Segmentation Development for Galveston Bay

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1.0 EXECUTIVE SUMMARY

Segmentation systems are a geographical subdivision of a natural landscape feature, in this case an estuary. Ideally, each subdivision or segment is a subset of the whole that reflects uniform characteristics across the segment. This idealization is seldom possible, since estuarine segments are interconnected and tend to form gradients for most characteristics.

Management activities, monitoring programs, and characterization studies are all enhanced by segmentation of the estuary into smaller more manageable units. Future management effectiveness can be improved by the geographic targeting of areas that may have defined impacts and require unique attention. During characterization, segmentation provides a rationale for grouping data to describe various portions of the estuary. This grouping of the data may also facilitate the intercomparison between segments of the estuary.

Systems of segmentation within an estuary provide three major roles in estuarine management. Existing information can be grouped and examined for spatial variations and similarities. Secondly, they are central to the effective design of estuarine monitoring projects, allowing the effort to be balanced or apportioned appropriately. Finally, segmentation facilitates both data reduction and presentation. Results are more easily understood when they are referenced to recognizable subareas.

1.1 Project Description

The purpose of this study is to develop a segmentation scheme for the Galveston Bay System that will facilitate the other efforts planned by the Galveston Bay National Estuary Program (GBNEP). The study is organized around four tasks: 1) the evaluation of existing segmentation schemes, 2) evaluation of natural features and anthropogenic inputs, 3) determination of segmentation criteria, 4) and the drafting of the boundaries. To facilitate the management and presentation of the large amounts of geobased data accumulated, a geographic information system (GIS) was developed for the study area.

Estevez and Palmer (1989) stated that segmentation systems have been used historically as a data management tool and that data within these segmentation systems should be labelled according to the segments of origin. They further listed three important roles segmentation systems play in estuarine management as:

- causing existing information on a system to be reviewed for the purpose of defining landscape-level diversity, and the similarity or dissimilarity of areas within the system;

- facilitating the design of data collection projects and simplifying the review of historic data; and

- simplifying data reduction, analysis, and presentation.

Several segmentation schemes currently exist for Galveston Bay, particularly with respect to natural resources data. Both State and Federal natural resource agencies collect data for the management of resources within Galveston Bay. These agencies include but are not limited to the Texas Water Commission (TWC), Texas Parks and Wildlife Department (TPWD), the U.S. Fish and Wildlife Service (USFWS), the National Marine Fisheries Service (NMFS), and the National Oceanographic and Atmospheric Administration (NOAA). A brief description of data collected by and segmentation schemes used by these agencies that may be useful in developing a segmentation scheme for Galveston Bay is presented in Section 3 of this report. The emphasis is primarily on aquatic resources.

1.2 Description of Study Area

The study area, the Galveston Bay System, is a large bay-estuary-lagoon system. The study area is shown in Figure 1. The system is composed of Galveston Bay, Trinity Bay, East Bay, West Bay, and a number of smaller embayments, all interconnected. Area watershed boundaries are shown in Figure 2. The system is separated from the Gulf of Mexico and the inner continental shelf by a geologically modern barrier island complex, Galveston and Follets Islands, and peninsula complex, Bolivar Peninsula.

Galveston Bay is subject to a wide variation in tidal extremes, fresh water input, pollutant loadings from domestic and industrial point and non-point sources, occasional severe weather systems, and variable temperature regimes. Alteration of the Bay by human activity has changed the circulation patterns of the system through the dredging of channels, spoil bank placement, and the construction of jetties, marinas, docks, and causeways. The inherent shallow character of Galveston Bay combined with its long reaches of open water and exposure to continuous wind make mixing of the water column pronounced (UTMSI, 1973).

Texas estuaries are generally of two geomorphological types: 1) coastal plain, composed of drowned river mouths and 2) bar built, in which an offshore sand bar partially encloses a body of water (Pritchard, 1967). The Galveston Bay system exhibits both. Galveston and Trinity Bays are examples of the coastal plain drowned river mouths. East Bay and West Bay are examples of bar built bays. Smaller embayments included in the Galveston Bay system include Clear Lake, Dickinson Bay, Chocolate Bay, Bastrop Bay, Christmas Bay, Dollar Bay, Jones Bay, Tabbs Bay, San Jacinto Bay, Moses Lake, and Drum Bay.

Two major rivers, the Trinity River and the San Jacinto River, discharge into the estuary. In addition, a number of smaller tributaries discharge into the system including Bastrop Bayou, Chocolate Bayou, Halls Bayou, Dickinson Bayou, Clear Creek, Buffalo Bayou, Cedar Bayou, and Double Bayou. Figure 2 is a drainage basin map for the larger tributaries to Galveston Bay.

Of the existing segmentation schemes reviewed, the Texas Water Commission scheme and the University of Texas Center for Research in Water Resources Scheme, which was a hydrographic subdivision of the TWC scheme satisfied the criteria the best. The TWC segmentation scheme encompasses a number of criteria uses including administrative and monitoring and subdivides the study area for this project into 29 segments. The results of this study subdivide the area into 44 segments which are described in more detail and shown on maps of the area.

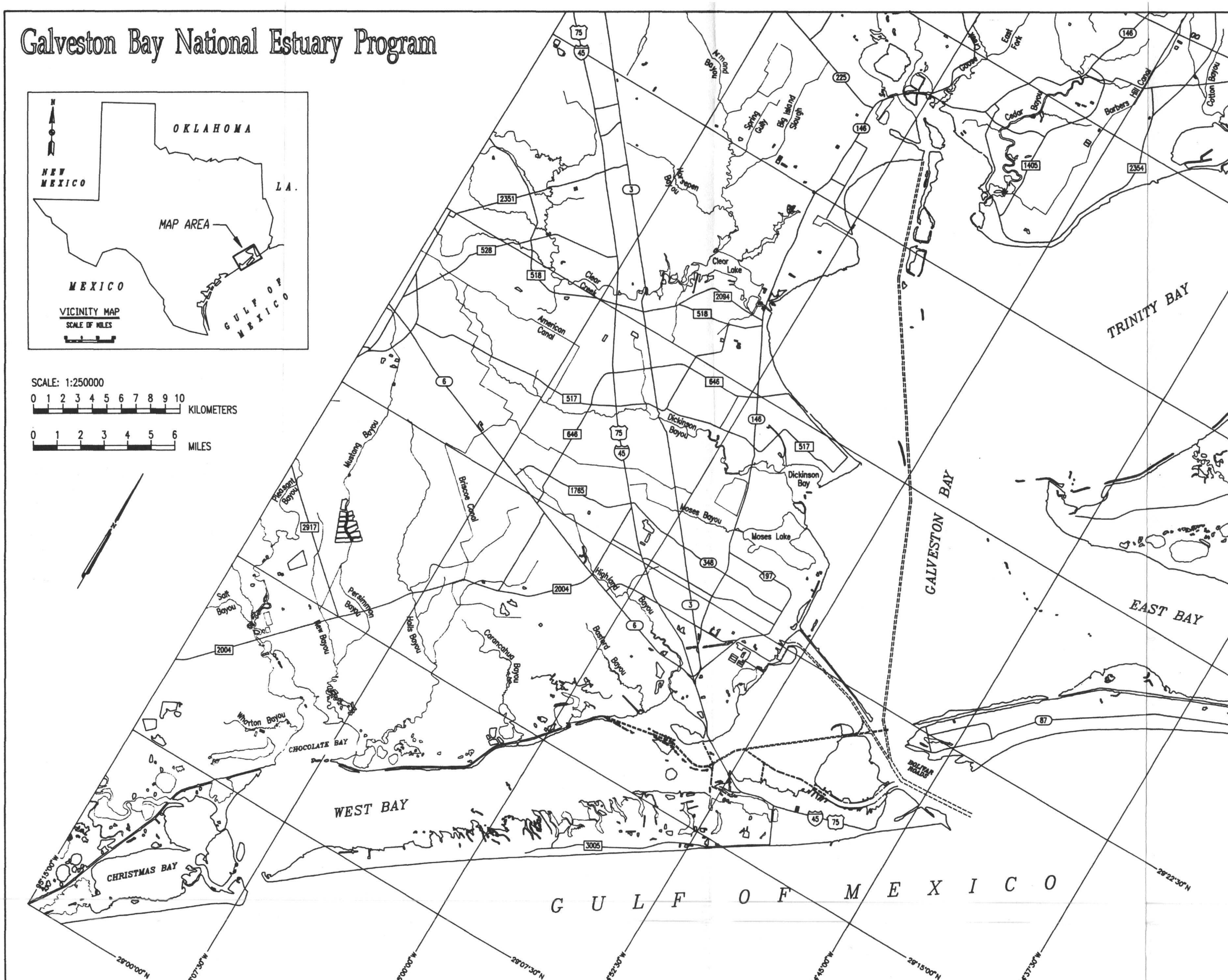

FIGURE – 1

STUDY AREA MAP

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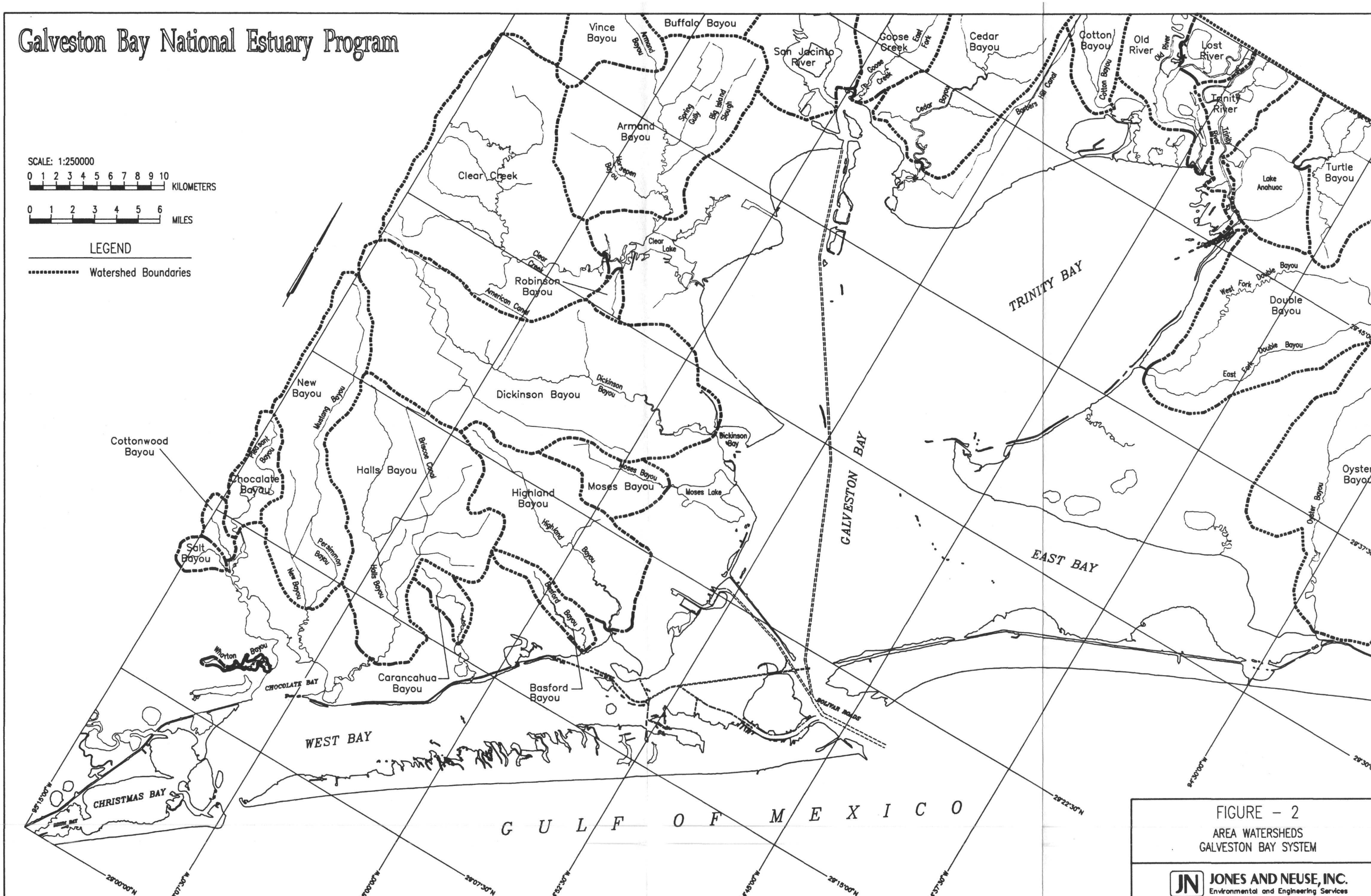


FIGURE – 2
AREA WATERSHEDS
GALVESTON BAY SYSTEM

2.0 METHODOLOGY

This section generally describes the methods employed in amassing and evaluating the information required for this project. The methods for evaluation of the information and determination of the segment boundaries are described in more detail in Section 4 of this report.

2.1 Data Collection

Existing segmentation schemes are largely the product of various governmental agencies, both Federal and State. All or most of this information is public and fairly easily accessible, usually through agency publications. A computerized library search assisted in identifying pertinent documents for determination of both existing segmentation and for the evaluation of natural and anthropogenic influences.

Boundaries and segmentation types sought included defined management areas, territorial jurisdictions, monitoring areas, navigational areas, and segmentation employed for hydraulic, water quality, or biological studies or modeling. As expected, the information gathered from the various governmental agencies was the most productive of these data.

The bulk of the information was obtained by consulting documents, maps, photographs, and records available in the Texas Water Commission Library and Central Records, the University of Texas Library System, the JN corporate library, and personal collections of many of the JN personnel.

