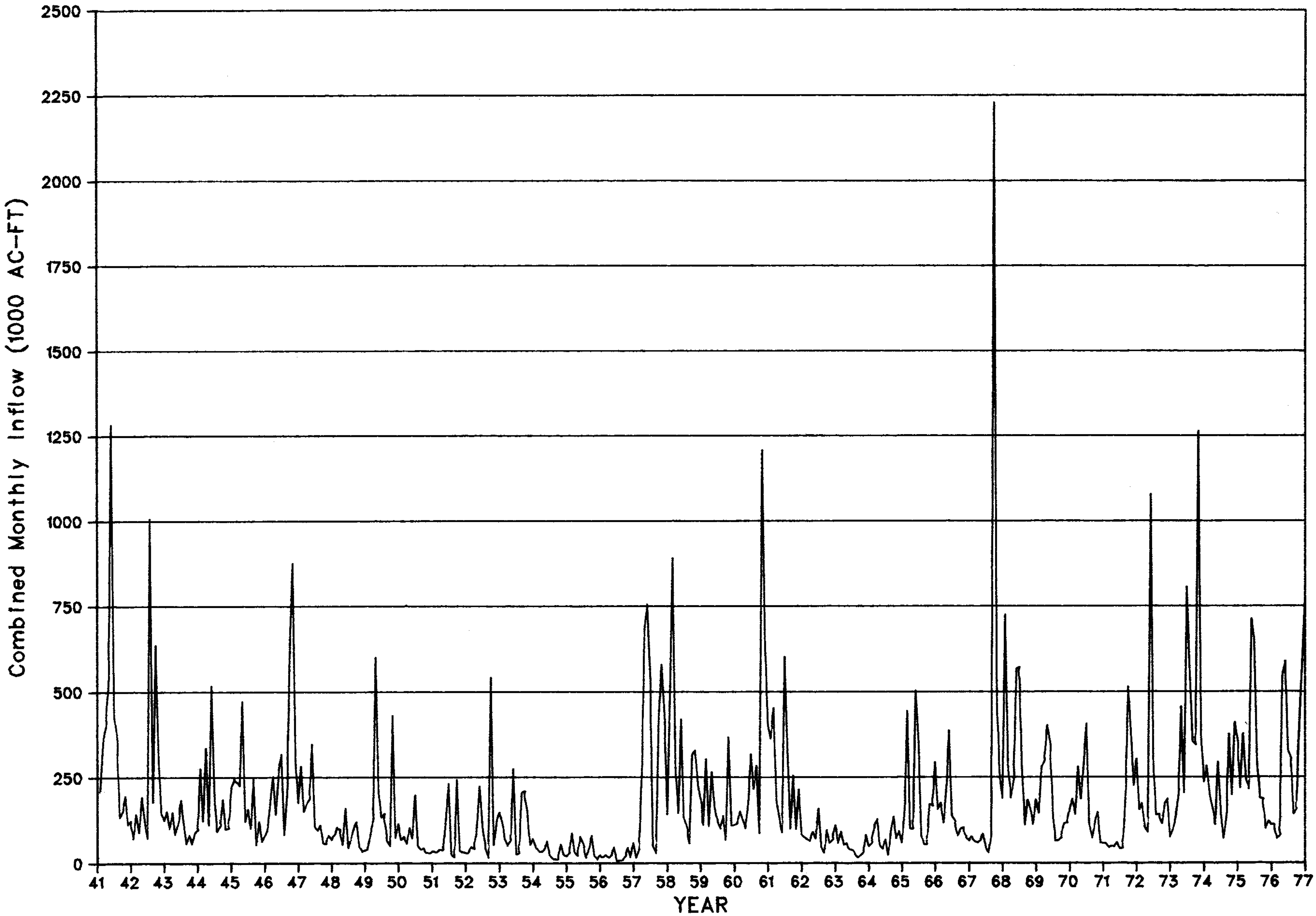


Figure III-7. Combined Monthly Inflow to the Guadalupe Estuary, 1941-1976

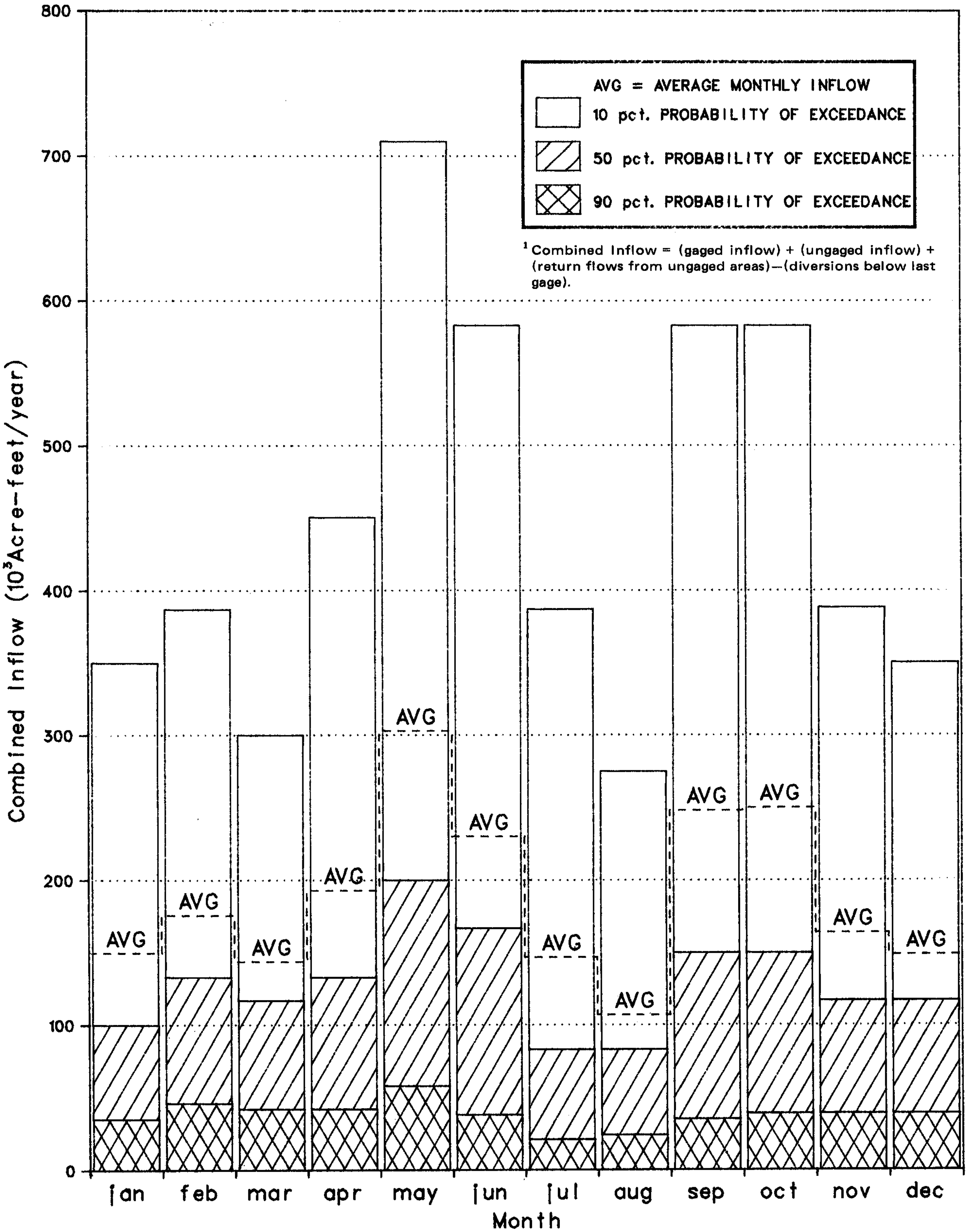


Figure III-8. Monthly Distribution of Combined Inflow,[1] Guadalupe Estuary, 1941-1976