In addition to information collected directly, JN instituted a mailout to solicit information and comments relevant to this study. The purpose was to solicit information and comments from entities that may not have direct jurisdictional or segmentational concerns with the Galveston Bay system, but which may have had information or comments valuable to this study. Entities contacted or from which information was obtained either directly or from published information are listed as follows:

Federal Agencies

U. S. Environmental Protection Agency

U. S. Department of the Interior - Fish and Wildlife

U. S. Army Corps of Engineers

National Oceanic and Atmospheric Administration

U. S. Coast Guard

U. S. Department of Transportation

State Agencies

Texas Water Commission

Texas Water Development Board

Texas Parks and Wildlife Department

Texas Department of Health

Texas Railroad Commission

Texas General Land Office

State Universities

Local Agencies and Groups

Cities and Towns bordering Galveston Bay

Counties bordering Galveston Bay

Utility Districts bordering Galveston Bay

Local Colleges

Industries bordering Galveston Bay

Private Universities and Colleges

Citizens Groups bordering Galveston Bay

The mailout was originally not to have included those agencies and entities whose files and publications were searched or obtained directly; however, they were included later in the project to solicit ideas, information sources that may have been missed, and comments on the project. A listing of the mailout addressees is included in the Appendix of this report.

2.2 Data Management

An enormous amount of information was amassed and reviewed as input to this project. Preference was given to geobased information, spatially-oriented information that was either already mapped or could be easily mapped, since the function of this project is to develop geobased segmentation from geobased data. Three types of data management were employed. Pertinent characteristic descriptions and the results of information reviewed were cataloged into a reference database. All mailout correspondence was filed into a sequential correspondence file. A GIS system was developed for the Galveston Bay system to store, manage, index, and present the massive amount of geobased information utilized during the course of this project.

2.2.1 Reference Database

Information utilized during the project was cataloged into a reference database that provided an extended bibliography. In addition to the reference to the source of the information, descriptor fields were included to characterize the type of information and the utility to this project. In addition to providing a bibliography for the report, the database allowed searching for information types during the GIS input and evaluation phases of the project. The database was constructed in Dbase IV and utilized with that software product. The database is available in both Dbase IV and ASCII formats and constitutes a project deliverable.

2.2.2 Sequential Correspondence File

The sequential correspondence file contains a copy of all outgoing correspondence from the mailout and any responses received. The sequential correspondence file is a set of conventional file folders, one for each entity contacted. The sequential correspondence file also constitutes a project deliverable.

2.2.3 GIS System

The GIS system was developed to store, manage, index, retrieve, and present the massive amount of geobased and graphical data accumulated for the project. Originally, these data were managed with an AutoCad-based system. As the amount of data grew, the file size became unmanageable on this system. Since the information was to be delivered in a GIS compatible form, the decision was made to transfer the information to an ARC/INFO-based GIS system.

The initial step in creating the GIS system was the construction of the base map coverage. USGS digitized map information was obtained in digitized line graph (DLG) format for the 38 7.5-minute quad maps required to encompass the area. These files were input, converted, and organized into separate coverage or layers. The features represented by the various layers and coverage were identified and name attributes were attached.

As the information for the project was received, it was assessed for potential utility to the project and for candidate entry into the GIS system. Some ARC/INFO files were obtained directly; however, the bulk of the geobased information required digitization. Maps and other pertinent geobased information was digitized for input and identified with a large high resolution digitizing board.

After the information was input to the GIS system, it could be visually reviewed for coincident spatial coverage and was of considerable utility to the synthesis and assessment of the information for the decision matrix described subsequently. In addition, the GIS system was employed to construct many of the maps that serve as figures in this report.

3.0 RESULTS

This section describes the results of the information gathering efforts undertaken during the course of the project. Emphasis was placed upon obtaining geobased data, particularly in the form of segmentation maps and maps of distributions of various parameters and features valuable in the assessment of the segmentation of an estuary. The major sources of information are discussed below. The information described below constitutes the bulk of that synthesized in the decision matrix presented in Section 4 of this report. In addition, information of a very specific nature and applicability was obtained, particularly from the mailout effort, and is referenced in the bibliography or one of the databases described previously.

3.1 Texas Water Commission

On September 1, 1985, the Texas Water Commission (TWC) assumed primary responsibility for protecting Texas' water resources as a result of Senate Bill 249 enacted by the 69th Texas Legislature (TWC, 1990a). This legislation abolished the Texas Department of Water Resources and transferred most of its functions to the TWC. The TWC currently has the primary responsibility for implementing the regulatory statutes and laws relating to Texas waters. The agency is responsible for implementing State laws relating to water and for enforcing all rules, standards, orders, permits, licenses, and laws under its jurisdiction.

3.1.1 TWC Stream Segmentation

All major water bodies in the state of Texas have been delineated into segments by the Texas Water Commission (TWC) as part of the water quality inventory mandated by section 305(b) of the Federal Clean Water Act. TWC segmentation for Galveston Bay and the Houston Ship Channel are shown in Figures 3 and 4, respectively. The purpose is to assess, on a continuing basis, the water quality of individual systems that can be segregated based on relatively homogeneous characteristics.

Designations assigned by the TWC to describe a segment include classifications and uses. Segment classifications include "water quality limited" or "effluent limited" designations. A segment is considered water quality limited if any of the following conditions are true:

- Stream monitoring data have shown significant violations of water quality standards as established by the Texas Surface Water Quality Standards.

- Advanced wastewater treatment for point sources of wastewater discharges is required to meet water quality standards or to protect existing conditions of exceptional water quality. Advanced treatment is defined as "treatment equal to or more stringent than the 30-day average of 10 mg/L BOD_5 and 15 mg/L NH_3-N".

- The segment is a reservoir for a domestic water supply.

All segmented waters that are not classified as "water quality limited" under the previous criterion are classified as "effluent limited" for which conventional wastewater treatment is adequate to protect existing waterbody conditions (TWC, 1990b).

These designations are determined based on water quality standards established by the TWC for the purpose of maintaining desirable uses. Numerical criteria are developed to maintain those designated uses. Designated uses are determined by taking into account a waterbody's physical characteristics, natural water quality, and actual uses. The nine categories of designated uses pertaining to the Galveston Bay system are contact recreation, non-contact recreation, limited quality aquatic habitat, high quality aquatic habitat, exceptional quality aquatic habitat, shellfish waters, industrial water supplies, navigation, and public water supply waterbodies.

Protection of the designated uses in the State of Texas is based on employing various regulatory actions to assure these uses are attainable including setting limits on the quantity of pollutant loadings from point source discharges, setting standards for water quality that must be maintained in the waterbody, and taking enforcement action against violators.

3.1.2 Statewide Monitoring Network

The Statewide Monitoring Network (SMN) database is a repository for all data collected by the Texas Water Commission and includes physical, chemical, and biological information. The monitoring network is coordinated by the Water Quality Standards and Evaluation Section and is carried out by the agency's Field Operations Division. Data stored in the SMN database are utilized by staff members in prioritizing and developing waste load evaluations to determine water quality effects of pollutant discharges. These data are available to those outside the TWC through the Texas Natural Resources Information System (TNRIS).

3.1.3 Clear Lake Board Order

The Texas Department of Water Resources (TDWR) prepared a staff report Board Order in October 1980 for the purpose of assessing future measures requiring implementation for protection of the Clear Lake watershed (TDWR, 1980). Information gathered during the study included ambient nutrient concentrations for the Clear Lake drainage area and the locations of wastewater permittees in the Clear Lake drainage. That report concluded that Clear Lake is nitrogen limited, Galveston Bay is the dominant source of phosphorous in Clear Lake, and that advanced wastewater treatment levels will be necessary to maintain dissolved oxygen levels and protect water quality in Clear Lake and its tributaries.

3.2 Texas Parks and Wildlife Department

The Parks and Wildlife Code states that Texas Parks and Wildlife Department (TPWD) is the State agency with primary authority for protecting the fish and wildlife resources of the State. As a result, TPWD has implemented a variety of programs to collect and manage data for the purposes of developing rules and regulations to protect fish and wildlife resources in Texas.

For the purposes of managing the fisheries resources in Texas, the TPWD in cooperation with the National Marine Fisheries Service (NMFS), collects landings data from recreational and commercial fishermen. These data are collected to assess the need for and the impact of saltwater fishing regulations (Quast et al., 1988). Texas commercial landings are reported for the Gulf of Mexico and bay systems which include Sabine Lake, Galveston Bay, Matagorda Bay, East Matagorda Bay, San Antonio Bay, Aransas Bay, Corpus Christi Bay, upper Laguna Madre, and lower Laguna Madre. Finfish landings by sport-boat fishermen are further subdivided into minor bays within the major bay systems (Osburn et al. 1988). The minor bays within the Galveston Bay System appear in Table 1.

Since 1975, the TPWD has conducted a Marine Resource Monitoring Program. According to the TPWD Coastal Fisheries Branch Marine Resource Monitoring Operations Manual for 1991, the purpose of this program is to determine and monitor trends in species composition, size, and relative abundance for selected finfishes and shellfishes in coastal systems and in the Gulf of Mexico. Field measurements are made for temperature, dissolved oxygen, salinity, and turbidity. The TPWD does not return to fixed stations; instead, sampling locations are randomly selected in order to eliminate long-term bias in the data that might result from continued sampling of the same stations. The Galveston Bay system is defined in the Operations Manual as follows:

> "All waters, including all saltwater bayous, bounded by a line behind the surfline from the bridge over the ICWW at High Island to the southwestern shoreline of Drum Bay and the north edge of Trinity Bay where the Trinity River enters the bay. On 21 November 1982, the area between the Baytown tunnel and the junction of the San Jacinto River and the Houston Ship Channel was added to the Galveston Bay System."

Each bay system is then subdivided into a grid of one-minute cells, each of which is designated according to the most appropriate gear type. In the field, the designated gear type is further subdivided into a 12 x 12 network of "gridlets"; each gridlet is five seconds on each side. All species greater than five millimeters in length are identified to species level and counted. Subsets of some fish species are weighed and measured according to procedures in the Operations Manual. As of June 1990, there were 12,000 records (i.e., station date-entries) for Galveston Bay.

TABLE 1

MINOR BAYS WITHIN THE GALVESTON BAY SYSTEM, THE TEXAS PARKS AND WILDLIFE DEPARTMENT

Galveston Bay System	Galveston Bay System (continued)
Alligator Lake Ash Lake Bryan Lake Bastrop Bay (includes Bastrop Bayou downstream from junction with Austin Bayou) Burnett Bay Black Duck Bay Carancahua Lake Cedar Lakes Cotton Lake Crystal Bay Bolivar Roads (east of a line between the ferry landing on Port Bolivar to range marker at the Coast Guard station at Fort Point to the end of the jetties) Quintana Channel (area between the ICWW southeast to the end of the jetties) Chocolate Bay Choctaw Lake Christmas Bay Clear Lake (includes Clear Creek downstream from the bridge on Highway 3) Crab Lake Cox Lake Dickinson Bay (included Dickerson Bayou downstream from bridge on St 146)) Dollar Bay Drum Bay Cow Trap Lakes East Bay (also includes all waters from bridge over ICWW at High Island to junction of ICWW East Bay) Freeport Bay Area Galveston Bay Green's Lake Hall's Lake Horeshoe Lake Hall's Lake (includes Highland Bayou downstream from the railroad bridge that connects Texas City with the GC&SF railroad)	Horeshoe Lake Jones Lake (Freeport area) Lake Como Lost Lake Lost Bay Moses Lake McNeal Lake Mud Lake Nicks Lake Oyster Lake (near Bastrop Bay) Oyster Creek Old Brazos River (from end of harbor to junction with ICWW) Oyster Lake (Bolivar Peninsula) Pelican Lake Swan Lake (Freeport area) Rollover Bay Salt Lake Swan Lake (Galveston area) Tabb's Bay San Jacinto Bay Scott Bay Taylor Lake Sweetwater Lake Trinity Bay (includes Trinity River Delta south of Big Hog Bayou) West Bay Rollover Pass (area between junction with Rollover Bay and surfline) San Luis Pass (area 1/2 mile bayward and 1/2 mile Gulfward off the Vacek bridge) San Bernard River (includes all water junction with the Gulf) Brazos River (includes all waters downstream from the Dow Chemical floodgate to the junction Gulf)

Chapter 77 of the Parks and Wildlife Code addresses TPWD shrimping regulations. According to §77.001, Trinity Bay, Galveston Bay, East Galveston Bay, and West Galveston Bay, exclusive of tributary bays, bayous, and inlets, lakes, and rivers, are defined as major bays. Nursery areas are defined as tributary bays, bayous, inlets, lakes, and rivers which are proven to serve as significant growth and development environments for postlarval and juvenile shrimp not including the outside waters, major bays, or bait bays. Bait bays are defined as including major bays. That portion of Chocolate Bay and West Galveston Bay north of the Gulf Intracoastal Waterway in Brazoria County is defined as a bait bay in the 1990-1991 Fiscal Texas Commercial Fishing Guide. The boundaries between bays are not defined any more specifically than this.

Oyster data are also collected in the TPWD Resource Monitoring Program. In addition, the location of major oyster reefs in Galveston Bay, Trinity Bay, and East Bay have been mapped by the TPWD (Benefield and Hofstetter, 1976) and are reproduced in Figure 5. The TPWD has not mapped oyster reefs in West Galveston Bay although there are many present there (Richard L. Benefield, TPWD, personal communication).

Two TPWD wildlife management areas (WMA) are located within the Galveston Bay System: Atkinson Island and Candy Abshier (Charlie Winkler, TPWD, personal communication). Atkinson Island WMA is part of an 152-acre spoil island located adjacent to the Houston Ship Channel near Morgan's Point. Candy Abshier WMA includes 205 acres of land and two acres of water located within Smith Point, Texas.