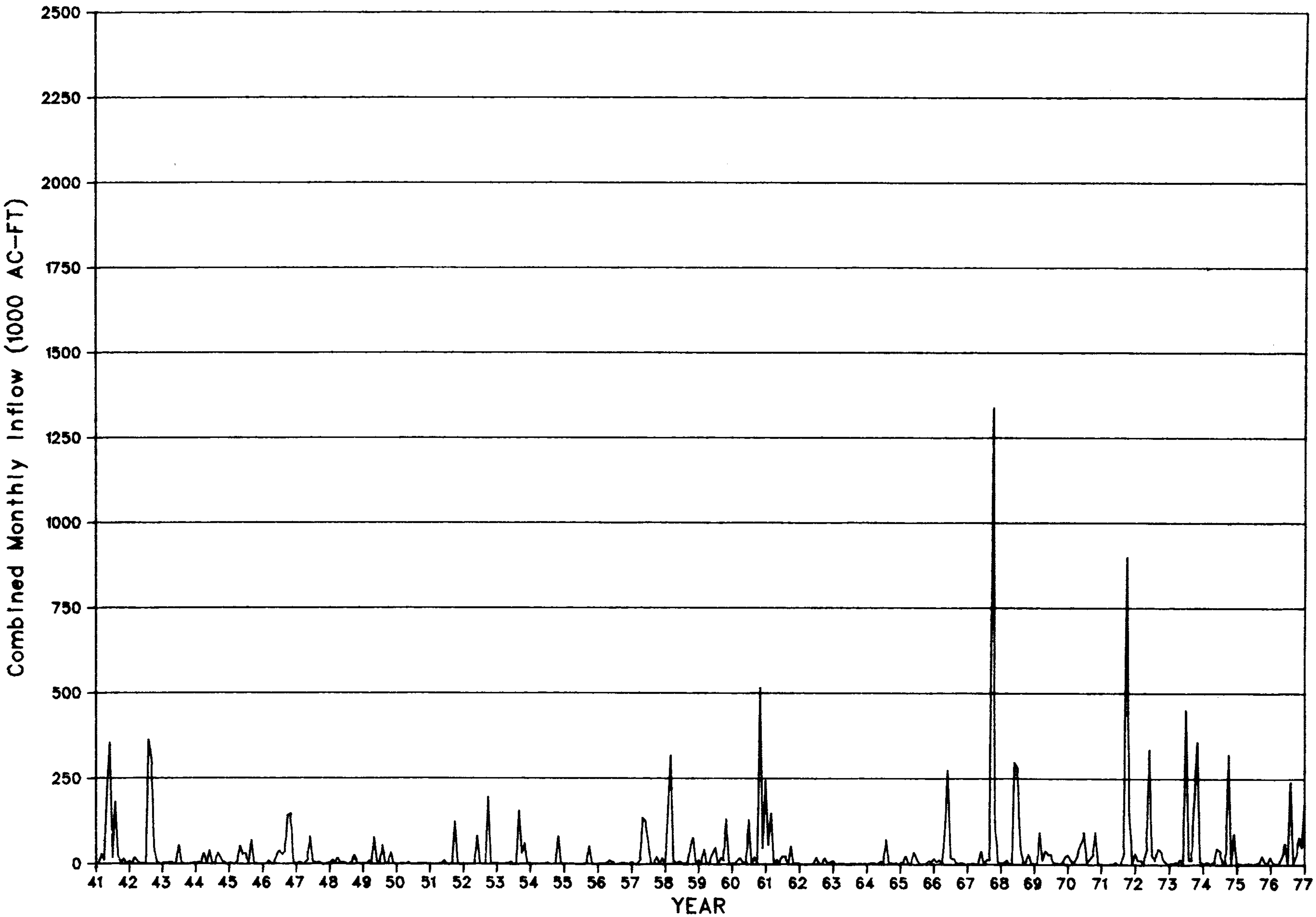


Figure III-9. Combined Monthly Inflow to the Mission-Aransas Estuary, 1941-1976

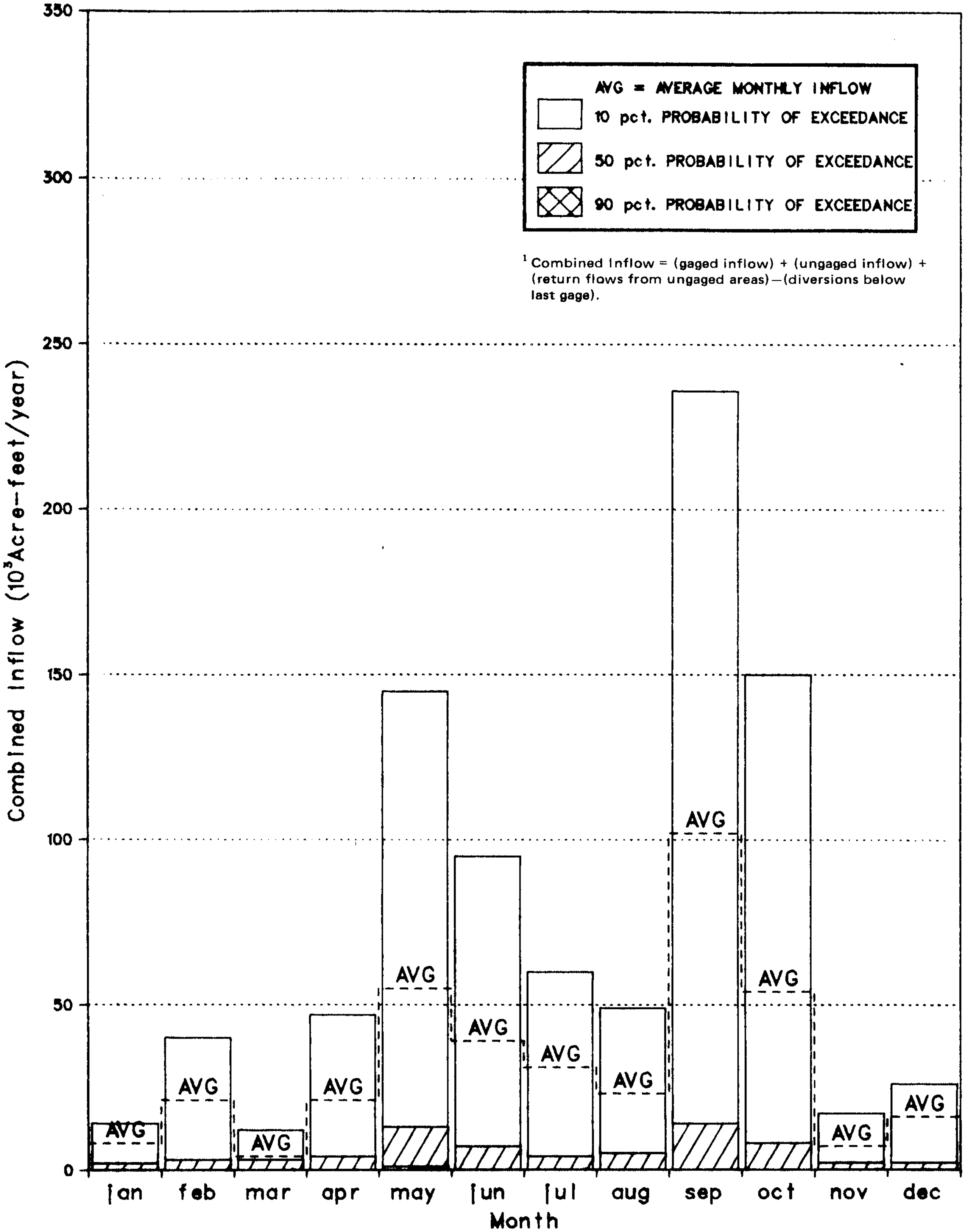


Figure III-10. Monthly Distribution of Combined Inflow,[1] Mission-Aransas Estuary, 1941-1976

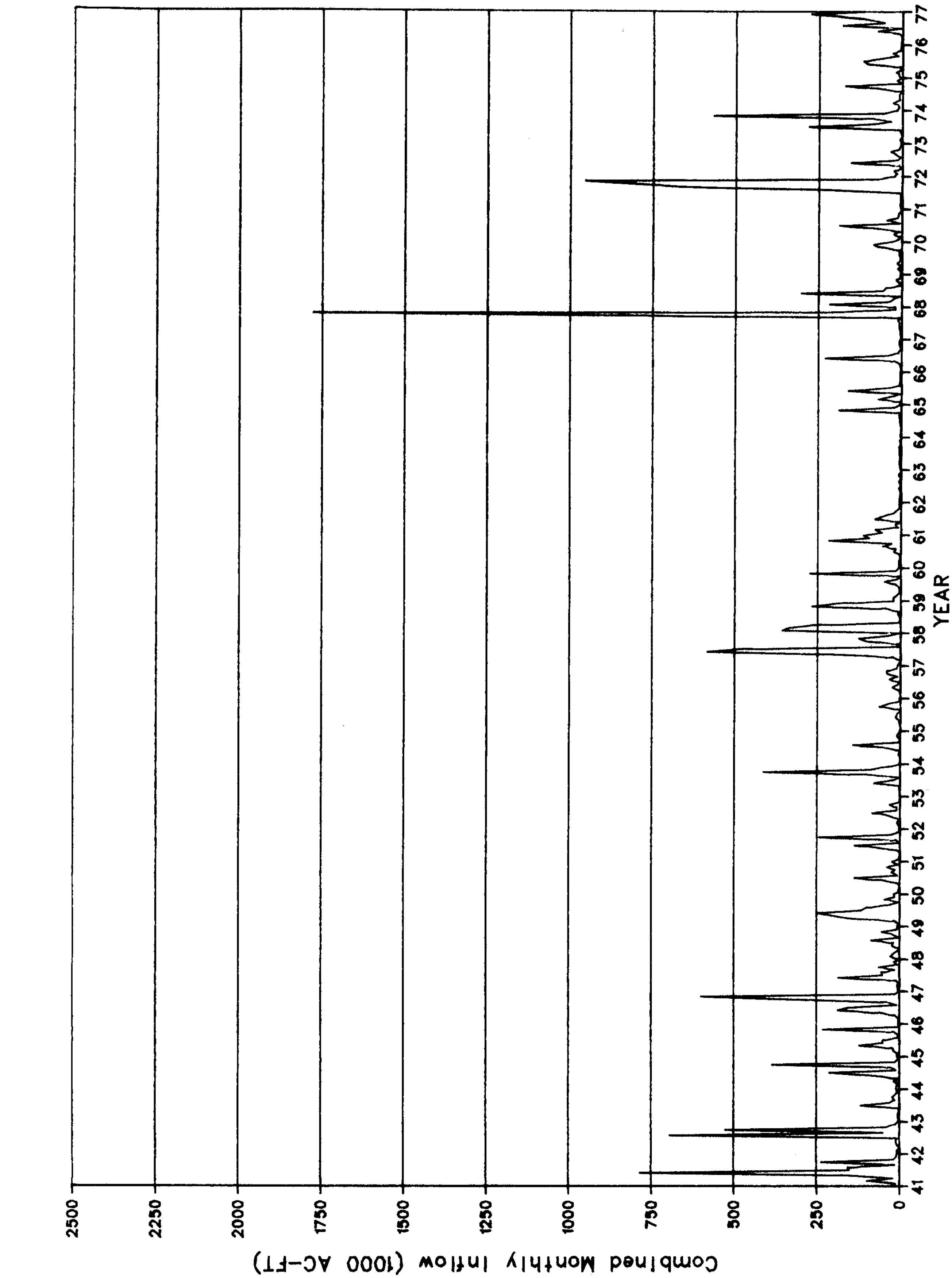


Figure III-11. Combined Monthly Inflow to the Nueces Estuary, 1941-1976

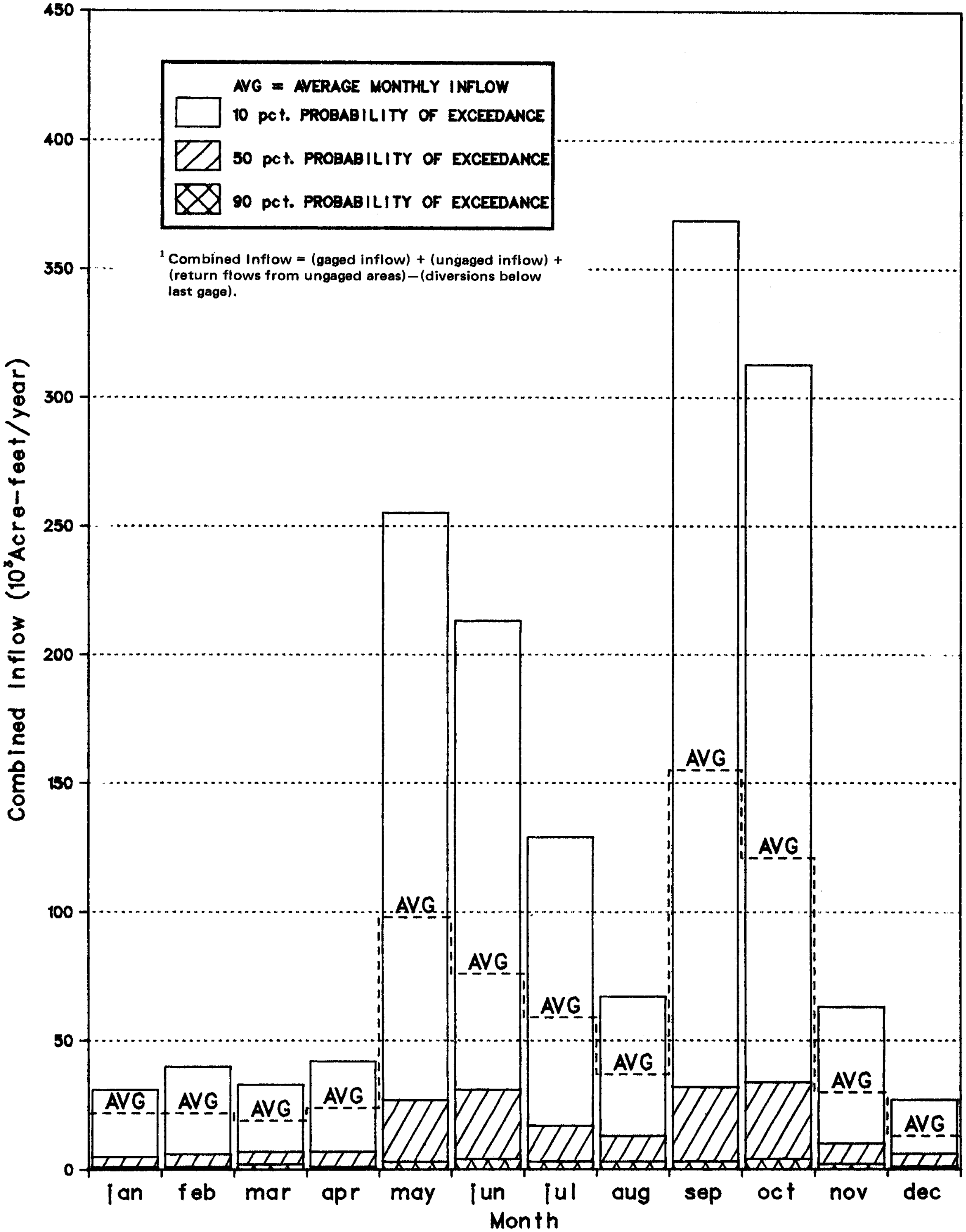


Figure III-12. Monthly Distribution of Combined Inflow,[1] Nueces Estuary, 1941-1976

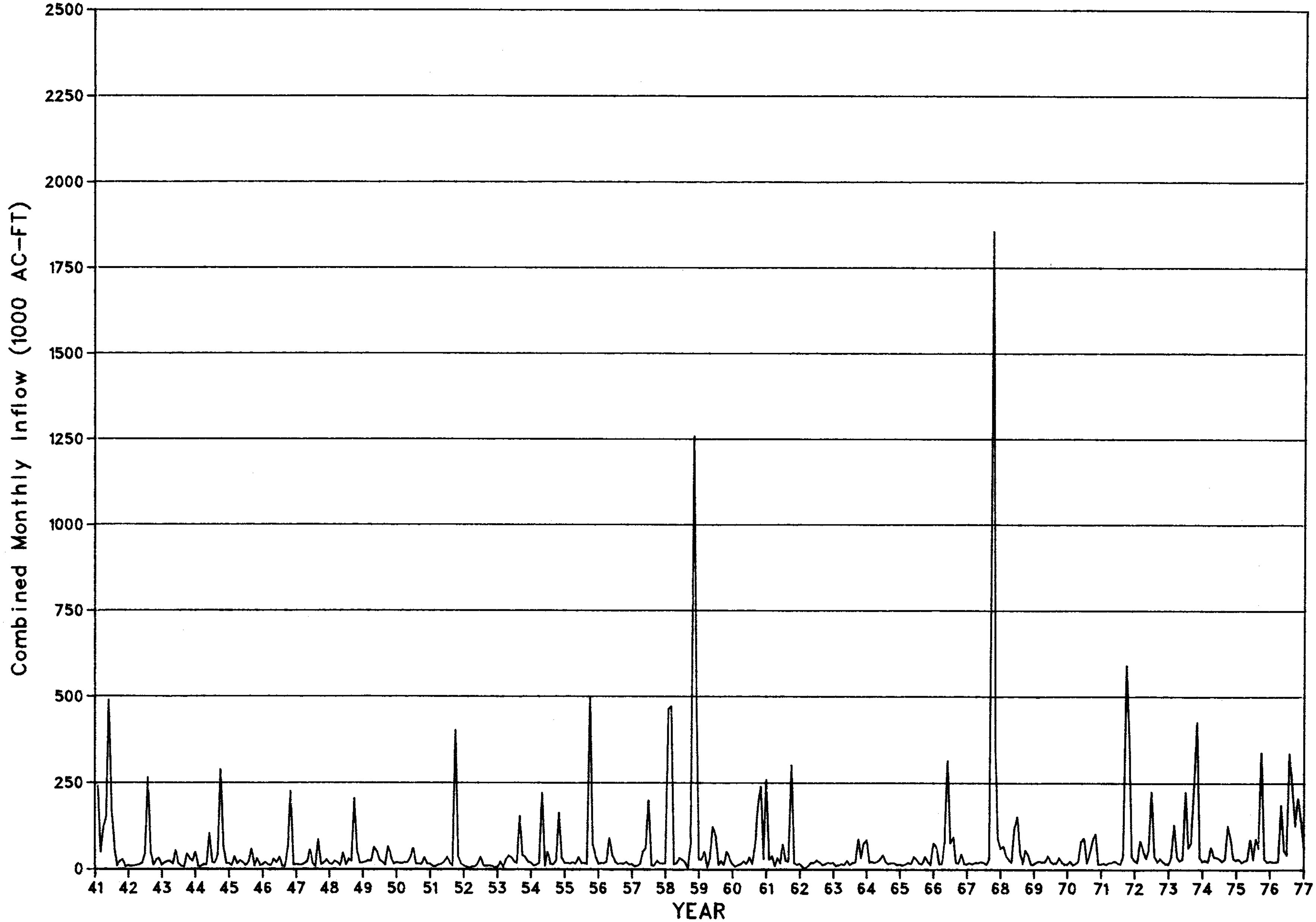


Figure III-13. Combined Monthly Inflow to the Laguna Madre Estuary, 1941-1976

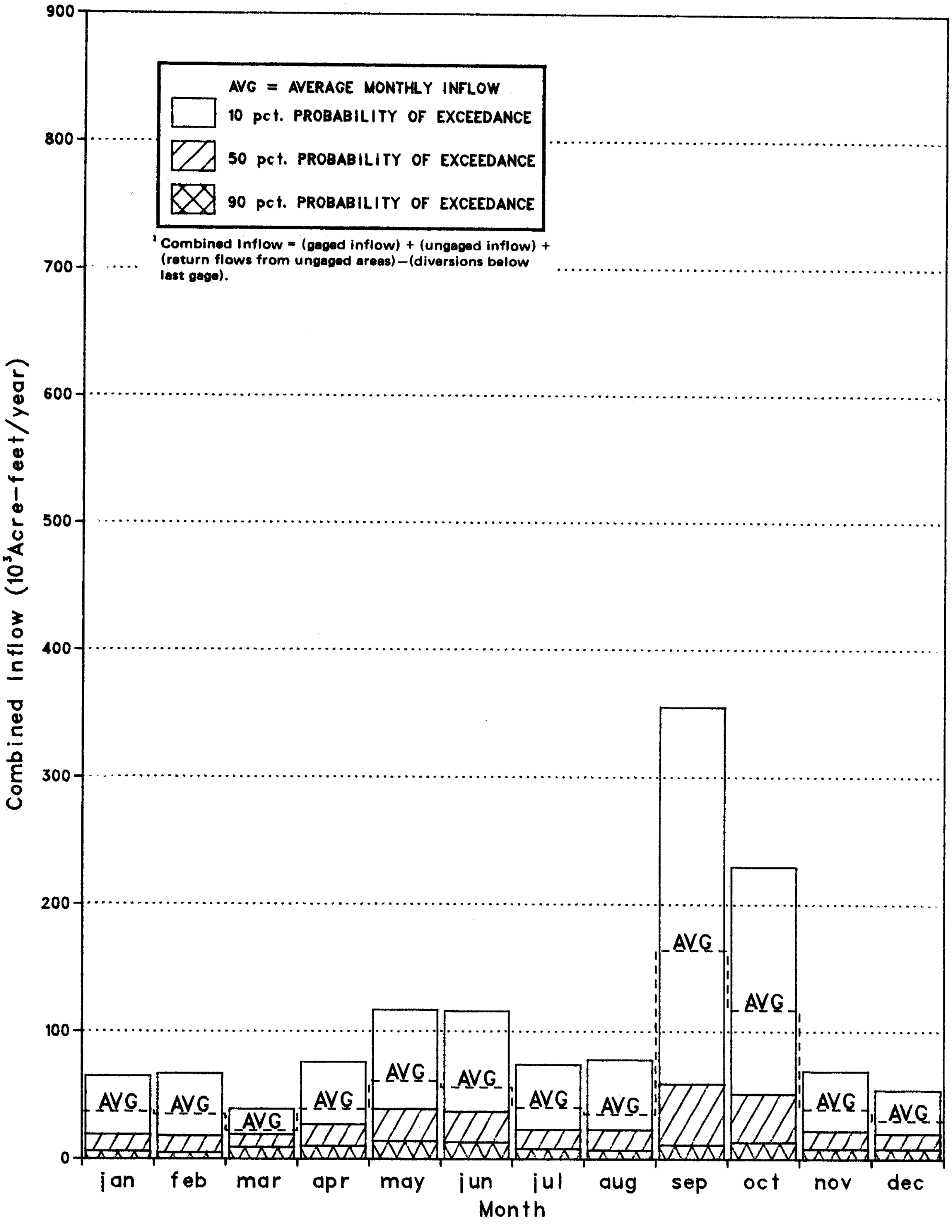


Figure III-14. Monthly Distribution of Combined Inflow,[1] Laguna Madre Estuary, 1941-1976

APPENDIX IV

Glossary of Terms

ABIOTIC : referring to something not living.

ALGAE : primitive aquatic plants varying from unicellular to large multicellular seaweeds lacking vascular tissue.

AUTOTROPHIC : referring to an organism able to synthesize the nutrients it requires from inorganic components (i.e., a primary producer).

BACTERIA : unicelular organisms lacking chlorophyll a closely allied to the fungi.

BAY : a wide recess in the shore formed by the sea or by a lake.

BIOMASS : the total biota of a particular region or habitat.

BIOTA : all living organisms, plant and animal of a region.

BIOTIC : referring to living organisms.

DETRITUS : all the particulate organic matter involved in the decomposition of dead organisms.

ECOSYSTEM : an interacting, self-sustaining, natural system of living organisms and of a chemical-physical component; the basic functional unit in ecology. The ecosystem is comprised of inorganic and organic substances, a climatic regime, producers and consumers.

ESTUARY : a broad, brackish portion of a low river course where the tide meets the downstream current, and mixing of salt and fresh waters occur.

FOOD CHAIN : the scheme of feeding relationships connecting the species of a community; of two basic types - a grazing food chain from a green plant to grazing hebivores and to carnivores, and a detritus food chain from dead organic matter to microorganisms and to detritus-feeding organisms and their predators; there are seldom more than six chain links because of large potential energy losses as heat at each stage.

FUNGI : plant organisms lacking photosynthetic pigments and thus unable to produce their own food.

GAGED INFLOW : freshwater flowing into an estuary that originates in a drainage area whose runoff is measured at a streamgage.

HERBIVORE : an animal that feeds chiefly on plants.

HETEROTROPHIC : referring to an organism unable to manufacture organic compounds.

HYPERSALINE : salinity significantly in excess of seawater salinity (35 parts per thousand).

LIFE CYCLE : the sequence of phases in the growth and development of an organism.

MARSH : an unwooded wet area, where the water level approximates the low shoreline of a bog or pond, supporting a dense vegetation of grasses.

NEKTON : swimming animals able to direct their own movements against marine currents.

NUTRIENTS : materials that are vital to the maintenance of living organisms.

OMNIVORE : an animal that feeds both on plants and animals.

PHYTOPLANKTON : minute floating plants (e.g., diatoms, dinoflagellates, coccolithophores).

RETURN FLOWS : wastewater discharged by man.

TROPHIC LEVEL : a means of classifying organisms whose food is obtained by one or more steps (e.g., a herbivore occupies a second level, the primary consumer level).

UNGAGED INFLOW : freshwater entering an estuary that is not measured by a streamgage.

ZOOPLANKTON : a feebly swimming and free floating heterotrophic aquatic animal.