Active colony sites for breeding pairs of colonial waterbirds observed in 1990 for counties surrounding Galveston Bay were considered for this segmentation report. This information was obtained from a report prepared by the TPWD and the Texas Colonial Waterbird Society (1990). Four colonies were located in Chambers County, 31 in Galveston County and four in Harris County (Table 2).

TABLE 2

COLONIAL WATERBIRD NESTING LOCATIONS IN

CHAMBERS, GALVESTON, AND HARRIS COUNTIES FOR 1990

Colony Number	*Colony Name*	*Number of Species*	*Number of Breeding Pairs*
Chambers County			
600-054	Catfish Acres	5	870
600-120	Trinity River Mouth	6	3,320
600-140	East of Lost Lake	4	425
600-260	Vingt-et-un Island	9	380
Galveston County			
600-051	Scholes Field	1	80
600-240	Redfish Island	2	40
600-261	Smith Point Island	12	1,602
600-300	Rollover Pass	10	1,438
600-340	Moses Lake Spoil Islands	4	82
600-341	Dickinson Bay Spoil Island	2	550
600-381	Bolivar Flats	1	2
600-422	Marker 52 Spoil Island	1	30
600-423	Jigsaw Island	2	270
600-424	North Deer Island	14	4,829
600-425	Down Deer Island	1	70
600-426	South Deer Island	7	620
600-427	Ganges Bayou	1	62
600-442	Little Pelican Island	15	15,574
600-443	Pelican Island	4	10,448
600-444	Fort San Jacinto	1	4
600-447	Maginolia Compress #15	1	4
600-449	Farmers Copper	1	50

TABLE 2

COLONIAL WATERBIRD NESTING LOCATIONS IN CHAMBERS, GALVESTON, AND HARRIS COUNTIES FOR 1990 (CONTINUED)

Colony Number	*Colony Name*	*Number of Species*	*Number of Breeding Pairs*
600-522	McAllis Point	1	20
600-523	Maggies Point	3	230
600-524	Snake Cove Point	2	26
600-526	Bay Harbor Bar	4	330
600-541	Oxen Bayou Point	2	90
600-542	Mensell Bayou Point	6	823
600-543	Starvation Point	2	17
600-544	Eckert Bayou Point	4	613
600-545	Hoeckers Point	2	85
600-546	Dana Cove	1	25
600-547	Carancahua Cove	6	682
600-548	Live Oak Grove	1	4
600-580	San Luis Pass	2	210
Harris County			
600-001	Sheldon Reservoir	5	1,110
600-160	Baytown Tunnel	2	60
600-161	Alexander Island	10	793
600-163	Exxon Baytown North Gate	1	32

3.3 Texas Department of Health

Chapter 436 of the Health and Safety Code allows the Commissioner of Health to close any polluted area to the taking of shellfish, which is defined as oysters, clams, and mussels. A polluted area is defined as an area that is continuously or intermittently subject to the discharge of sewage or other wastes or to the presence of coliforms in quantities likely to indicate that shellfish taken from this area may be unfit for human consumption. This chapter further states that the Commissioner shall outline polluted areas on maps. The maps indicating polluted areas for Galveston Bay appear in Figure 6. These maps are segmented or divided into three areas:

- Approved Areas
- Conditionally Approved Areas
- Polluted Areas

According to the Texas Department of Health (TDH, 1990), polluted areas are closed to the harvesting of shellfish. Conditionally approved areas are subject to classification changes based upon meteorological conditions. All other areas not specifically defined as either polluted or conditionally approved are approved for the harvesting of shellfish. This segmentation or classification system for shellfish is subject to change by the TDH at anytime due to rainfall and runoff, flooding, hurricanes, or other extreme weather conditions. Failure or inefficient operation of wastewater treatment facilities may also result in changes (TDH, 1990).

3.4 Texas General Land Office

Information obtained from the Texas General Land Office (GLO) included oyster reef locations, state land tract boundaries, and dredge spoil disposal locations. This information was provided in the form of an ARC/INFO file that was transferred to the JN GIS system. Figure 7 is a map of the GLO land tracts within the Galveston Bay system. Dredge spoil areas are shown in Figure 8.

3.5 Texas Water Development Board

The Texas Water Development Board (TWDB), created in 1957, became responsible for long-range planning and water financing in 1985 through legislative action. Currently, the TWDB has the primary responsibility for water planning and for administering water financing for the State of Texas (TWC,1990a). These include water quality monitoring in coastal waterways, inflow assessments for embayments, overseeing the use of Federal funds for the Construction Grants Program, and coordination with the Texas Parks and Wildlife Department concerning studies and analyses used in decisions regarding the effects of water allocation on Texas' estuaries (David Brock, TWDB, personal communication).

3.5.1 Coastal Data System

The Texas Water Development Board collects and maintains data relating to water quality for the purpose of assessing trends and current conditions in estuarine systems along the Texas coast (David Brock, TWDB, personnel communication). These data are predominantly water quality oriented but include sediment analysis and aquatic organism tissue analysis. The program was originally a cooperative effort between the U.S. Geological Survey and the TWDB between 1967 and 1983. The Texas Water Commission involvement extended from 1984 until the end of routine monitoring in 1989. Data from the Coastal Data System is maintained on the Texas Water Commission mainframe computer and is accessed through the Texas Natural Resource Information System (TNRIS). The database includes data for all seven of the major bay systems located along the Texas Gulf Coast, including Galveston Bay.

Sampling stations in the study area are established along transects as shown in Figure 9. The transects are oriented perpendicular to the centerline of embayments. Sampling locations for the Galveston Bay system include Galveston Bay, Trinity Bay, East Bay, West Bay, Chocolate Bayou, Dickinson Bayou, Moses Bayou, and Clear Creek. Two additional sampling points are located approximately 3 miles into the Gulf of Mexico.

3.5.2 Segment Boundary Analysis

The Texas Department of Water Resources conducted an analysis of Galveston Bay segment boundaries based on physical characteristics and nutrient processes using historical data collected by the USGS between 1941 and 1976. The report was one in a series of reports on major Texas estuaries developed to analyze existing data for the purpose of water quality planning under Section 208 of PL 92-500. The report includes three sections. The first section presents an analysis of the appropriateness of existing bay segment boundaries for water quality planning purposes. The second section presents physical characteristics of Galveston Bay along with a summary of circulation and salinity patterns under average conditions of seasonal tidal amplitude, wind, and freshwater inflow. The third part of this report deals with nutrient processes taking place in the Bay including the effects of inflows on nutrient cycling and contributions of nutrients from deltaic marshes. Circulation and salinity patterns were simulated by TDWR using computer models calibrated from sampling efforts in the estuary. The results of the computer simulation suggested that West Bay and Trinity Bay segments are appropriate for current conditions. Because of the influence of Hanna Reef on circulation, the previous boundary between Galveston and East Bay was moved east of its previous location. Predictions made by salinity simulations resulted in the division of Galveston Bay into upper and lower segments, Segments 2421 and 2439, respectively. An analysis of net circulation patterns simulated by the tidal hydrodynamic model indicated that the circulation in Galveston Bay is dominated by movement of water along the Houston Ship Channel. The simulated circulation patterns in Trinity, East, and West Bays were predicted by the simulation to be dominated by internal circulation currents (TDWR, 1979).

3.5.3 Freshwater Inflow Information

The TDWR developed a series of reports for Texas bays and estuaries as mandated by Senate Bill 137 which called for comprehensive studies of the effects of freshwater inflows to the bays (TDWR, 1981). The Galveston Bay system study was completed by TDWR in 1981 and includes modeled circulation and salinity patterns for each month of the year. This 1981 study was also intended to supplement knowledge gained from the "Analysis of Bay Segment Boundaries, Physical Characteristics, and Nutrient Processes" the 1979 TDWR 208 study referenced previously. Mathematical computer models calibrated with data collected from the bay were used to predict hydraulic conditions in the bay. Historical stream flow data was obtained from USGS continuous recording stream gaging stations. Salinity data continuously collected using in-place "sonde" meter devices was used to calibrate a model for predicting circulation patterns. Examples of net circulation and salinity patterns in the Bay estimated for the month of January are presented in Figures 10 and 11. Simulated net circulation patterns indicate boundaries occur at the Houston Ship Channel, midway across Trinity Bay, Chocolate Bayou, Clear Lake, and near the East Bay-Galveston Bay convergence. Modeled salinity concentration patterns suggest boundaries exist for Trinity Bay, East Bay, Dickinson Bay, and Chocolate Bayou. The report includes similar figures for each month which show similar patterns throughout most of the year (TDWR, 1981).

3.5.4 <u>1989 Study of Circulation patterns in Galveston Bay</u>

The TWDB has collected data from Galveston Bay in addition to that maintained in the Coastal Data system. The TWDB conducted an intensive study in May of 1989 for the purpose of assessing circulation patterns in Galveston Bay based on flows measured at the passes within the bay. At that time, current speed and direction data were collected at monitoring points located at major passes and inlets within the Bay system during two complete tide cycles (TWDB, 1989). This study was a joint effort between the TWDB, Texas Water Commission, Texas Parks and Wildlife Department, Tarrant County Water Control and Improvement District No. 1, and the U.S. Army Corps of Engineers. Since 1989, the TWDB has collected salinity data from five locations in the Bay using Datasonde meters which take readings every 1.5 hours. Information gathered from these sources was used by the TWDB to develop a two-dimensional model for the Galveston Bay system (Brock, 1990).

3.6 U.S. Environmental Protection Agency

The U.S. Environmental Protection Agency (EPA) has developed an independent segmentation scheme that includes both freshwater streams and tidal waters. The framework for this segmentation scheme was originally established whereby unique segment codes were established for waterways in ascending order from most downstream to upstream segments within each hydrologic unit. A hydrologic unit is identified by a unique hydrologic unit code (HUC). This is a unique number that identifies a "geographic area representing part or all of a surface drainage basin or distinct hydrologic feature as delineated by the Office of Water Data Coordination on the State Hydrologic Unit maps" (Buckner, 1989). New codes are established as new waterbodies are added to the system. Only part of the Galveston Bay system has yet been segmented by the EPA as of this time although full coverage of the entire Texas coast will eventually be available (Parrish, 1991).

3.7 U. S. Fish and Wildlife Service

3.7.1 Threatened and Endangered Species

Species listed as either threatened and endangered for Chambers, Galveston, and Harris counties by the U.S. Fish and Wildlife Service (USFWS) appear in Table 3. There are several threatened and endangered reptiles, specifically sea turtles such as the loggerhead, green, leatherback, hawksbill, and Kemp's ridley, that occur within the bay itself. According to Kathy Nemec, USFWS Clear Lake City, sea turtles can range throughout Galveston Bay. These species require undisturbed shoreline for nesting purposes. However, there are no known sea turtle nesting locations around the bay. According to C.T. Fontaine with the NMFS in Galveston, the habitat used by sea turtles within Galveston Bay is not known. Most of the information about sea turtles utilizing Galveston Bay comes from the Headstart Program for the Kemp's ridley sea turtle and the Turtle Stranding Network (Fontaine, 1991). Kemp's ridley sea turtles that are released by the Headstart Program are tagged. The general public is very aware of this program so a great deal of information is received by NMFS when tagged sea turtles or wild sea turtles are observed. Information about stranded sea turtles or dead sea turtles that washed ashore is available from the Stranding Network (Fontaine, 1991).

TABLE 3

THREATENED AND ENDANGERED SPECIES FOR CHAMBERS, GALVESTON, AND HARRIS COUNTIES, U.S. FISH AND WILDLIFE SERVICES

Common Name	*Scientific Name*	*Status*
Chambers County Reptiles		
Loggerhead sea turtle	*Caretta caretta*	Threatened
Green sea turtle	*Chelonia mydas*	Threatened
Leatherback sea turtle	*Dermochelys coriacea*	Endangered
Hawksbill sea turtle	*Eretmochelys imbricata*	Endangered
Kemp's ridley sea turtle	*Lepidochelys kempii*	Endangered
Chambers County Birds		
Brown Pelican	*Pelecanus occidentalis*	Endangered
Piping Plover	*Charadrius melodus*	Threatened
Bald eagle (N)	*Haliaeetus leucocephalus*	Endangered
Arctic peregrine falcon	*Falco peregrinus tundrius*	Threatened
Galveston County Reptiles		
Loggerhead sea turtle	*Caretta caretta*	Threatened
Green sea turtle	*Chelonia mydas*	Threatened
Leatherback sea turtle	*Dertmochelys coriacea*	Endangered
Hawksbill sea turtle	*Eretmochelys imbricata*	Endangered
Kemp's ridley sea turtle	*Lepidochelys kempii*	Endangered
Galveston County Birds		
Brown pelican	*Pelecanus occidentalis*	Endangered
Piping plover (W)	*Charadrius melodus*	Threatened
Attwater's greater prairie-chicken (R)	*Tympanuchus cupido attwateri*	Endangered
Bald eagle	*Haliaeetus leucocephalus*	Endangered
Arctic peregrine falcon	*Falco peregrinus tundrius*	Threatened
Harris County Plants		
Prairie dawn	*Hymenoxys texana*	Endangered
Harris County Amphibians		
Houston toad (H)	*Bufo houstonensis*	Endangered
Harris County Birds		
Bald eagle (N)	*Haliaeetus leucocephalus*	Endangered
Arctic peregrine falcon	*Falco peregrinus tundrius*	Threatened
Red-cockaded woodpecker	*Picoides borealis*	Endangered

The USFWS lists several birds as threatened and endangered in Chambers, Galveston, and Harris counties (Table 3). Brown pelicans are known to occur throughout the Texas coast (Figure 12) and are listed as endangered in Chambers and Galveston counties. Two roosting sites but no nesting sites are known for Galveston Bay according to the 1990 Colonial Water Bird Survey (TPWD, 1990).