APPENDIX V

Tables of Socio-Economic Data

Table V-1. Estimated Annual Sport Fishing Visitation to the Texas Bay and Estuarine Systems a/

Season b/	Boat	Wade-Bank	Pier	Total - All Strata
		thousands of people		
Fall c/	110.1 (2.58)	142.8 (2.02)	32.8 (1.27)	285.7 (2.00)
Winter	46.0 (2.31)	73.3 (1.91)	8.8 (2.03)	128.1 (2.06)
Spring	92.0 (2.51)	156.0 (2.20)	42.7 (2.23)	290.7 (2.30)
Summer	156.6 (2.68)	190.6 (2.27)	71.3 (2.48)	418.5 (2.39)
Total All Seasons	404.7 (2.57)	562.7 (2.14)	155.6 (1.92)	1,123.0 (2.24)

a/ Nueces and Mission-Aransas (1976-1977), Lavaca-Tres Palacios (1975-1976), Sabine-Neches (1975-1976), Trinity-San Jacinto (1976-1977), Guadalupe (1976-1977), and Laguna Madre (1976-1977)

b/ Fall = September, October, and November
Winter = December, January, and February
Spring = March, April, and May
Summer = June, July, and August

c/ The figures in parentheses indicate the average number of fishermen per party for the respective fishing type and quarter.

Table V-2. Estimated Annual Sport Fishing Expenditures by Season and Fishing Party Type

Season a/	Boat	Wade-Bank	Pier	Total	Percent
			thousands of 1976 dollars b/		
Fall	4,572.9	5,859.0	1,248.3	11,680.2	27.2
Winter	1,888.8	2,435.5	266.3	4,590.6	10.7
Spring	3,450.9	5,533.7	1,691.6	10,676.2	24.8
Summer	6,060.5	6,512.5	3,101.4	15,674.4	37.3
Total	15,973.1	20,340.7	6,307.6	42,621.4	100.0

a/ Fall = September, October, and November
Winter = December, January, and February
Spring = March, April, and May
Summer = June, July, and August

b/ 1975 expenditures for the Lavaca-Tres Palacios and Sabine-Neches estuaries have been converted to 1976 dollars.

Table V-3. Direct and Total a/ Economic Impact from Sport Fishing Expenditures b/

	Direct c/		Total	
	Regional	State	Regional	State d/
Output (thousands)	$38,221.6	$42,621.4	$78,987.9	$137,658.1
Employment (Man-Years)	2,312	2,697	3,201	4,581
Income (thousands)	13,537.6	15,732.0	23,560.4	39,107.6
State Tax Revenues (thousands)	e/	332.4	804.4	1,410.5
Local Tax Revenues (thousands)	e/	479.0	1,375.3	2,170.0

a/ Total = direct expenditures plus the indirect and induced multiplier impacts.
b/ Values in 1976 dollars.
c/ Direct impacts for the regions and state differ due to the travel expenditure adjustment. They represent the gross receipts by sport fishing industries.
d/ Statewide expenditures include the regional impacts.
Data not available.

Table V-4. Annual Direct and Total a/ Economic Impact of Commercial Fishing from the Texas Bay and Estuarine Systems b/

	Fishing Sector	Total	
		Regional	State
Output (1,000's 1976 $)	133,610.6	261,322.6	416,186.9
Employment (Man-Years)	4,865	8,215	10,339
Income (1,000's 1976 $)	44,639.3	96,532.6	114,455.1
State Tax Revenues (1,000's 1976 $)	507.7	2,414.4	3,781.2
Local Tax Revenues (1,000's 1976 $)	601.2	4,208.9	5,251.0

a/ Total = direct, indirect and induced
b/ Nueces and Mission-Aransas, Lavaca-Tres Palacios, Sabine-Neches, Trinity, San Jacinto, Guadalupe, and Laguna Madre. The commercial fish catch data are based on averages for the period 1972 through 1976.

Table V-5. Population Estimates and Projections

Estuary	1970	1975	1980	1990	2000	2010	2020	2030	1970-2000 Annual % Change	1970-2030 Annual % Change
Sabine-Neches	317,572	320,400	329,300	342,300	359,600	385,200	426,200	485,900	0.4	0.7
Annual % Change		0.2	0.5	0.4	0.5	0.7	1.0	1.3		
Trinity-San Jacinto	2,032,223	2,279,400	2,594,500	3,181,300	3,849,600	4,578,000	5,415,700	6,386,800	2.2	1.9
Annual % Change		2.3	2.6	2.1	1.9	1.7	1.7	1.7		
Lavaca-Tres Palacios	112,485	117,100	123,700	137,200	152,600	171,700	198,600	236,000	1.0	1.2
Annual % Change		0.8	1.1	1.0	1.1	1.2	1.5	1.7		
Guadalupe	89,993	95,200	102,600	117,700	134,700	155,200	182,900	219,800	1.4	1.5
Annual % Change		1.1	1.5	1.4	1.4	1.4	1.7	1.9		
Nueces and Mission-Aransas	303,228	317,300	335,700	369,500	409,900	469,500	558,900	693,600	1.0	1.4
Annual % Change		0.9	1.1	1.0	1.0	1.4	1.8	2.2		
Laguna Madre	189,782	219,000	252,000	304,200	364,200	441,600	528,900	623,100	2.2	2.0
Annual % Change		2.9	2.8	1.9	1.8	1.9	1.8	1.7		
Area Total a/	2,995,290	3,253,200	3,635,200	4,334,500	5,135,900	6,046,000	7,128,300	8,425,400	1.9	1.8
Annual % Change		1.9	2.2	1.8	1.7	1.6	1.7	1.7		
State Total	11,198,655	12,193,200	13,393,100	15,593,700	18,270,700	21,540,600	25,548,400	30,464,900	1.6	1.7
Annual % Change		1.7	1.9	1.5	1.6	1.7	1.7	1.8		

a/ The individual estuary figures will not add to the area totals since some coastal counties are in more than one of the estuarine study areas. The area totals are the sum of the population estimates and projections for the individual counties, and do not double count the population of counties in more than one estuarine area. See Figure V-1.

Table V-6. Employment by Industrial Sector - 1970

Sector	1970							
	Sabine-Neches	Trinity-San Jacinto	Lavaca-Tres Palacios	Guadalupe	Nueces and Mission-Aransas	Laguna Madre	Total a/	Percent of Total Employment of Study Area
Wholesale and Retail Trade	23,227	182,446	8,289	7,022	23,525	12,974	250,641	22.1
Manufacturing	34,152	168,481	6,474	5,278	11,284	5,538	225,929	20.0
Professional Services	18,097	134,513	6,307	4,923	17,081	10,602	186,600	16.5
Construction	8,907	75,548	3,815	2,855	9,241	3,912	101,423	9.0
Agriculture, Forestry, and Fisheries	1,230	8,761	3,267	1,970	4,488	6,994	24,740	2.2
Mining	2,244	22,192	2,254	1,630	4,782	582	32,054	2.8
Civilian Government	3,641	29,464	1,237	1,058	8,345	3,042	45,729	4.0
Amusement and Recreation	608	6,377	239	242	729	407	8,360	0.7
All Other	22,170	193,080	7,517	6,529	23,093	10,249	256,109	22.7
Total	114,276	820,862	39,399	31,507	102,568	54,300	1,131,405	100.0

a/ The individual estuary figures will not add to the sector totals since some coastal counties are in more than one of the estuarine study areas. The sector totals are the sum of the employment estimates for the individual counties, and do not double count the employment of counties in more than one estuarine area. See Figure V-1.

Table V-7. Earnings by Industrial Sector - 1970 ($1000 - 1967)

Sector	1970							
	Sabine-Neches	Trinity-San Jacinto	Lavaca-Tres Palacios	Guadalupe	Nueces and Mission-Aransas	Laguna Madre	Total a/	Percent of Total Earnings of Study Area
Wholesale and Retail Trade	123,041	1,278,019	40,823	36,077	135,879	56,191	1,633,953	19.1
Manufacturing	396,716	1,495,264	56,978	54,680	98,439	31,154	2,078,551	24.3
Professional Services	70,276	620,975	20,106	16,383	58,159	26,767	796,283	9.3
Construction	72,581	642,310	19,969	15,983	53,267	14,666	802,793	9.4
Agriculture, Forestry, and Fisheries	10,444	46,246	19,192	16,037	39,302	39.236	154,420	1.8
Mining	4,284	305,741	15,793	10,400	39,881	3,509	369,208	4.3
Civilian Government	90,927	684,847	17,218	15,298	149,215	58,381	1,000,588	11.7
Amusement and Recreation	1,972	32,899	724	744	2,749	1,245	39.589	0.5
All Other	154,668	1,330,801	33,235	29,422	122,379	40,920	1,682,003	19.8
Total	924,909	6,437,102	224,038	195,024	699,270	272,069	8,557,388	100.0

a/ The individual estuary figures will not add to the sector totals since some coastal counties are in more than one of the estuarine study areas. The sector totals are the sum of the earnings estimates for the individual counties, and do not double count the earnings of counties in more than one estuarine area. See Figure V-1.

APPENDIX VI

Fundamental Relationships Between Estuarine Systems and Freshwater Inflow

FUNDAMENTAL RELATIONSHIPS BETWEEN ESTUARINE SYSTEMS AND FRESHWATER INFLOW

Introduction

Environments of Texas estuarine systems vary widely. Natural and man-made changes in the estuaries, as well as in the influencing river basins, have molded and shaped the unique environmental characteristics of each system to varying degrees. Furthermore, the wide variability of environmental stresses which can be tolerated by Texas estuarine systems makes it difficult to segregate natural from man-made pressures and their effects on the estuaries.

The most severe drought on record occurred in the 1950's, creating harsh conditions in both inland and coastal environments of Texas. Water quality conditions in many estuaries exceeded environmental limits of many estuarinedependent organisms. Documented reports indicate that in some bays the salinities exceeded the average Gulf salinity by 40 percent due to low freshwater inflows and high evaporation rates. Similar estuarine conditions occurred during a less severe Texas drought in the early 1960's. Nevertheless, estuarine biological productivity recovered rapidly in the years following both drought periods.

Fundamental to these discussions is the concept of seasonal dynamics; that is, the environmental needs of an estuarine ecosystem are not static annual needs. In fact, dynamic equilibrium about the productive range is both realistic and desirable for an estuarine environment. However, extended periods of inflow conditions which consistently fall below maintenance levels can lead to a degraded estuarine environment, loss of important "nursery" functions for estuarine-dependent fish and shellfish, and a reduction in the potential for assimilation of organic and nutritive wastes. During past droughts, Texas estuaries severely declined in their fisheries production and began to take on characteristics of marine lagoons, including the presence of starfish and sea urchin populations.

Physical and Chemical Factors

Hydrology

A primary factor distinguishing an estuary from a strictly marine environment is the input of freshwater from various sources. Sources of freshwater inflow to Texas estuaries include: (1) gaged inflow (as measured at the most downstream flow gage 1/ of each river system and includes wastewater discharges (return flows), reservoir spills and releases, and unregulated runoff), (2) ungaged runoff, and (3) direct precipitation on the estuary's surface. The measurement of each of these sources of freshwater inflow is necessary to develop analytical relationships between freshwater inflow and resulting changes in the estuarine environment. Gaged inflow is the simplest of the three sources to quantify; however, gaged records do require adjustment to reflect for diversions and return flows downstream of streamgage locations.

Computation of ungaged inflow utilized soil moisture data and runoff coefficients developed from field surveys. Direct precipitation on an estuary is assumed to be an average of the daily precipitation recorded at weather stations in the coastal regions adjacent to each bay.