The piping plover, which is listed as threatened in Chambers and Galveston counties, is a winter resident of the Texas coast. However, it does not nest in Texas. Winter concentration sites within Galveston Bay for the piping plover are located in Figure 13.

The bald eagle is listed as endangered in Chambers, Galveston, and Harris counties. Bald eagle nesting sites are known to occur within Chambers, Galveston, and Harris counties. However, specific nesting sites for the bald eagle did not appear on maps obtained from the USFWS.

The Arctic peregrine falcon is listed as threatened in the counties surrounding Galveston Bay. However, according to Ms. Kathy Nemec, USFWS, it is known only as a migrant, and no important use sites are known within Chambers, Galveston, or Harris counties.

The Attwater's greater prairie chicken is listed as endangered in Galveston County by the USFWS. Its known area of distribution in Galveston County appears in Figure 14.

The only amphibian listed as endangered in the three-county area of concern is the Houston toad. It occurred historically in Harris County, but its current existing distribution does not include Harris County.

Prairie dawn is the only plant species listed as endangered in the three-county area of concern by the USFWS. It is listed as endangered in Harris County.

3.8 National Wildlife Refuges

The Anahuac National Wildlife Refuge includes 24,000 acres along the north shore of East Bay approximately 16 miles southeast of the town of Anahuac. The refuge provides wintering habitat for large concentrations of geese and other waterfowl. Species of special interest found here include the endangered bald eagle and perigrine falcon, the alligator, mottled duck, wood stork, and least tern (USFWS, 1988).

The Brazoria National Wildlife Refuge includes approximately 12,000 acres along the west shore of Bastrop Bay, Christian Bay, and Drum Bay. The refuge has been set aside as a waterfowl wintering area. The Brazoria Refuge is within the Freeport Christmas bird count circle which frequently achieves the highest number of species seen in a 24-hour period. Fishing and waterfowl hunting is permitted in season but are restricted to boat access only (USFWS, 1988).

3.9 U.S. Army Corps of Engineers

Locations of current dredge disposal areas permitted by the U.S. Army Corps of Engineers were provided on maps for the Galveston Bay area through the Corps District Office in Galveston (USCOE, 1990). Generally, these disposal sites are located along the intracoastal waterway from east of Chocolate Bay to the mouth of East Bay Bayou, in the north section of Galveston Bay, off the eastern shore near Texas City, at Pelican Island, and along the eastern end of Galveston Island.

These spoil sites can alter circulation patterns in the Bay due to the alteration of the Bay bottom contours and the shallow nature of these waters. Circulation patterns altered by channels would be further enhanced by the presence of long narrow spoil areas like those located along the intracoastal waterway. The spoil sites in the northern end of Galveston Bay, located to the east of the Houston Ship Channel, should enhance the channeling effect on inflows from the San Jacinto River already created by the ship channel and thereby increase the boundary effect along the channel. As discussed in Section 3.4 of this report, spoil area location information that was incorporated into the GIS system was obtained through the General Land Office. Dredge spoil areas inside the study area are shown in Figure 8.

3.10 National Marine Fisheries Services

Bessette (1985) reported that the NMFS divided the Galveston Bay system into five areas. These areas were Upper and Lower Galveston Bay, Trinity Bay, East Bay, and West Bay. The NMFS and predecessor agencies have used these subdivisions since 1961 (U.S. Department of the Interior, et. al., 1962). These areas were further subdivided which resulted in the segmentation system observed in Figure 15. This segmentation system was developed to report commercial fishery statistics. The subdivisions within five areas were arbitrarily selected (Zoula Zein-Eldin, personal communication). After 1975, all subdivisions in Galveston Bay were discontinued. Commercial fishery statistics were reported for inshore (Galveston Bay) and offshore (Gulf of Mexico) areas except for special surveys where the pre-1975 subdivisions were used (Zoula Zein-Eldin, personal communication).

3.11 National Oceanographic and Atmospheric Administration

The Coastal Ocean Management Planning and Assessment System (COMPAS) is being developed within the Strategic Assessment Program of NOAA. The purpose of COMPAS in Texas is to convert existing estuarine-related natural resource data into a common format that can be visually displayed to assist in management decisions regarding impacts to natural resources. Data currently being used for COMPAS include but are not limited to the following:

- Water Rights
- U.S. Geological Survey Freshwater Gaging Stations
- Texas Water Commission Stream Monitoring Network Stations with some Water Quality Data
- Land Use Data
- Habitat Types (e.g., bottom sediment types, saltmarsh, freshwater marsh, forested lands, tidal flats, etc.)
- Recreational Sites
- Point and Nonpoint Source Pollutant Loadings
- Physical and Hydrological Characteristics
- Highways

- Shellfish Locations
- Housing and Population
- Coastal Tracts
- NPDES Permitted Facilities
- NOAA National Status and Trends Data
- Finfish and Shellfish Distribution Data

A simple two-dimensional model will also be developed that will be used to estimate pollutant concentration isobars given certain flow regimes and point source locations. The Marine Resources Module will include distribution profiles for five life stages of 40 species of freshwater and saltwater finfish and shellfish. Distribution profiles within three zones (i.e., 0 to 0.5 parts per thousand (ppt), 0.5 to 25 ppt, and greater than 25 ppt). The predicted completion date for COMPAS in Texas is February 1992.

NOAA navigational charts at a scale of 1:25,000 were utilized in developing the shoreline boundaries and embayment features such as ship channels, markers, and bay bottom obstructions. Hydrography and topography for these maps are developed by the National Ocean Service, Charting and Geodetic Services with additional data provided by the U.S. Army Corps of Engineers, U.S. Geological Survey, and the U.S. Coast Guard (NOAA,1990). Figure 16 is a bathymetric map of the area developed from the NOAA charts.

3.12 Texas Water Quality Board/ University of Texas Marine Science Institute

The Galveston Bay Project was a comprehensive program implemented to study specific features of the Galveston Bay system including its water sources and industrial and urban impacts. One of the components of the study was the "Toxicity Studies of Galveston Bay Project" conducted by the University of Texas Marine Science Institute (UTMSI) located in Port Aransas and contracted through the Texas Water Quality Board to conduct toxicity studies on living communities in the Bay and its primary productivity. The scope of the study was to "determine the water quality of relatively stable salinity/temperature areas representing five general locations in the Galveston Bay system" (UTMSI, 1973). These five sampling locations, shown in Figure 17, were established in the Bay within described limits of temperature and salinity to more each data collection project associated with Galveston Bay as well as sources through which these can be obtained. The CRWR developed segmentation for Galveston Bay and the Houston Ship Channel based on hydrographic boundaries for use in the GBNEP status and trends project (Ward,1991). The process involved three systems: Galveston Bay, the Houston Ship Channel, and the proximal Gulf of Mexico. Under the chosen scheme, Galveston Bay includes separate segments for the Texas City Ship Channel and the Houston Ship Channel due to the "peculiar hydrodynamics of salinity intrusion and increased tidal response dictated by the deeper water, and also due to the effect of dredge disposal areas on the lateral boundaries of these channels". Areas where the return waters of major power plants enter the Bay are segmented separately to isolate the resulting thermal plume. Segment boundaries also occur at the mouths of East Bay due to Hanna Reef, Trinity Bay, Tabbs Bay, Clear Lake, Dickinson Bay, and Chocolate Bay. The inland portion of the Houston Ship Channel defines a separate segment while all major inlets entering it are also delineated. Trinity Bay segments are oriented longitudinally to track the plume of runoff from the Trinity River. Hanna Reef, Carancahua Reef, and the mid-Bay reef/Red Fish Bar complexes define physical boundaries in the Bay. Whenever possible, the boundaries of the hydrographic segments defined in this study were made to coincide with the larger Texas Water Commission segments in order to simplify the aggregation process. The final segmentation scheme developed by CRWR is shown in Figure 22 through 24.

3.13.2 Bureau of Economic Geology

The Bureau of Economic Geology (BEG) developed its submerged lands series of atlases for the Bay systems of Texas in order to better define natural resource boundaries along the Texas coast. The Submerged Lands of Texas Project is based primarily on an intensive sampling program in which approximately 6,700 surficial bottom samples were collected at regularly-spaced intervals across the submerged lands (White, 1985). This information is intended for utilization by State, Federal, regional, and local agencies and for private businesses and individuals. The atlas on the Galveston-Houston area is the second in a series of seven publications focusing on the submerged lands and coastal wetlands of Texas from the Rio Grande to Sabine Lake. The series provide an extensive spatial data base on sediment texture, sediment geochemistry, benthic macroinvertebrates, and associated wetlands. Maps are included with each series publication which indicate the locations of homogeneous deposits of these resources.

"Textural analyses" of sediments by BEG "included quantitative determination of the gravel, sand, and mud fractions in each sample followed by more detailed textural analysis of the sand and mud fractions. Size distribution in the sand fraction was determined with a rapid sediment analyzer and in the mud (silt and clay) fraction with a Coulter Counter (Shideler, 1976)." Sediment texture maps showing gravel, sand and mud distribution are shown in Figure 25 and sand, silt, and clay distributions are shown in Figure 26.

Geochemistry data developed by the BEG and presented in White, (1985) were obtained from the sediment sampling efforts of BEG during 1976 and 1977. "Geochemical data on submerged lands consist of analyses of whole sediment samples to determine the concentration of total organic carbon (TOC) and a spectrum of major and trace elements. More than 6,500 samples were analyzed for TOC by staff at the Bureau's Mineral Studies Laboratory, using a wet-combustion technique (Jackson, 1958). Approximately 3,800 samples were analyzed for trace and major element concentrations. The U.S. Geological Survey performed most of these latter analyses using an emission spectrograph and a computerized system of spectral analysis (Dorrzapf, 1973), which provides semiquantitative results (relative standard deviation for each reported concentration being plus 50 percent and minus 33 percent) (White, 1985).

The distribution of wetlands from adjacent areas was interpreted and delineated by the BEG using National Aeronautics and Space Administration (NASA) stereoscopic, color-infrared (CIR) positive transparencies taken in 1979, at a scale of approximately 1:66,000. Wetlands found in Galveston Bay border submerged lands and occur in some inland areas. Wetland classification in these efforts was based primarily on vegetation and general moisture and salinity conditions. In the Galveston-Houston area, 19 map units including three marsh categories were used by the BEG to delineate wetlands.

3.14 Texas A&M University

A compilation of information sources pertaining to studies involving the marine environment and associated industry in Galveston Bay is available through the Sea Grant Program at Texas A&M University in College Station. Information categories available through this source include marine fishing, mariculture operations, oceanography, environmental quality, marine education, marine business, marine economics, coastal and ocean engineering, marine transportation, and marine recreation (TAMU, 1988). Information resulting from projects within the Sea Grant Program are made available to the public by the Marine Information Service within the Sea Grant Program.

3.15 Houston-Galveston Area Council

Coastal preserves were created at Armand Bayou and Christmas Bayou near Galveston Bay under the existing joint Texas General Land Office (GLO) and Texas Parks and Wildlife Department (TPWD) Coastal Preserves Program. Coastal preserves are established in order to protect areas of unique environmental characteristics. Armand Bayou (TWC Segment 1113) is located between the City of Houston and Clear Lake. Christmas Bay (TWC Segment 2434) is on the western extent of West Bay (HGAC, 1991). The administrative boundaries of both are defined as the area located within each respective watershed that is also below the mean high tide line (MacRae,1991). Both preserves are composed entirely of State-owned lands.

3.16 City and County Jurisdictional Areas

The study area is comprised of four counties: Harris County, Brazoria County, Galveston County, and Chambers County. The county boundaries within the study area are shown on Figure 27. These were obtained from the State Department of Highways and Public Transportation (SDHPT, 1988). All of Trinity Bay and the bulk of upper Galveston Bay are within Chambers County. The Chambers/Harris county line forms a boundary across the northern edge of Galveston Bay from the southeastern corner of the city limits of the City of Morgans Point, separating Galveston Bay from the lower end of the Houston Ship Channel, to the northern end of Atkinson Island to the northern side of the mouth of Ash Lake, separating Galveston Bay and Tabbs Bay.

Harris County encloses the entire Houston Ship Channel, Buffalo Bayou Tidal, San Jacinto River Tidal, Tabbs Bay, San Jacinto Bay, Black Duck Bay, Scott Bay, and Burnett Bay. The Harris/Galveston county line forms a boundary that divides Clear Lake approximately down the middle of the bay and continues upstream to Clear Creek which forms the county line.

Galveston County encloses the bulk of lower Galveston Bay, all of East Bay, and most of West Bay, Dickinson Bay, Moses Lake, and Dollar Bay. The Galveston/Chambers county line forms an approximate boundary between upper and lower Galveston Bay from Eagle Point to just north of Smith Point.

Brazoria County includes the far western end of West Bay, Chocolate Bay, Bastrop Bay, Christmas Bay, and Drum Bay. The Brazoria/Galveston county line forms a boundary across the western end of West Bay from a point southwest of Carancahua Point diagonally across West Bay to the center of San Luis Pass.

Generally, city boundaries within the study area tend to follow the shoreline. However, in some cases, city boundaries do extend into parts of the Galveston Bay system. Also shown in Figure 27 are city boundaries that extend into and encompass parts of the Galveston Bay system.

The City of Houston corporate boundaries are drawn to include the Houston Ship Channel/San Jacinto River down to a point just north of the Baytown Tunnel and south of Alexander Island where they abut the corporate boundaries of La Porte and Baytown. The Baytown corporate boundary includes Goose Creek and forms a boundary separating it from the San Jacinto River. The La Porte corporate boundary encompasses most of Lower San Jacinto Bay, the southern portion of Upper San Jacinto Bay, and most of Santa Anna Bayou.

The city limits of the small town of Shoreacres extends approximately one-half mile into Galveston Bay for a distance of approximately one-quarter mile. The Seabrook city limits extend approximately 0.6 miles into upper Galveston Bay along approximately four miles of bay frontage. In addition, the city limits of Seabrook encompass parts of Taylor Lake and Clear Lake. The city limits of Pasadena encompasses most of Armand Bayou.

Nassau Bay city limits enclose a small part of Clear Lake, while the city limits of League City enclose a large portion of Clear Lake. Near the confluence of Clear lake with Galveston Bay, the community of Clear Lake Shores encloses a small part of Clear Lake.

The City of Texas City has a rather complex corporate boundary that encloses most of lower Dickinson Bayou and Dickinson Bay, all of Moses Lake and Dollar Bay, and parts of lower Galveston Bay. The Texas City corporate boundary is drawn to include the Texas City Dike and a zone of Galveston Bay on either side and most of the Texas City Ship Channel. The boundary of the Village of Tiki Island is a rectangle of approximately two square miles that includes portions of Jones Bay and West Bay.

The corporate limits of the City of Galveston includes a large portion of West Bay, part of lower Galveston Bay, part of Bolivar Roads, and a considerable area of the Gulf of Mexico. Within the corporate boundaries of Galveston are the Corporate boundaries of Jamaica Beach which include a small portion of West Bay.

Galveston Bay National Estuary Program

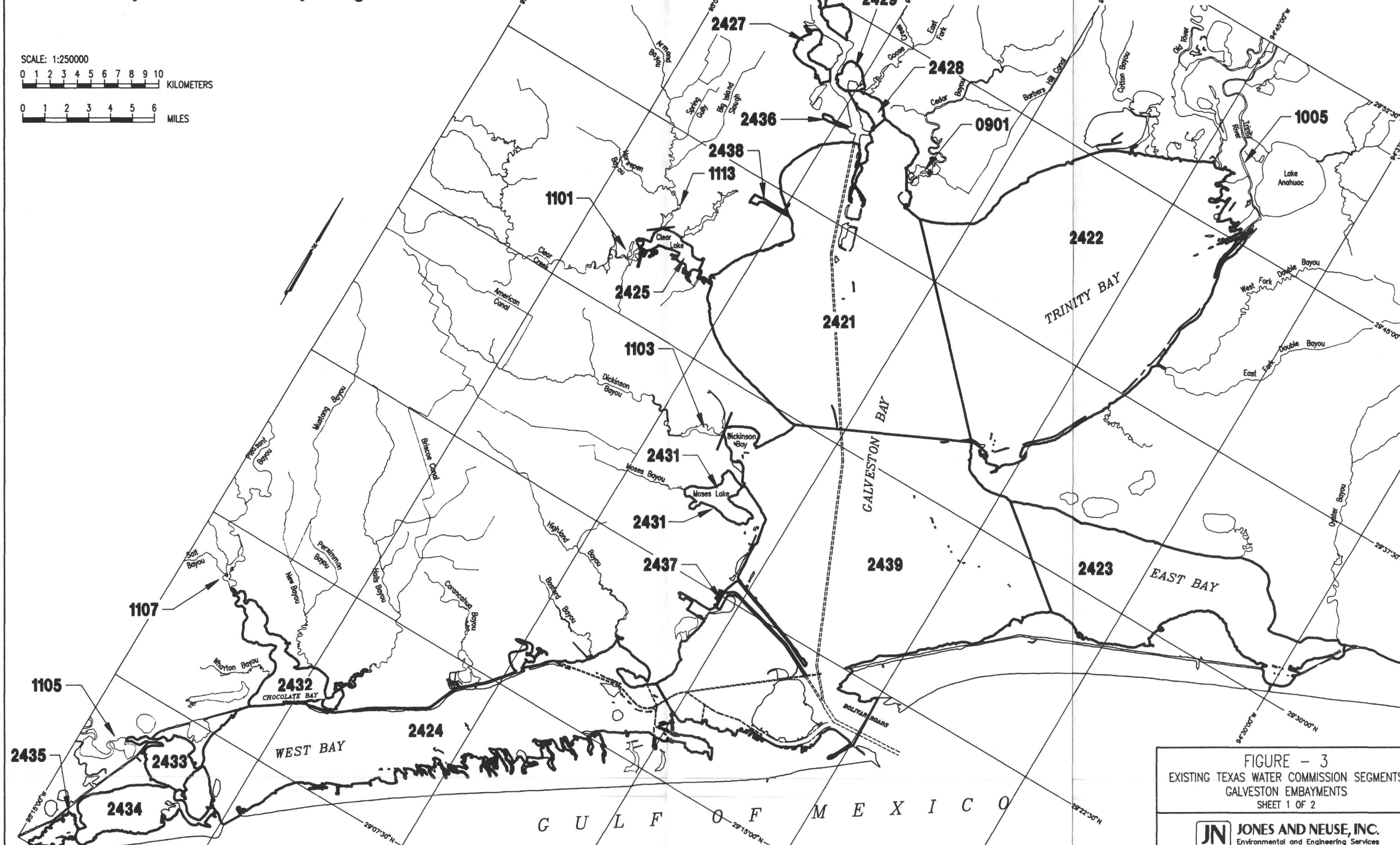
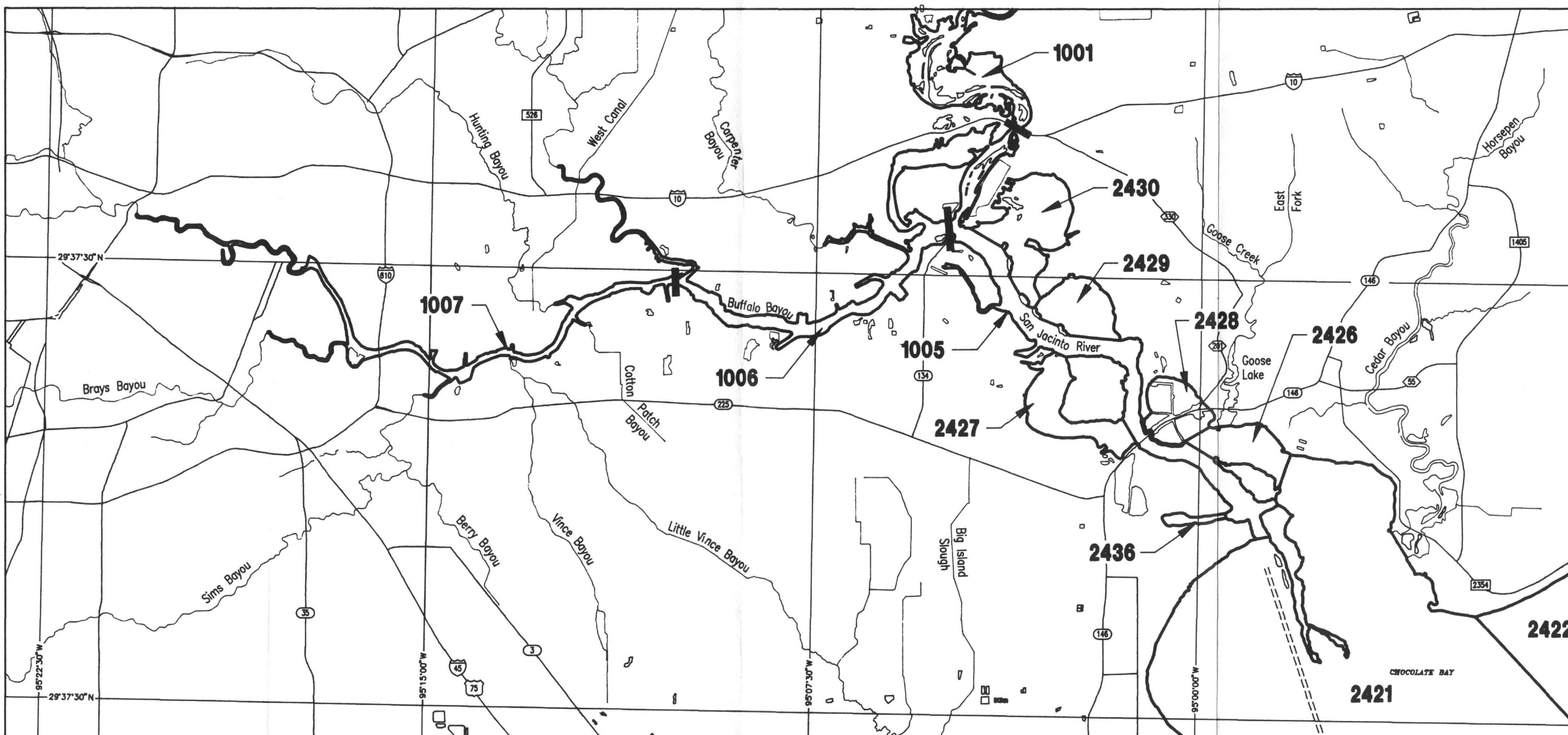


FIGURE – 3
EXISTING TEXAS WATER COMMISSION SEGMENTS
GALVESTON EMBAYMENTS
SHEET 1 OF 2

JONES AND NEUSE, INC.
Environmental and Engineering Services

Galveston Bay National Estuary Program

SEE FIGURE 3 SHT. 1 OF 2 FOR GALVESTON BAY AREA SEGMENTATION.



SCALE: 1:126720

0 1 2 3 4 5 6 7 KILOMETERS

0 1 2 3 4 MILES

FIGURE – 4

EXISTING TEXAS WATER COMMISSION SEGMENTS

HOUSTON SHIP CHANNEL

SHEET 2 OF 2

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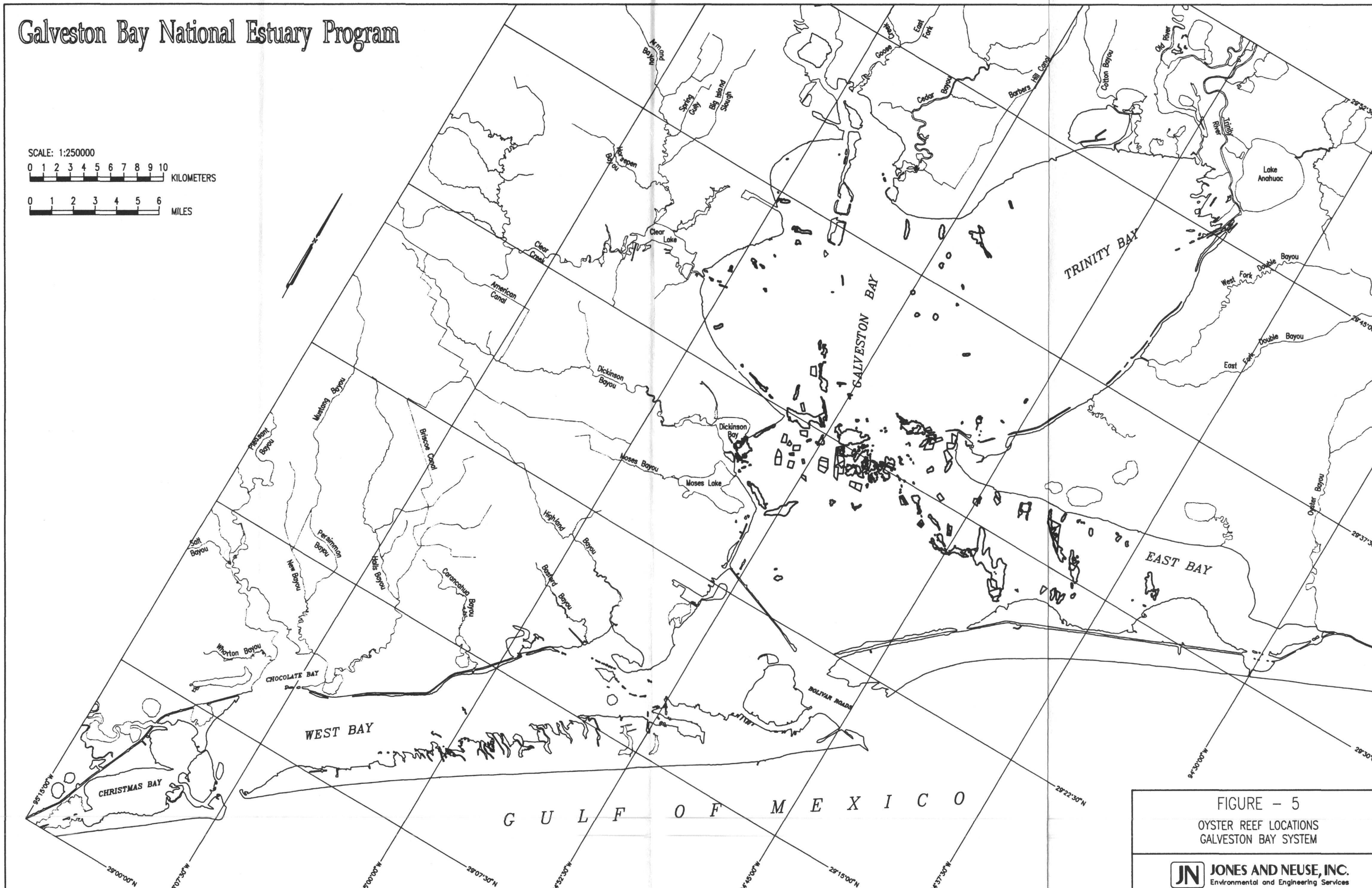