Water Quality

The factors which affect the water quality of aquatic ecosystems and their importance to the various biological components (as defined by the chemical and physical properties of the water body) include nutrients, such as nitrogen and phosphorus; the basic cellular building

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1/ Due to tidal influences, the most downstream streamgage on a river is not located at the mouth of the river, and thus does not measure all of a river basin's flow contribution to an estuary.

block, carbon; trace elements necessary for biological growth; the presence of sufficient concentrations of dissolved oxygen for respiration of aerobic organisms; and the occurrence of toxic chemicals that may inhibit growth and productivity (Figure VI-1). The presence of pollutants can have significant impacts upon estuarine water quality. Waste loads which enter the aquatic ecosystem can be of several types, including predominantly municipal and industrial treated and untreated effluent and agricultural return flow. Economic and business activities, by altering land use patterns, may also result in changes to the physical and chemical quality of direct runoff.

The single most important water quality constituent to the estuarine ecology is the concentration of dissolved solids, termed salinity. The level of salinity in Texas estuaries dictates the health and diversity of their aquatic ecologies. The inflow of freshwater generally alters salinity regimes in Texas bays and estuaries in the characteristic pattern indicated in Figure VI-2.

Biological Factors

An estuarine ecosystem is comprised of a myriad of life forms, living interdependently, yet all dependent on the "health" of the aquatic environment. Among the general groupings of life forms that occur in the estuary, the most prominent are bacteria, phytoplankton (algae), macrophytes (vascular plants), zooplankton, nekton (finfish), and benthic (bottom dwelling) animals.

Severe droughts, floods, and hurricanes are factors that largely control and influence species composition in estuaries. While the number of species generally remains low, the population of a species fluctuates with the seasons and with hydrologic cycles. The fluctuating conditions provide for a continuing shift in dominant organisms, thereby preventing a specific species from maintaining a persistent dominance.

Natural stresses encountered in an estuary are due, in part, to the fact that these areas represent a transition zone between freshwater and marine environments. Biological communities' composition changes, with respect to the number of species and types of organisms, when salinity is altered (Figure VI-3). The number of species is lowest in the estuarine transition zone between freshwater and marine environments. The number and type of species may vary from one geographic locality to another; however, most species have a wide distribution in Texas bays and estuaries.

Food Chain

To evaluate the effects of freshwater inflow on an estuary, it is necessary to consider the significant interactions among dominant organisms for each of the estuary's production levels. A complicated food web consisting of several food chains exists within each estuary with water the primary medium of life support. The aquatic ecosystem has four major components, all interrelated through various life processes (Figure VI-1):

1. Chemical elements including basic substances essential to life such as carbon dioxide (CO_2), nitrate (NO_3), ammonia (NH_3), phosphate (PO_4), and dissolved oxygen (DO),
2. Autotrophic organisms such as vascular plants and algae that can transform basic substances into living cell material through utilization of sunlight,
3. Heterotrophic organisms such as zooplankton, shellfish, and fish species that utilize other biota as food material, and
4. Decomposers including bacteria in both liquid and solid (sediment) phases and fungi.

The food chain relationships occurring in an estuarine system typical of those along the Texas Gulf Coast are large in number and complex in scope (Figure VI-4). The

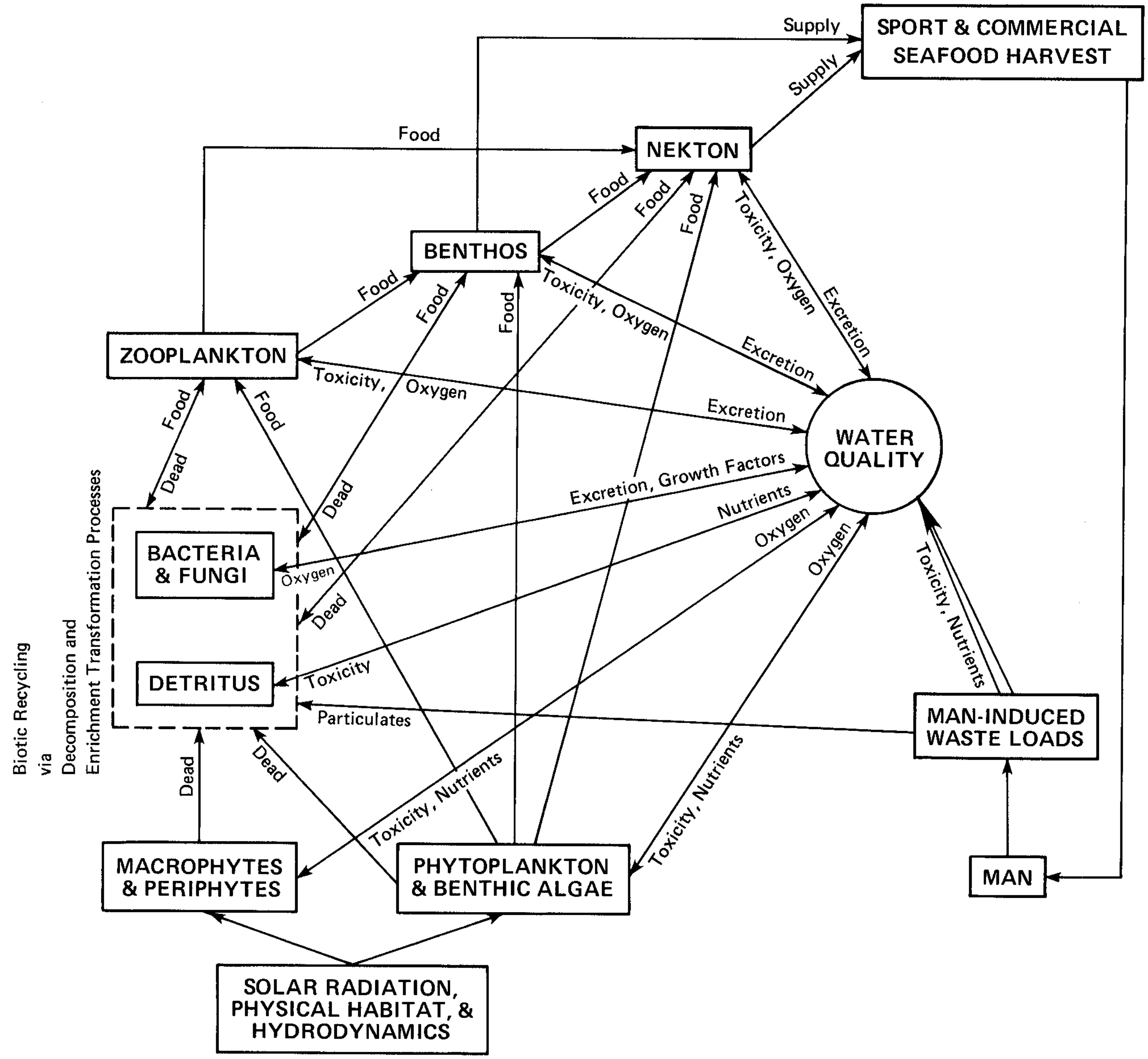

Figure VI-1. Component Schematic Diagram of a Generalized Texas Estuarine Ecosystem

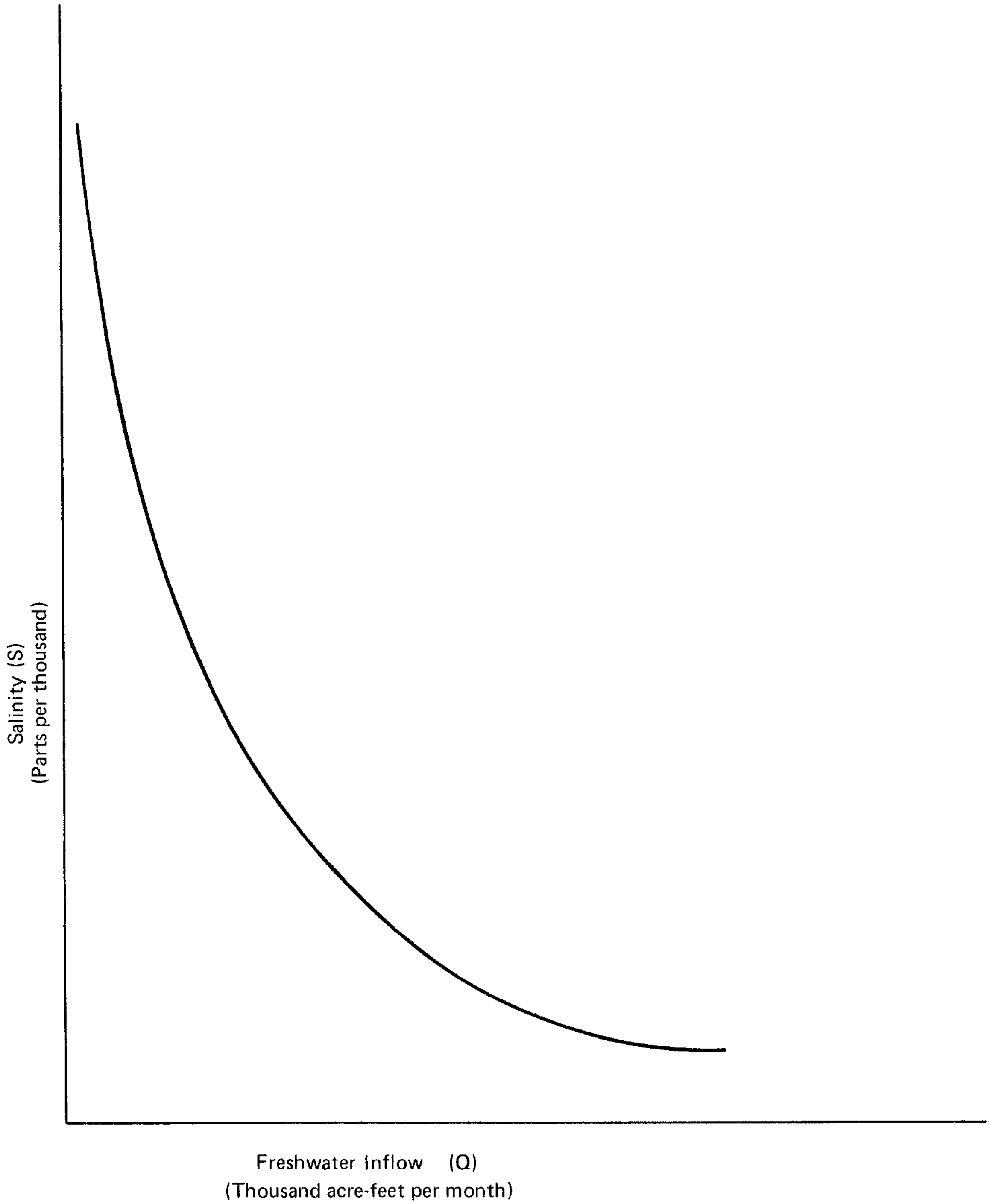

Figure VI-2. Typical Variation of Freshwater Inflow Versus Salinity in a Texas Estuary

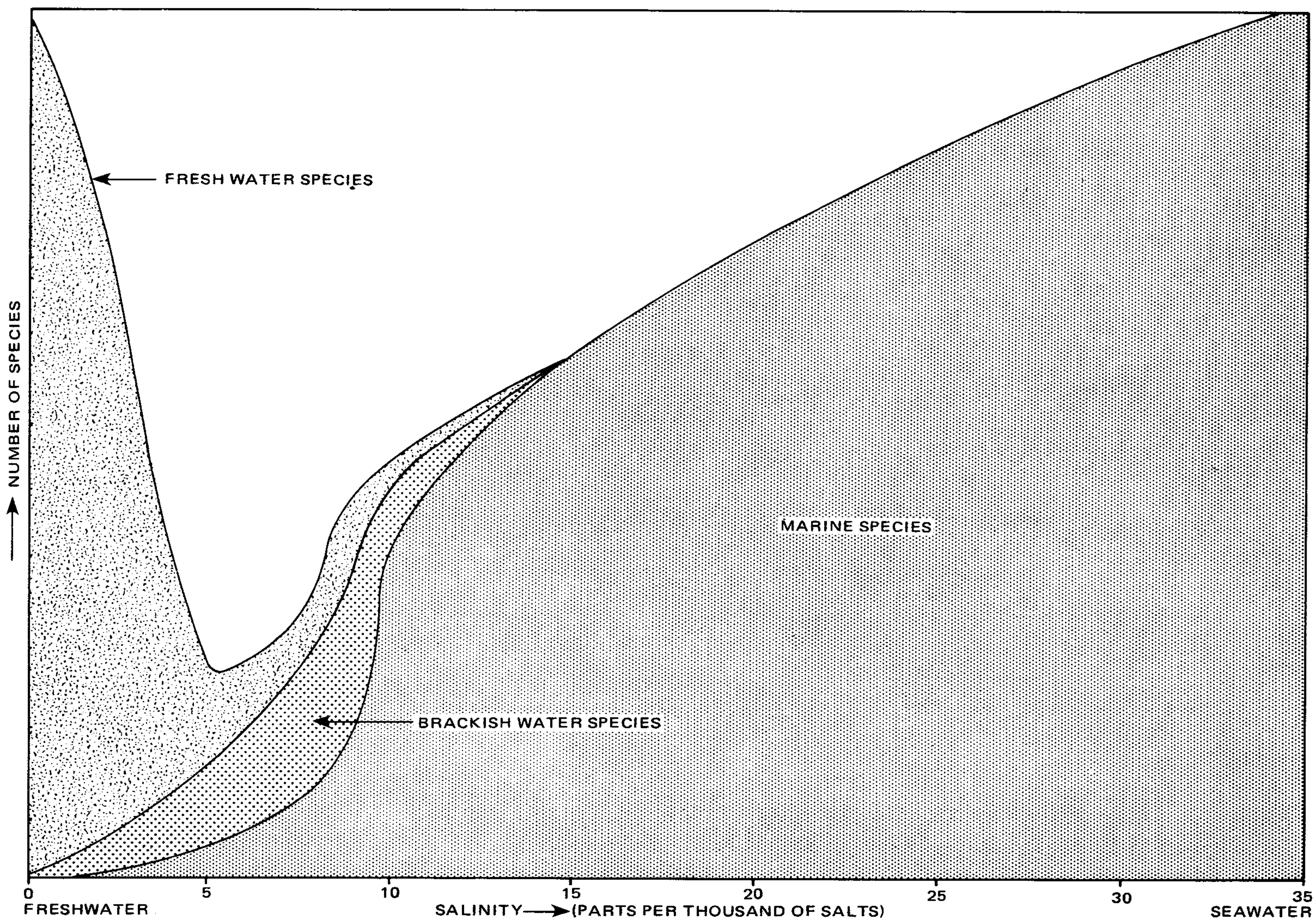

Figure VI-3. Species Composition of Estuarine Environments

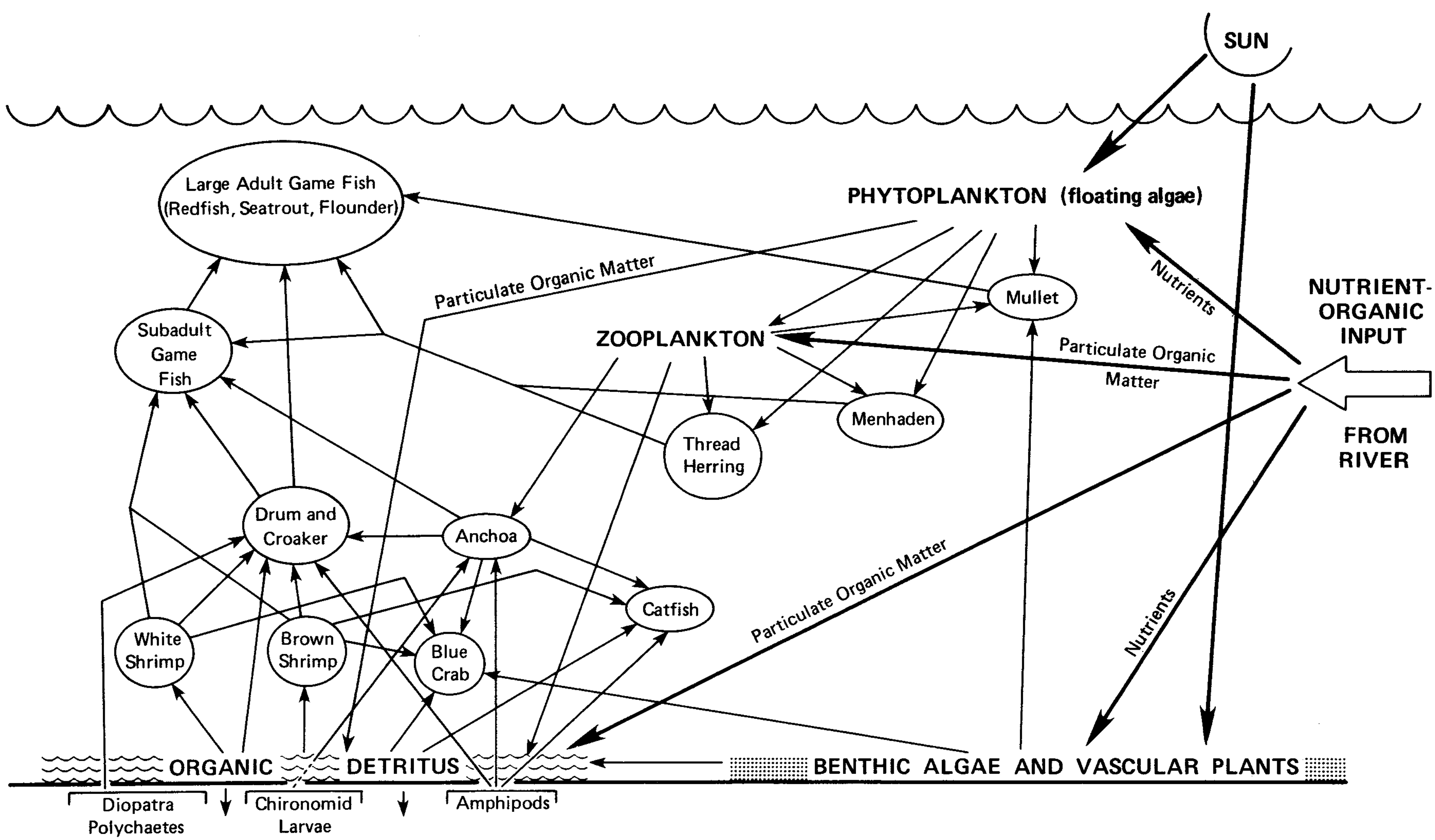

Figure VI-4. Simplified Trophic Relationships in a Texas Estuary

river inflow transports into the estuary nutrients and organic materials, both of which contribute to supporting the extensive populations of species within the system. Exact quantitative relationships among the estuarine organisms and the aquatic environment are extremely complex and many are still unknown.

Life Cycles

Many organisms of estuarine systems are not permanent residents, in that they spend only part of their life cycle in the estuary. Migration patterns constitute an integral part of the life history of many estuarine-dependent species. These migrations occur in seasonal cycles and most are involved with spawning (reproduction). Larval and postlarval organisms, utilizing currents and tides, may migrate into the estuary because of food and physiological requirements for lowered salinity, and for protection against predators and parasites. Juvenile forms use the shallow tertiary bay "nursery" areas during early growth, migrating back to the Gulf of Mexico in their subadult and/or adult life stages.

Virtually all (over 97.5%) of the Gulf fisheries species are estuarine-dependent; however, the seasonal aspects of their life cycles are quite different. Some species, such as the redfish, spawn in the fall and the young are particularly depend- ent on migration to and utilization of the "nursery" habitats during this season. Others, such as shrimp, spawn primarily in the spring and early summer, and their young move inshore to shallow, low salinity estuarine areas for growth and development at this time. Not all estuarine-dependent species are migratory between the marine and estuarine environments; however, there are few true year-round residents (e.g., bay oysters) capable of completing their life cycle totally within the estuary.

For high estuary productivity to occur, the timing of freshwater inflow, including inundation of marshes, which both irrigates and fertilizes estuarine plants must coincide with the subtropical climatic regime of the Gulf region. Nature's seasons provide environmental cues, such as increases or decreases in salinity and temperature, that enable estuarine-dependent species to reproduce and grow successfully in the coastal environments; i.e., apparently these species have adjusted their life cycles to the schedule of natural processes in the ecosystem and thereby reduce competition and predation. Coincidence of seasonal events, such as spring rains, inundation of marshes and nutrient cycling is made more complex by both antecedent events and ambient conditions. For example, winter inundation and fertilization of marshes may not be as beneficial to the estuarine system as similar events in the spring because low winter temperatures do not support high biological activity. Consequently, the growth and survival of many economically important seafood species will be limited if antecedent events and ambient conditions are unfavorable and untimely for the season.

Habitat

The marsh wetlands adjacent to each Texas estuary are among the most important areas of the estuarine ecosystems. The Texas marshes are tracts of soft, wet land located adjacent to or near the bay margins and along the channels of inflowing streams including the associated deltas. Depending upon the specific location, estuarine marsh communities may be frequently inundated by tidal fluctuations or only occasionally inundated by the seasonal flooding of inflowing streams. Texas estuarine marshes are dominated by salt-tolerant vegetation, such as the cord grass Spartina, which produces significant quantities of vegetation which when decomposed becomes organic material that forms the base of the food chain and thereby provides input to the productivity in higher levels of the food chain such as fish, shrimp, and oysters. Vascular plant production of several delta marshes along the Texas Gulf Coast has been measured at about 100 million pounds dry weight per year (or 45,500 metric tons/yr) each, with production exceeding 15,000 dry weight lbs/acre/year (or 1,680 $g/m^2/yr$) in the most productive areas. Throughout the world, only tropical rain forests, coral reefs, and some algal beds produce more abundantly per unit of area.

Marsh production is a major source of organic material supporting the estuarine food web in coastal areas from New England and the South Atlantic, to the Gulf of Mexico. Because of high plant productivities an estuarine marsh can assimilate substantial volumes of nutrient-rich municipal and industrial wastes and incorporate them into the yield of organic material which supports fisheries species. These high food density areas serve as "nursery" habitats for many economically important estuarinedependent species, as well as providing food and cover for a variety of water fowl and mammals. Delta marshes also serve other beneficial functions acting as a temporary floodwater storage area and aiding in erosion control by absorbing potentially destructive wave energy.