FIGURE – 5
OYSTER REEF LOCATIONS
GALVESTON BAY SYSTEM

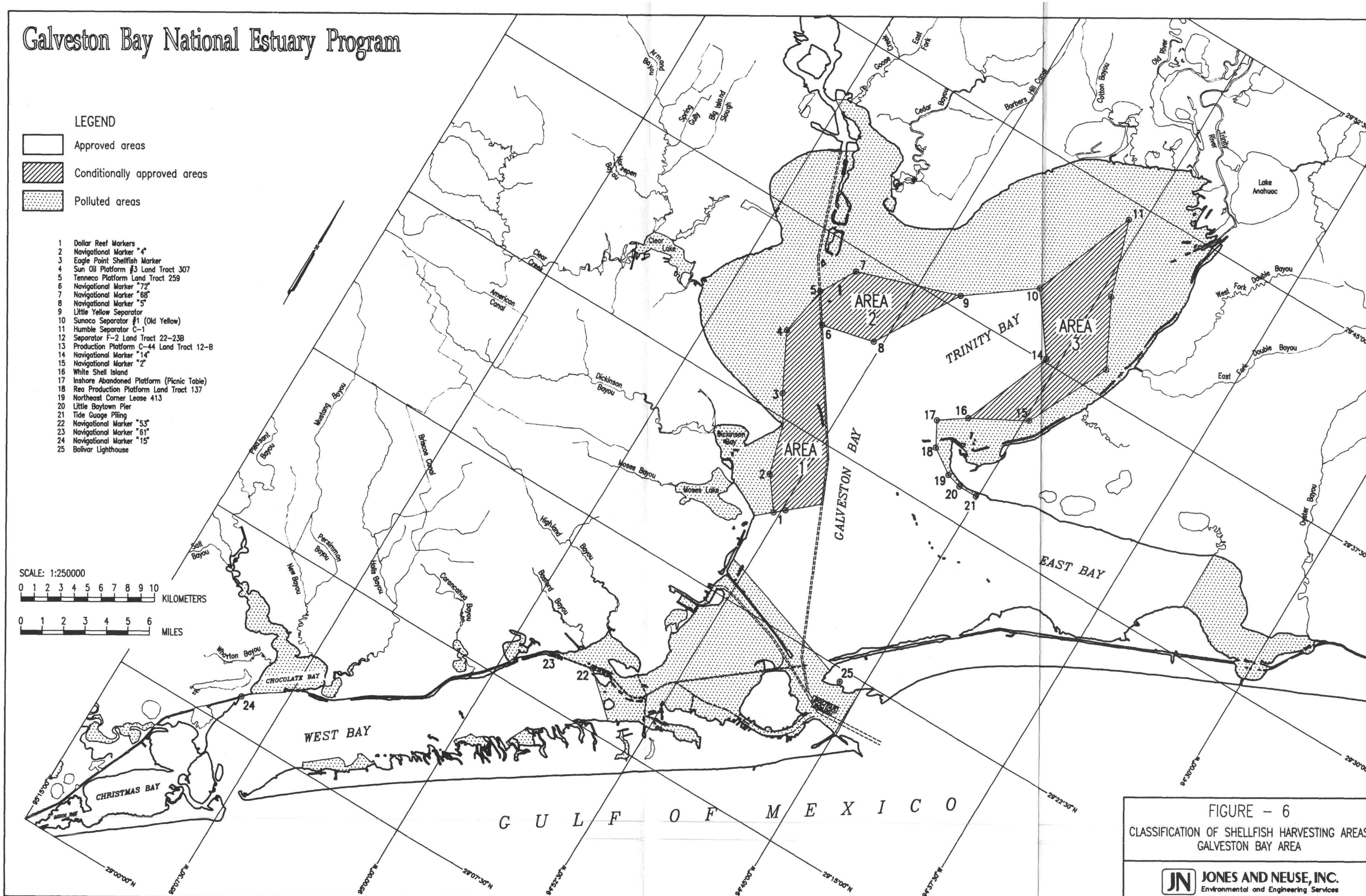

FIGURE – 6
CLASSIFICATION OF SHELLFISH HARVESTING AREAS
GALVESTON BAY AREA

Galveston Bay National Estuary Program

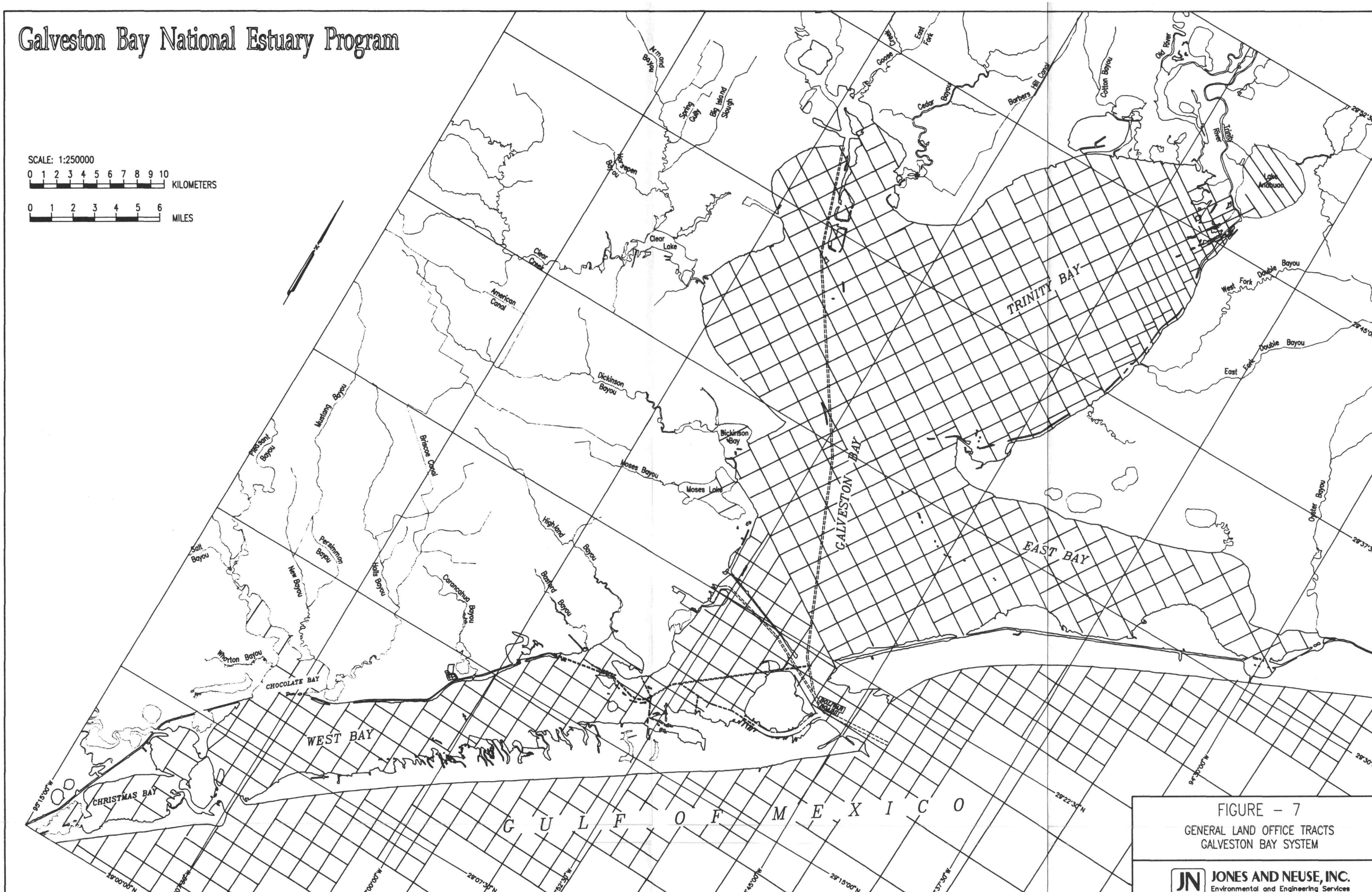

FIGURE – 7
GENERAL LAND OFFICE TRACTS
GALVESTON BAY SYSTEM

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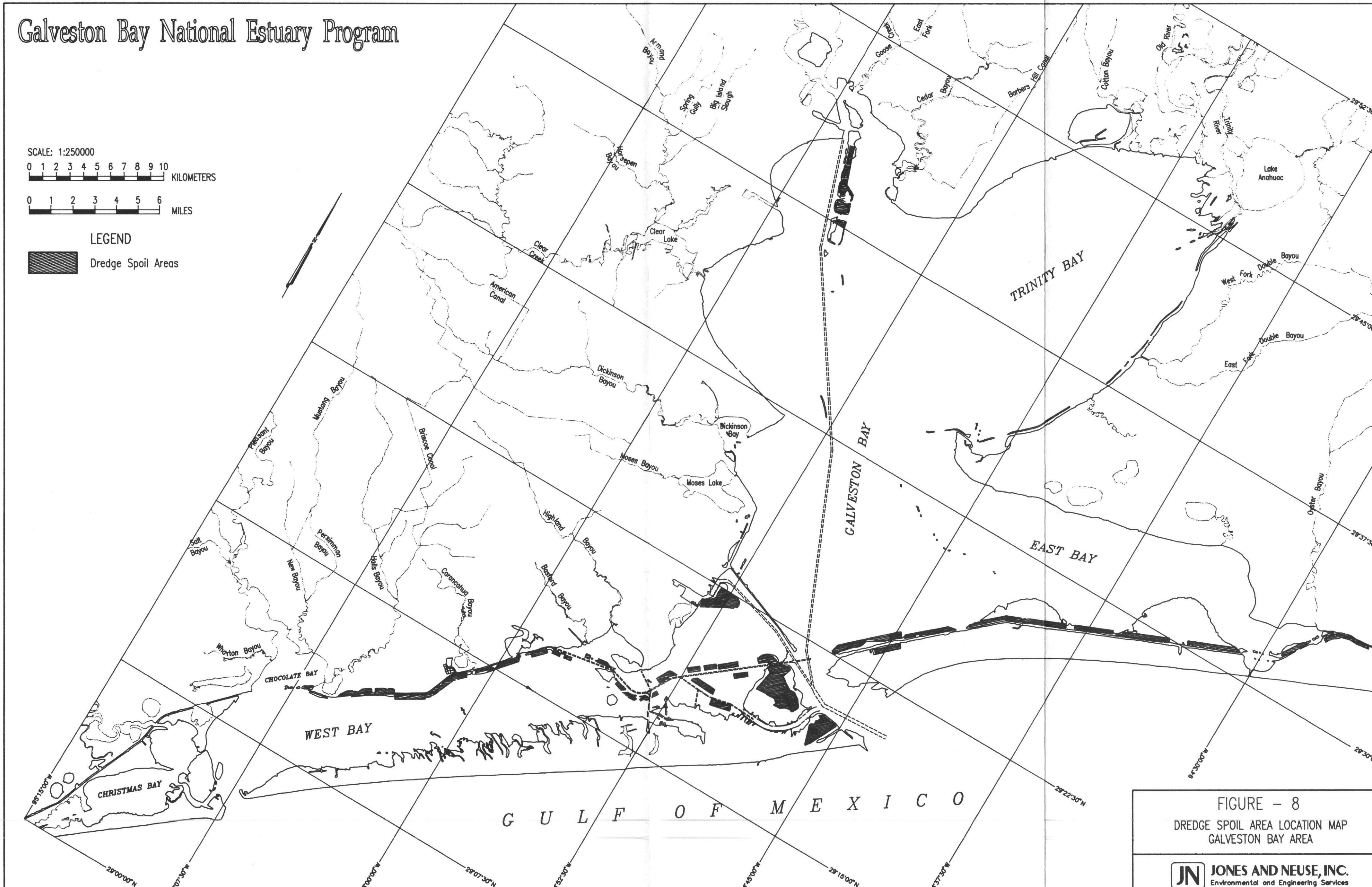