Texas estuarine systems are among the most diverse in the world and vary from extreme oligohaline (low salinity) conditions on the northeastern coast to extreme hypersaline (high salinity) conditions on the southwestern coast. Yet, along the geographic gradients of salinity and temperature are populations of fish and shellfish species which are dependent upon the estuaries and have adapted to their variable conditions. One important parameter of flux, the amount and timing of freshwater inflow to the estuaries, has been examined in detail through an analysis of Texas coastal fisheries as a function of the seasonal freshwater inflows to each estuarine system. The analysis produced over 115 statistically significant multiple regression harvest equations,the results of which are summarized in Tables VI-1 through VI-10. Since several of the species adaptations are temporal in nature, they are reflected in the seasonal analysis of freshwater inflow effects. Major seasonal response differences are noted among the species, especially between fisheries populations inhabiting the high rainfall ("wet") upper coast versus the "dry" lower coast of Texas. Overall, 67 percent of harvest correlations to winter inflows are negative, 86 percent are positive to spring inflows, 51 percent are negative to summer inflows, 57 percent are positive to early fall (autumn) inflows and 76 percent are positive to late fall inflows.

Summary

The ecosystems which have developed within the seven major Texas estuaries are in large part dependent upon the amount, as well as, the seasonal and spatial distribution of freshwater inflow and associated nutrients. Freshwater flows enter the bays from rivers, streams, and local rainfall runoff. Freshwater dilutes the saline tidal water of the Gulf and transports nutritive and sedimentary building blocks that maintain marsh environments and contribute to estuarine production of fish and shellfish.

The health of estuarine aquatic organisms is largely dependent upon water quality. Toxic materials and other pollutants create stress that can inhibit reproduction and growth, and may have long-lasting effects on the estuary.

An estuarine ecosystem is a complex interrelationship of organic and inorganic constitutents. Basic inorganic elements and nutrients are assimilated by algae and other primary-producer organisms. These organisms in turn are consumed by predators. Organic material is made available for reuse in the ecosystem by bacteria and fungi.

Many species inhabiting Texas estuaries are not permanent residents. Juveniles enter the estuary in larval or postlarval forms and remain during early growth. Finfish and shellfish species, in particular, have migratory life cycles, with the adults residing in the Gulf of Mexico, larval and postlarval organisms migrating into the estuaries, juveniles use the shallow nursery areas during early growth, and subadults to adults migrating back into the Gulf.

Estuarine wetlands and river deltas are the most important habitat areas for juvenile forms of many aquatic species. These marsh systems contribute nutrients to the estuaries while providing nursery habitats for many species of estuarine organisms.

Table VI-1. Summary of Seasonal Relationships of Freshwater Inflow to Commercial Fisheries Harvest on the Texas Coast.

Fisheries Component	Winter Inflow (Jan. - March)	Spring Inflow (April - June)	Summer Inflow (July - Aug.)	Early Fall Inflow (Sept. - Oct.)	Late Fall Inflow (Nov. - Dec.)	Equational Models[1]
Cynoscion nebulosus	(+) = 1 (-) = 10	(+) = 7 (-) = 0	(+) = 6 (-) = 7	(+) = 5 (-) = 3	(+) = 8 (-) = 1	15
Sciaenops ocellatus	(+) = 2 (-) = 7	(+) = 14 (-) = 1	(+) = 4 (-) = 9	(+) = 7 (-) = 4	(+) = 10 (-) = 2	17
Pogonias cromis	(+) = 0 (-) = 6	(+) = 3 (-) = 3	(+) = 7 (-) = 1	(+) = 0 (-) = 8	(+) = 6 (-) = 0	10
Estuarine Fish[2]	(+) = 3 (-) = 10	(+) = 8 (-) = 2	(+) = 7 (-) = 7	(+) = 4 (-) = 6	(+) = 9 (-) = 3	16
Crassostrea virginica	(+) = 3 (-) = 3	(+) = 3 (-) = 0	(+) = 2 (-) = 5	(+) = 1 (-) = 3	(+) = 3 (-) = 1	8
Callinectes sapidus	(+) = 5 (-) = 0	(+) = 5 (-) = 1	(+) = 6 (-) = 2	(+) = 5 (-) = 0	(+) = 3 (-) = 0	9
Penaeus setiferus	(+) = 5 (-) = 0	(+) = 11 (-) = 0	(+) = 2 (-) = 7	(+) = 6 (-) = 2	(+) = 1 (-) = 3	14
Penaeus aztecus and *P. duorarum*	(+) = 1 (-) = 5	(+) = 4 (-) = 3	(+) = 4 (-) = 1	(+) = 4 (-) = 2	(+) = 1 (-) = 0	11
Penaeid Shrimp[3]	(+) = 4 (-) = 7	(+) = 11 (-) = 1	(+) = 3 (-) = 4	(+) = 7 (-) = 0	(+) = 3 (-) = 4	15
Summary of Correlative Trends	(+) = 24 (-) = 48	(+) = 66 (-) = 11	(+) = 41 (-) = 42	(+) = 39 (-) = 30	(+) = 44 (-) = 14	115

[1]Multiple regression equations ($P \leq 0.05$, mean $R^2 = 70\%$)
[2]Fish species include *Micropogonias undulatus*, *Pogonias cromis*, *Sciaenops ocellatus*, *Cynoscion nebulosus*, *Paralichthys lethostigma*, *Arius felis*, and *Archosargus probatocephalus*
[3]Shrimp species include *Penaeus setiferus*, *P. aztecus*, and *P. duorarum*

Table VI-2. Seasonal Relationships of Freshwater Inflow to Commercial Harvest of *Cynoscion nebulosus* in Texas Estuaries (1962-1976). Signs (+/-) are From Multiple Regression Coefficients of the Equational Harvest Models.[1]

Estuary and Freshwater Inflow Category	Winter Inflow (Jan. - March)	Spring Inflow (April - June)	Summer Inflow (July - Aug.)	Early Fall Inflow (Sept. - Oct.)	Late Fall Inflow (Nov. - Dec.)
TRINITY-SAN JACINTO ESTUARY					
Trinity River	-		-	+	
San Jacinto River			-	+	+
Combined Inflow[2]	-		-	+	+
LAVACA-TRES PALACIOS ESTUARY					
Lavaca River					
Colorado River	-	+		-	
Combined Inflow					
GUADALUPE ESTUARY					
Guadalupe River	-	+	-	-	+
Combined Inflow	-	+	-	-	+
MISSION-ARANSAS ESTUARY					
Mission and Aransas Rivers	-		-	+	+
Combined Inflow			-	+	+
NUECES ESTUARY					
Nueces River	-	+	+		
Combined Inflow	-	+	+		
NUECES/MISSION-ARANSAS ESTUARIES					
Mission, Aransas, and Nueces Rivers	-	+			+
Combined Inflow	-		+		+
LAGUNA MADRE ESTUARY					
Upper Laguna Madre		+	+		
Lower Laguna Madre			+		
Combined Inflow	+		+		-
Summary of Correlative Trends	(+)=1 (-)=10	(+)=7 (-)=0	(+)=6 (-)=7	(+)=5 (-)=3	(+)=8 (-)=1

[1]Number of harvest models = 15 significant multiple regression equations ($P \leq 0.05$, mean R^2 = 75%)
[2]Combined inflow includes all gauged and ungauged freshwater flows from river and coastal drainage basins contributing to each estuary

Table VI-3. Seasonal Relationships of Freshwater Inflow to Commercial Harvest of *Sciaenops ocellatus* in Texas Estuaries (1962-1976). Signs (+/-) are From Multiple Regression Coefficients of the Equational Harvest Models.[1]

Estuary and Freshwater Inflow Category	Winter Inflow (Jan. - March)	Spring Inflow (April - June)	Summer Inflow (July - Aug.)	Early Fall Inflow (Sept. - Oct.)	Late Fall Inflow (Nov. - Dec.)
TRINITY-SAN JACINTO ESTUARY					
Trinity River	-	+	-	+	+
San Jacinto River		+	-	+	+
Combined Inflow[2]		+	-		+
LAVACA-TRES PALACIOS ESTUARY					
Lavaca River			-	+	+
Colorado River		+	-		
Combined Inflow		+	-		
GUADALUPE ESTUARY					
Guadalupe River	-	+	-	-	+
Combined Inflow	-	+	-	-	+
MISSION-ARANSAS ESTUARY					
Mission and Aransas Rivers		+		+	
Combined Inflow		+		+	
NUECES ESTUARY					
Nueces River	-	+		-	+
Combined Inflow	-	+	+	-	+
NUECES/MISSION-ARANSAS ESTUARIES					
Mission, Aransas, and Nueces Rivers	-	+	+		+
Combined Inflow	-	+	+		+
LAGUNA MADRE ESTUARY					
Upper Laguna Madre		+	+		
Lower Laguna Madre	+	-	-	+	-
Combined Inflow	+			+	-
Summary of Correlative Trends	(+)=2 (-)=7	(+)=14 (-)=1	(+)=4 (-)=9	(+)=7 (-)=4	(+)=10 (-)=2

[1]Number of harvest models = 17 significant multiple regression equations ($P \leq 0.05$, mean R^2 = 71%)
[2]Combined inflow includes all gauged and ungauged freshwater flows from river and coastal drainage basins contributing to each estuary

Table VI-4. Seasonal Relationships of Freshwater Inflow to Commercial Harvest of *Pogonias cromis* in Texas Estuaries (1962-1976). Signs (+/-) are From Multiple Regression Coefficients of the Equational Harvest Models.[1]

Estuary and Freshwater Inflow Category	Winter Inflow (Jan. - March)	Spring Inflow (April - June)	Summer Inflow (July - Aug.)	Early Fall Inflow (Sept. - Oct.)	Late Fall Inflow (Nov. - Dec.)
GUADALUPE ESTUARY					
Guadalupe River			+	-	+
Combined Inflow[2]			+	-	+
MISSION-ARANSAS ESTUARY					
Mission and Aransas Rivers	-		-		+
Combined Inflow		-			+
NUECES ESTUARY					
Nueces River	-	+		-	
Combined Inflow	-	+	+	-	
NUECES/MISSION-ARANSAS ESTUARY					
Nueces, Mission, and Aransas Rivers	-	+	+	-	+
Combined Inflow	-		+	-	+
LAGUNA MADRE ESTUARY					
Upper Laguna Madre					
Lower Laguna Madre	-	-	+	-	
Combined Inflow		-	+	-	
Summary of Correlative Trends	(+)=0 (-)=6	(+)=3 (-)=3	(+)=7 (-)=1	(+)=0 (-)=8	(+)=6 (-)=0

[1]Number of harvest models = 10 significant multiple regression equations ($P \leq 0.05$, mean R^2 = 75%)
[2]Combined inflow includes all gauged and ungauged freshwater flows from river and coastal drainage basins contributing to each estuary

Table VI-5. Seasonal Relationships of Freshwater Inflow to Commercial Fish[1] Harvest in Texas Estuaries (1962-1976). Signs (+/-) are From Multiple Regression Coefficients of the Equational Harvest Models.[2]

Estuary and Freshwater Inflow Category	Winter Inflow (Jan. - March)	Spring Inflow (April - June)	Summer Inflow (July - Aug.)	Early Fall Inflow (Sept. - Oct.)	Late Fall Inflow (Nov. - Dec.)
TRINITY-SAN JACINTO ESTUARY					
Trinity River	-			+	
San Jacinto River			-	+	+
Combined Inflow[3]					
LAVACA-TRES PALACIOS ESTUARY					
Lavaca River			-	+	+
Colorado River	-	+		-	
Combined Inflow	+		-		
GUADALUPE ESTUARY					
Guadalupe River	-	+	-	-	+
Combined Inflow	-	+	-	-	+
MISSION-ARANSAS ESTUARY					
Mission and Aransas Rivers	-		-		+
Combined Inflow	-		-	+	+
NUECES ESTUARY					
Nueces River	-	+	+		
Combined Inflow	-	+	+	-	+
NUECES/MISSION-ARANSAS ESTUARIES					
Mission, Aransas, and Nueces Rivers	-	+	+	-	+
Combined Inflow	-	+	+	-	+
LAGUNA MADRE ESTUARY					
Upper Laguna Madre		+	+		-
Lower Laguna Madre	+	-	+		-
Combined Inflow	+	-	+		-
Summary of Correlative Trends	(+)=3 (-)=10	(+)=8 (-)=2	(+)=7 (-)=7	(+)=4 (-)=6	(+)=9 (-)=3