FIGURE – 8
DREDGE SPOIL AREA LOCATION MAP
GALVESTON BAY AREA
JN JONES AND NEUSE, INC.
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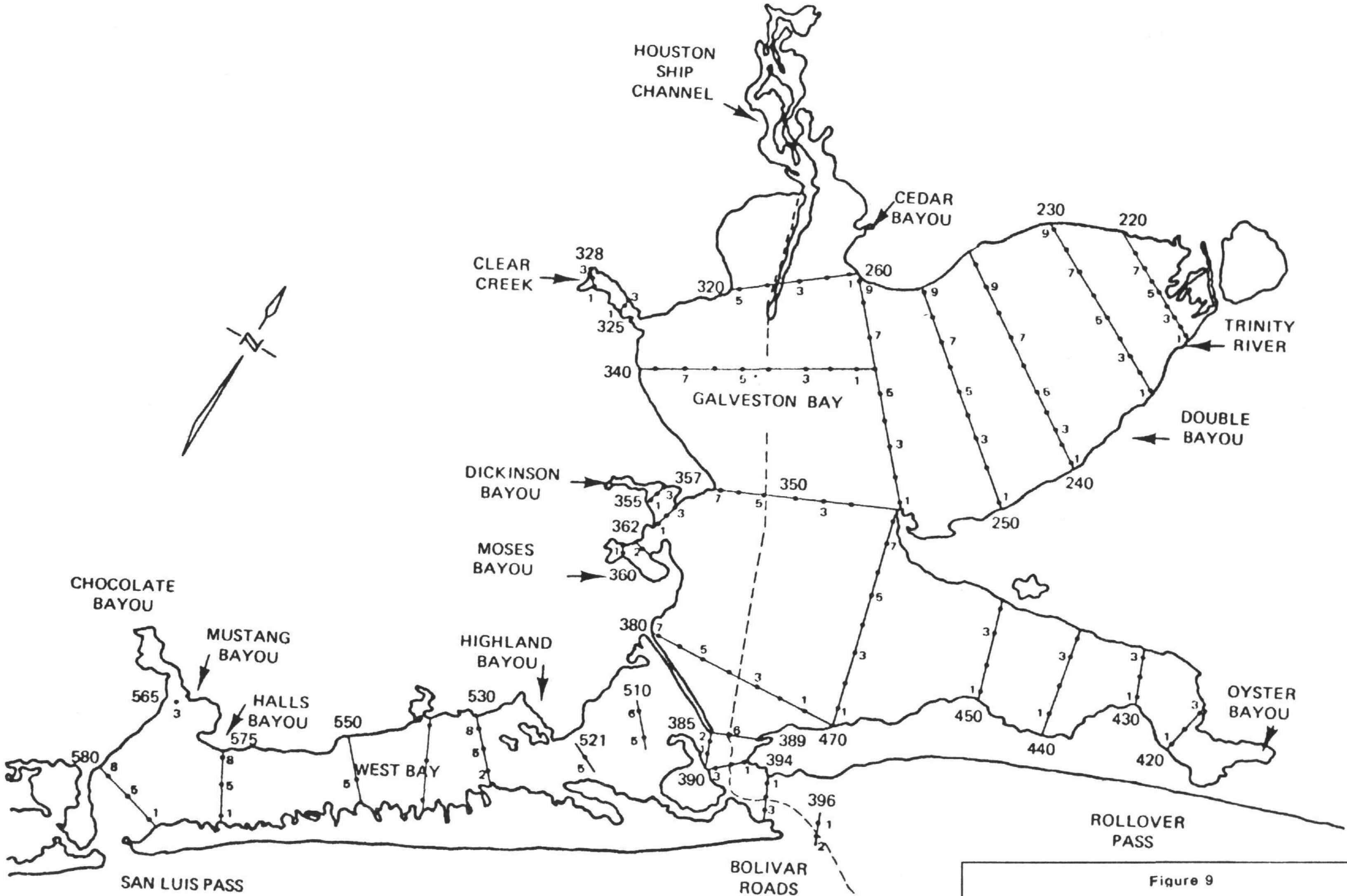

Figure 9

Coastal Data System Sampling Point Locations

Galveston Bay System

From: TDWR, 1979, "Trinity-San Jacinto Estuary: An Analysis of Bay Segment Boundaries, Physical Characteristics, and Nutrient Processes"

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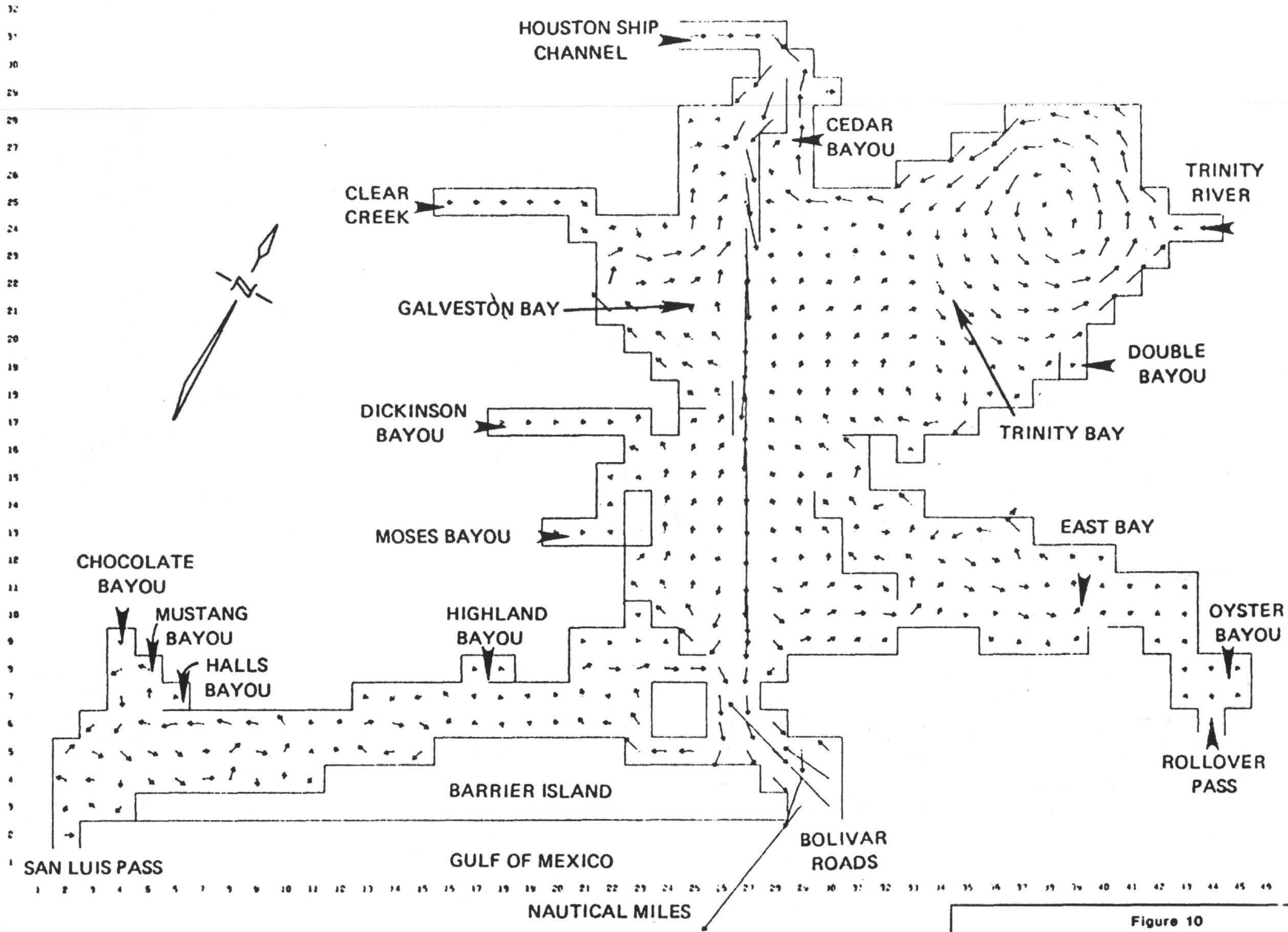

Figure 10

Net Circulation Patterns Developed from TDWR Study
Galveston Bay System

From: TDWR, 1981, "Trinity-San Jacinto Estuary: A Study of the Influence of Freshwater Inflows"

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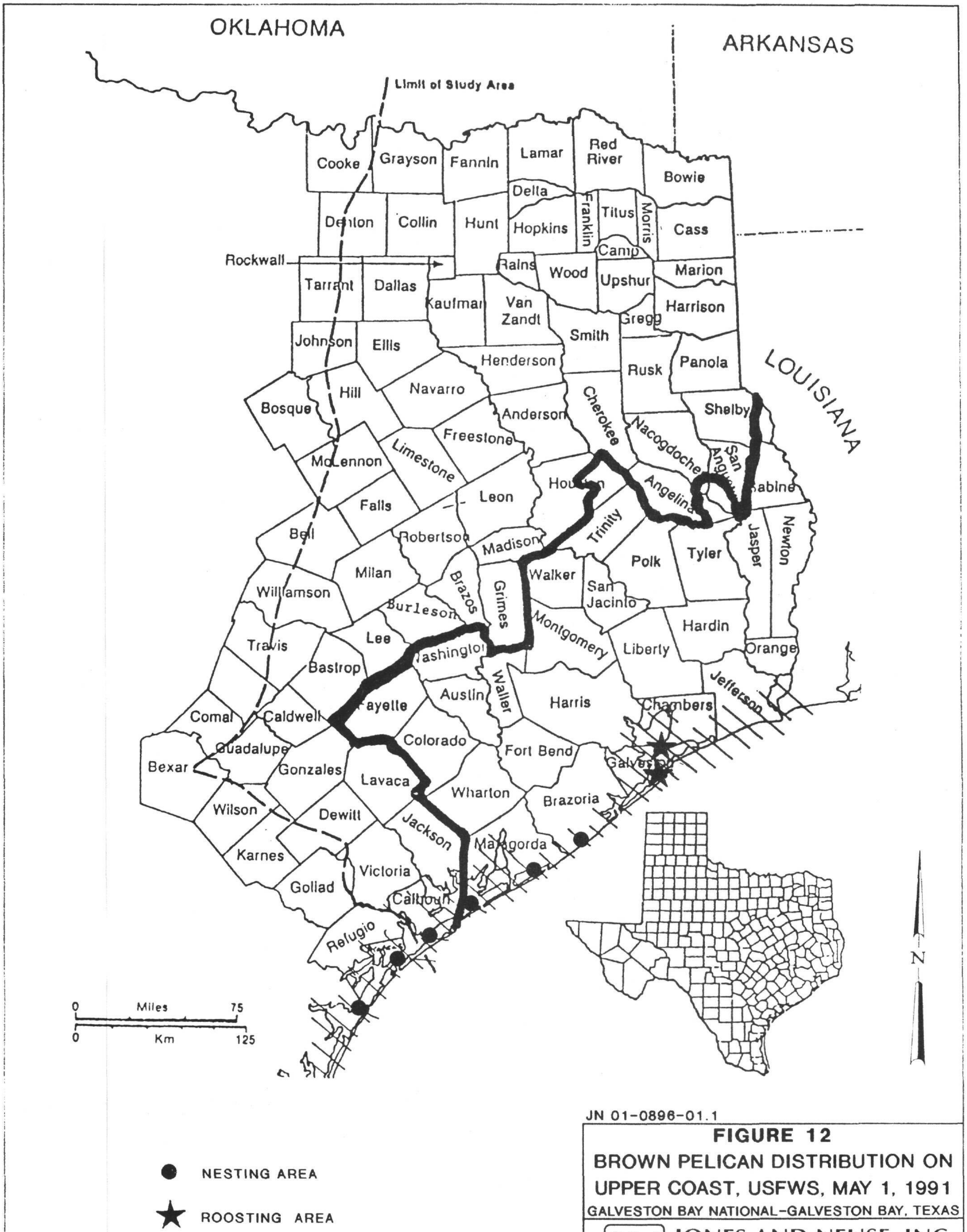
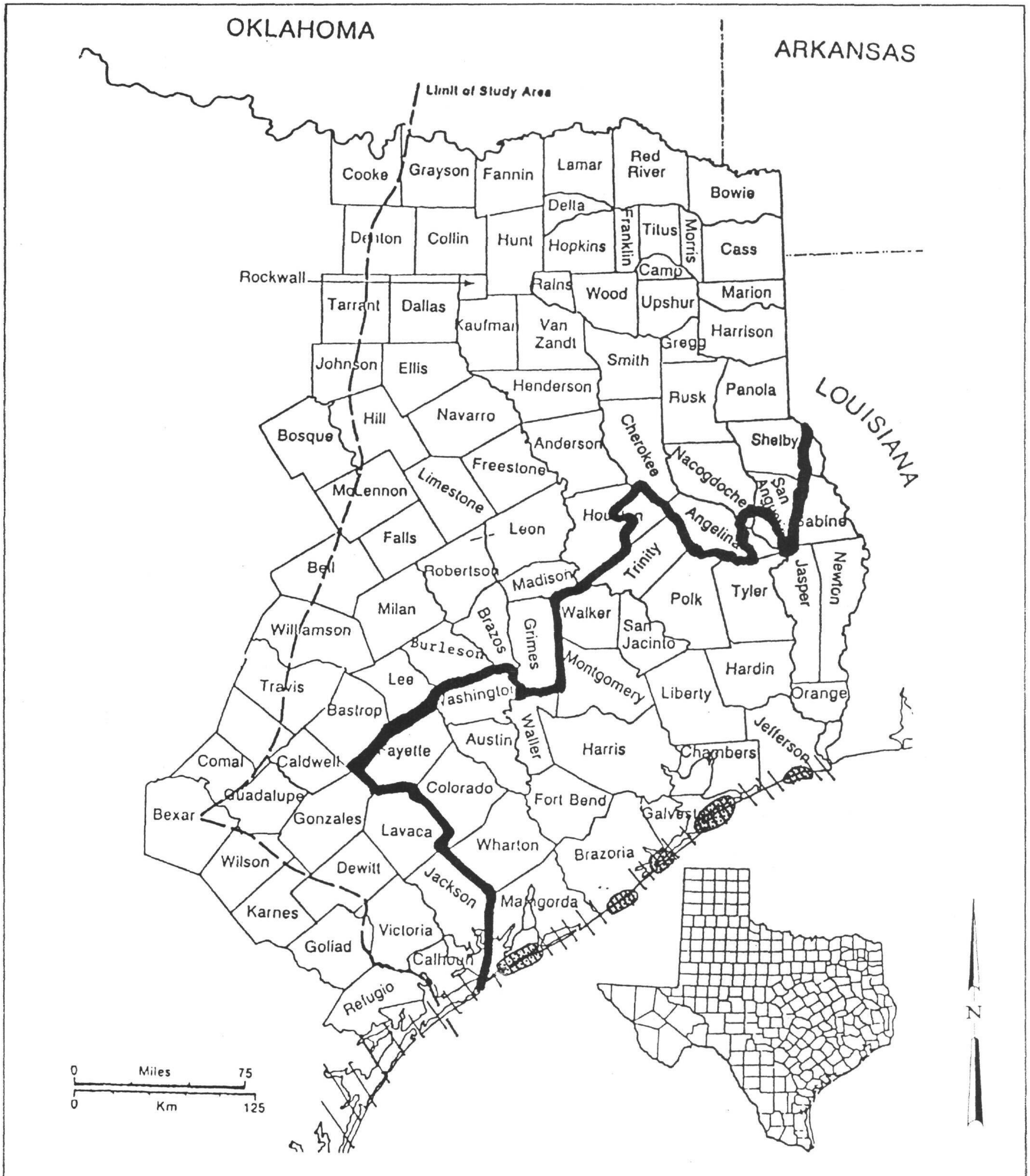