[1]Fish species include *Micropogonias undulatus*, *Pogonias cromis*, *Sciaenops ocellatus*, *Cynoscion nebulosus*, *Paralichthys lethostigma*, *Arius felis*, and *Archosargus probatocephalus*

[2]Number of harvest models = 16 significant multiple regression equations ($P \leq 0.05$, mean $R^2 = 71\%$)

[3]Combined inflow includes all gauged and ungauged freshwater flows from river and coastal drainage basins contributing to each estuary

Table VI-6. Seasonal Relationships of Freshwater Inflow to Commercial Harvest of *Crassostrea virginica* in Texas Estuaries (1962-1976). Signs (+/-) are From Multiple Regression Coefficients of the Equational Harvest Models.[1]

Estuary and Freshwater Inflow Category	Winter Inflow (Jan. - March)	Spring Inflow (April - June)	Summer Inflow (July - Aug.)	Early Fall Inflow (Sept. - Oct.)	Late Fall Inflow (Nov. - Dec.)
TRINITY-SAN JACINTO ESTUARY					
Trinity River	-	+	-	-	
San Jacinto River	-	+	-	-	
Combined Inflow[2]		+	-	-	-
LAVACA-TRES PALACIOS ESTUARY					
Lavaca River			-		+
Colorado River					
Combined Inflow	+		-		+
MISSION-ARANSAS ESTUARY					
Mission and Aransas Rivers	+		+		+
Combined Inflow	+			+	
LAGUNA MADRE ESTUARY					
Upper Laguna Madre					
Lower Laguna Madre	-		+		
Combined Inflow					
Summary of Correlative Trends	(+)=3 (-)=3	(+)=3 (-)=0	(+)=2 (-)=5	(+)=1 (-)=3	(+)=3 (-)=1

[1] Number of harvest models = 8 significant multiple regression equations ($P \leq 0.05$, mean R^2 = 57%)
[2] Combined inflow includes all gauged and ungauged freshwater flows from river and coastal drainage basins contributing to each estuary

Table VI-7. Seasonal Relationships of Freshwater Inflow to Commercial Harvest of *Callinectes sapidus* in Texas Estuaries (1962-1976). Signs (+/-) are From Multiple Regression Coefficients of the Equational Harvest Models.[1]

Estuary and Freshwater Inflow Category	Winter Inflow (Jan. - March)	Spring Inflow (April - June)	Summer Inflow (July - Aug.)	Early Fall Inflow (Sept. - Oct.)	Late Fall Inflow (Nov. - Dec.)
TRINITY-SAN JACINTO ESTUARY					
Trinity River					
San Jacinto River					
Combined Inflow[2]		+	-	+	
LAVACA-TRES PALACIOS ESTUARY					
Lavaca River	+		+	+	
Colorado River		-	+	+	
Combined Inflow			+	+	+
MISSION-ARANSAS ESTUARY					
Mission and Aransas Rivers	+		+	+	
Combined Inflow					
NUECES ESTUARY					
Nueces River	+	+		-	+
Combined Inflow	+	+		-	+
NUECES/MISSION-ARANSAS ESTUARIES					
Mission, Aransas, and Nueces Rivers	+	+	+		
Combined Inflow		+	+		
Summary of Correlative Trends	(+)=5 (-)=0	(+)=5 (-)=1	(+)=6 (-)=1	(+)=5 (-)=2	(+)=3 (-)=0

[1]Number of harvest models = 9 significant multiple regression equations ($P \leq 0.05$, mean R^2 = 71%)
[2]Combined inflow includes all gauged and ungauged freshwater flows from river and coastal drainage basins contributing to each estuary

Table VI-8. Seasonal Relationships of Freshwater Inflow to Commercial Harvest of *Penaeus setiferus* on the Texas Coast (1959-1976). Signs (+/-) are From Multiple Regression Coefficients of the Equational Harvest Models.[1]

Estuary and Freshwater Inflow Category	Winter Inflow (Jan. - March)	Spring Inflow (April - June)	Summer Inflow (July - Aug.)	Early Fall Inflow (Sept. - Oct.)	Late Fall Inflow (Nov. - Dec.)
TRINITY-SAN JACINTO ESTUARY					
Trinity River					
San Jacinto River					
Combined Inflow[2]		+	-	+	
LAVACA-TRES PALACIOS ESTUARY					
Lavaca River		+			-
Colorado River					
Combined Inflow		+			-
GUADALUPE ESTUARY					
Guadalupe River	+		-	+	
Combined Inflow	+		-	+	
MISSION-ARANSAS ESTUARY					
Mission and Aransas Rivers		+		-	
Combined Inflow		+	+	-	
NUECES ESTUARY					
Nueces River		+	-	+	
Combined Inflow		+	-	+	
NUECES/MISSION-ARANSAS ESTUARIES					
Nueces, Mission, and Aransas Rivers	+	+	+	+	
Combined Inflow	+	+			+
LAGUNA MADRE ESTUARY					
Upper Laguna Madre		+			
Lower Laguna Madre	+		-		-
Combined Inflow					
TEXAS GULF COAST		+	-		
Summary of Correlative Trends	(+)=5 (-)=0	(+)=11 (-)=0	(+)=2 (-)=7	(+)=6 (-)=2	(+)=1 (-)=3

[1] Number of harvest models = 14 significant multiple regression equations ($P \leq 0.05$, mean R^2 = 69%)
[2] Combined inflow includes all gauged and ungauged freshwater flows from river and coastal drainage basins contributing to each estuary

Table VI-9. Seasonal Relationships of Freshwater Inflow to Commercial Harvest of *Penaeus aztecus* and *P. duorarum*[1] on the Texas Coast (1959-1976). Signs (+/-) are From Multiple Regression Coefficients of the Equational Harvest Models.[2]

Estuary and Freshwater Inflow Category	Winter Inflow (Jan. - March)	Spring Inflow (April - June)	Summer Inflow (July - Aug.)	Early Fall Inflow (Sept. - Oct.)	Late Fall Inflow (Nov. - Dec.)
TRINITY-SAN JACINTO ESTUARY					
Trinity River		-	+		
San Jacinto River		-	-	+	+
Combined Inflow[3]	-	-	+	-	
GUADALUPE ESTUARY					
Guadalupe River			+	+	
Combined Inflow			+	+	
MISSION-ARANSAS ESTUARY					
Mission and Aransas Rivers		+			
Combined Inflow					
NUECES ESTUARY					
Nueces River					
Combined Inflow					
NUECES/MISSION-ARANSAS ESTUARIES					
Nueces, Mission, and Aransas Rivers	-	+			
Combined Inflow	-	+			
LAGUNA MADRE ESTUARY					
Upper Laguna Madre	-				
Lower Laguna Madre	+			+	
Combined Inflow					
TEXAS GULF COAST	-	+		-	
Summary of Correlative Trends	(+)=1 (-)=5	(+)=4 (-)=3	(+)=4 (-)=1	(+)=4 (-)=2	(+)=1 (-)=0

[1]Harvest mostly *P. aztecus*
[2]Number of harvest models = 11 significant multiple regression equations ($P \leq 0.05$, mean R^2 = 63%)
[3]Combined inflow includes all gauged and ungauged freshwater flows from river and coastal drainage basins contributing to each estuary

Table VI-10. Seasonal Relationships of Freshwater Inflow to Commercial Harvest of Penaeid[1] Shrimp on the Texas Coast (1959-1976). Signs (+/-) are From Multiple Regression Coefficients of the Equational Harvest Models.[2]

Estuary and Freshwater Inflow Category	Winter Inflow (Jan. - March)	Spring Inflow (April - June)	Summer Inflow (July - Aug.)	Early Fall Inflow (Sept. - Oct.)	Late Fall Inflow (Nov. - Dec.)
TRINITY-SAN JACINTO ESTUARY					
Trinity River					
San Jacinto River					
Combined Inflow[3]	-	-	+		
LAVACA-TRES PALACIOS ESTUARY					
Lavaca River	-	+	-		-
Colorado River	-	+	-	+	-
Combined Inflow	-	+			-
GUADALUPE ESTUARY					
Guadalupe River	+			+	
Combined Inflow	+			+	
MISSION-ARANSAS ESTUARY					
Mission and Aransas Rivers	+	+	+		+
Combined Inflow		+			+
NUECES ESTUARY					
Nueces River		+		+	-
Combined Inflow	-	+			
NUECES/MISSION-ARANSAS ESTUARIES					
Mission, Aransas, and Nueces Rivers		+	+	+	
Combined Inflow		+		+	
LAGUNA MADRE ESTUARY					
Upper Laguna Madre	-	+	-		+
Lower Laguna Madre	+			+	
Combined Inflow					
TEXAS GULF COAST	-	+	-		
Summary of Correlative Trends	(+)=4 (-)=7	(+)=11 (-)=1	(+)=3 (-)=4	(+)=7 (-)=0	(+)=3 (-)=4

[1]Shrimp species include *Penaeus aztecus*, *P. setiferus*, and *P. duorarum*
[2]Number of harvest models = 15 significant multiple regression equations ($P \leq 0.05$, mean $R^2 = 73\%$)
[3]Combined inflow includes all gauged and ungauged freshwater flows from river and coastal drainage basins contributing to each estuary

TEXAS DEPARTMENT OF WATER RESOURCES
1700 N. Congress Avenue
Austin, Texas

Harvey Davis
Executive Director

December 21, 1979

The Honorable William P. Clements, Jr.
Governor of Texas

The Honorable William P. Hobby
Lieutenant Governor of Texas

The Honorable Bill Clayton
Speaker of the House

The Legislature of the State of Texas

Submitted herewith is a summary report of the Department's studies of the effects of freshwater inflows on Texas estuaries as mandated by Senate Bill No. 137 (Schwartz, 64th Legislature, 1975). This legislation, codified as Section 16.058 of the Texas Water Code, directed that the Department conduct these studies with the cooperation and assistance of the Texas Coastal and Marine Council, Texas Parks and Wildlife Department, and General Land Office, and that we report our findings by December 31, 1979.

This report summarizes findings contained in five detailed technical reports on six individual Texas estuaries, which include (1) the Sabine-Neches estuary, (2) the Trinity-San Jacinto estuary, (3) the Lavaca-Tres Palacios estuary, (4) the Guadalupe estuary, and (5) the Mission-Aransas and Nueces estuaries. These reports have been distributed in draft form to federal agencies, other State agencies, and various public interest groups for review and comment.

An important product of these studies has been the development of a data base and analytical techniques that can serve planning functions and water management decisions with respect to the effects of future water resources development and use in an estuary's contributing drainage basins. The present study results also provide the Legislature with important information, regarding choices that can be made and means whereby freshwater for bays and estuaries and other uses can be determined, for use in policy decisions. However, the continued value of these bay and estuary studies will depend considerably on the extent to which the data base can be kept current through continued data collection as conditions change.

Sincerely yours,

Harvey Davis
Executive Director

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