JN 01-0896-01.1

FIGURE 12
BROWN PELICAN DISTRIBUTION ON UPPER COAST, USFWS, MAY 1, 1991
GALVESTON BAY NATIONAL-GALVESTON BAY, TEXAS

JN JONES AND NEUSE, INC.
Environmental and Engineering Services



JN 01-0896-01.1

FIGURE 13
PIPING PLOVER WINTER CONCENTRATION SITES ON UPPER TEXAS COAST, USFWS, MAY 1, 1991
GALVESTON BAY NATIONAL–GALVESTON BAY, TEXAS

JN JONES AND NEUSE, INC.
Environmental and Engineering Services

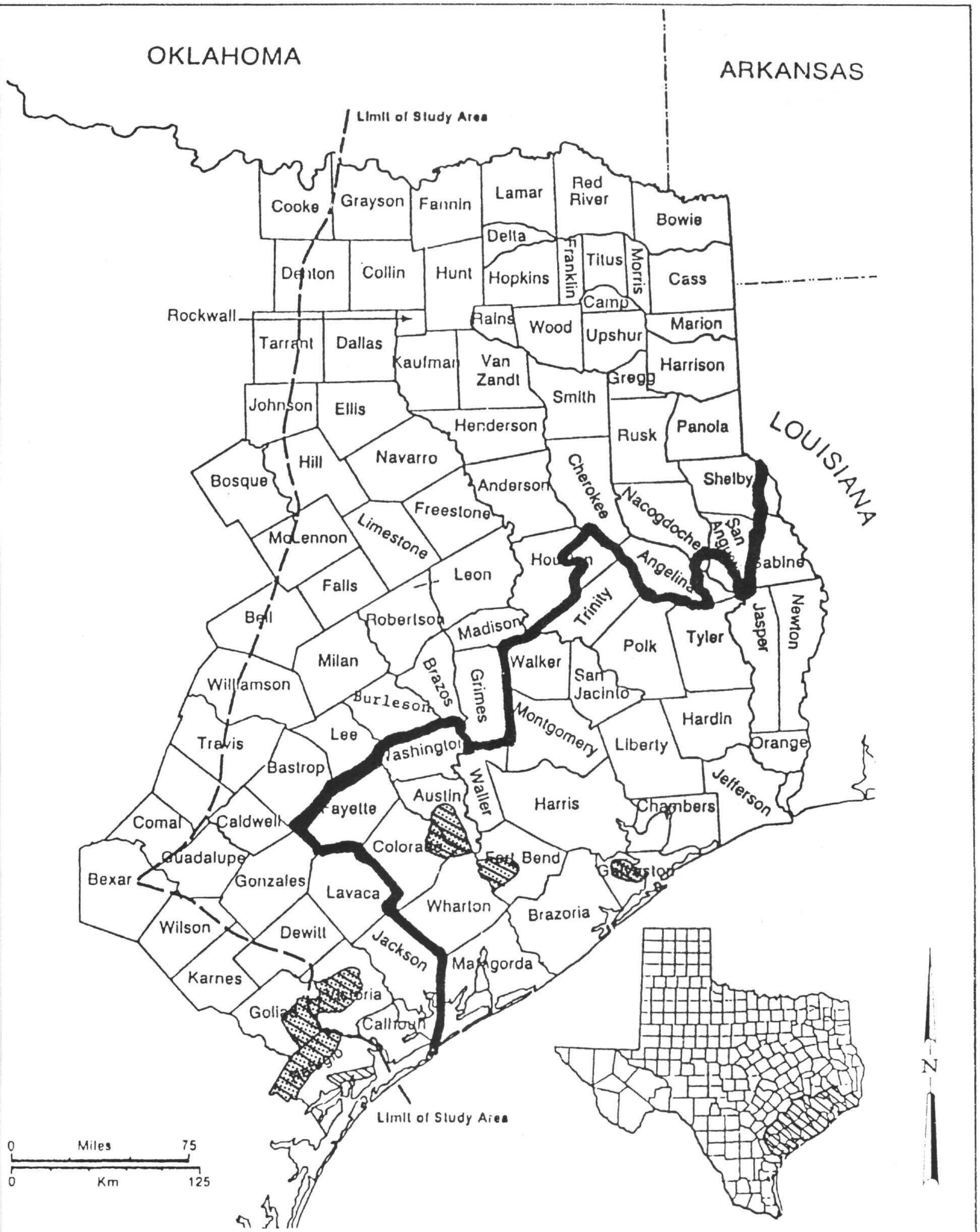


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FIGURE 14
ATTWATER'S PRAIRIE CHICKEN DISTRIBUTION ON UPPER TEXAS COAST, USFWS, MAY 1, 1991
GALVESTON BAY NATIONAL-GALVESTON BAY, TEXAS

JN JONES AND NEUSE, INC.
Environmental and Engineering Services

JN 01-0896-01.1

FIGURE 15

SUBDIVISIONS OF GALVESTON BAY USED BY THE NMFS

GALVESTON BAY NATIONAL-GALVESTON BAY, TEXAS

JN JONES AND NEUSE, INC.
Environmental and Engineering Services

Galveston Bay National Estuary Program

Source: The University of Texas at Austin
Bureau of Economic Geology

FIGURE – 16
BATHYMETRIC MAP
GALVESTON BAY AREA

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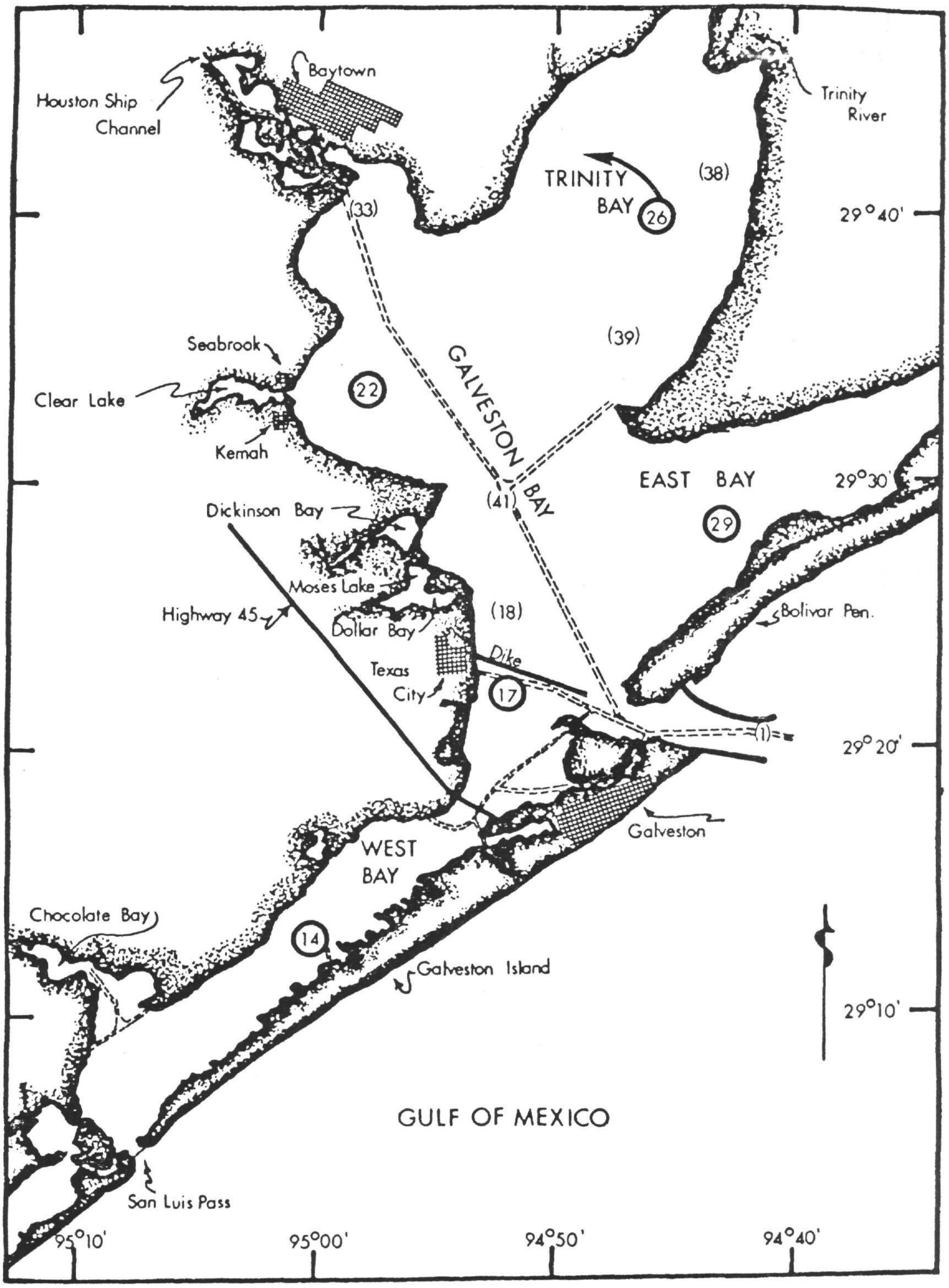

From: UTMSI, 1973, "Toxicity Studies of Galveston Bay Project"

Figure 17

TWQB/UTMSI Sampling Station Locations

Galveston Bay System

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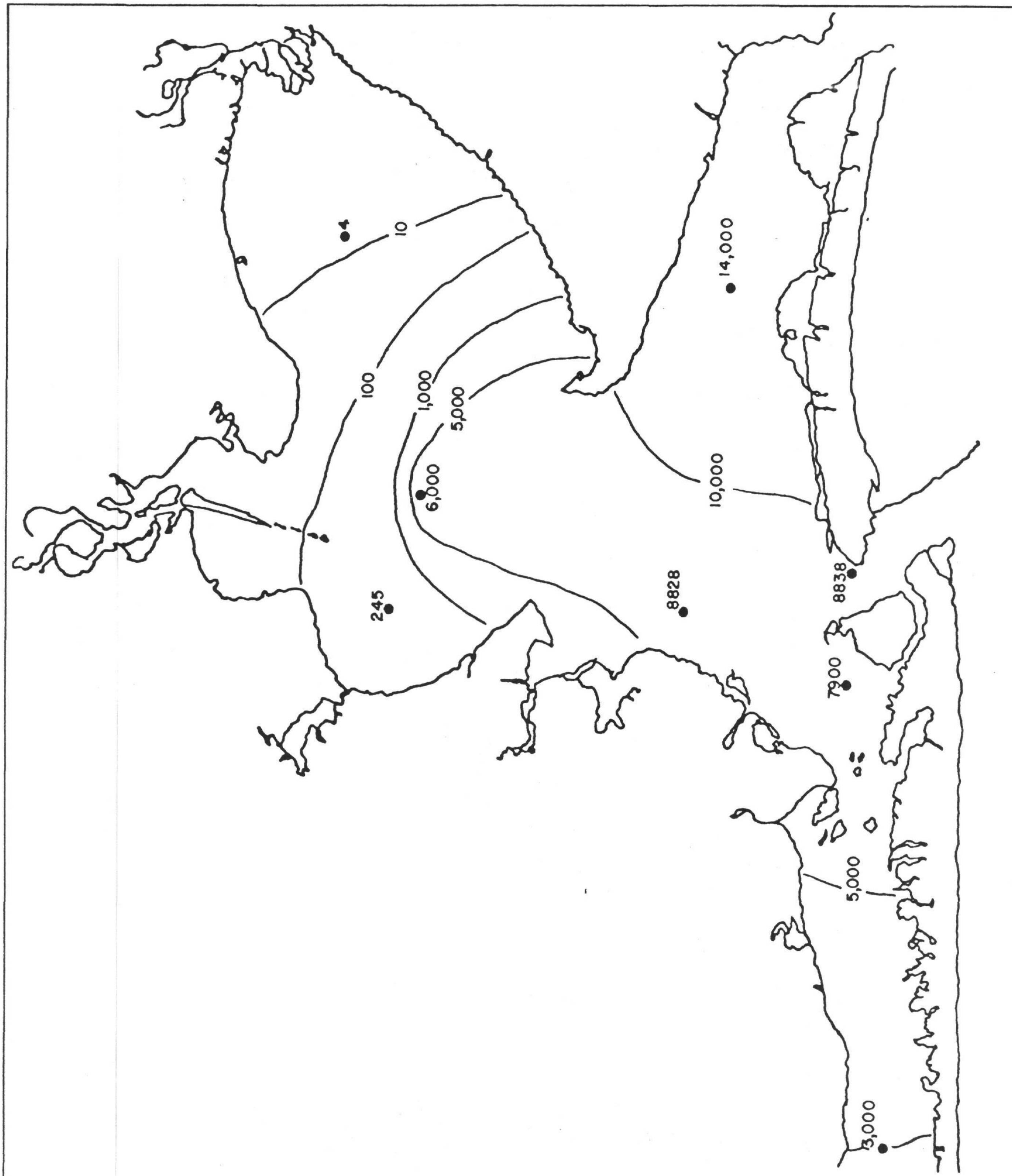

From: UTMSI, 1973, "Toxicity Studies of Galveston Bay Project"

* Contours produced from data obtained from Copeland, 1970

Values are number of cells per 100 ml.

Figure 18

October, 1969 Phytoplankton Populations

Galveston Bay System

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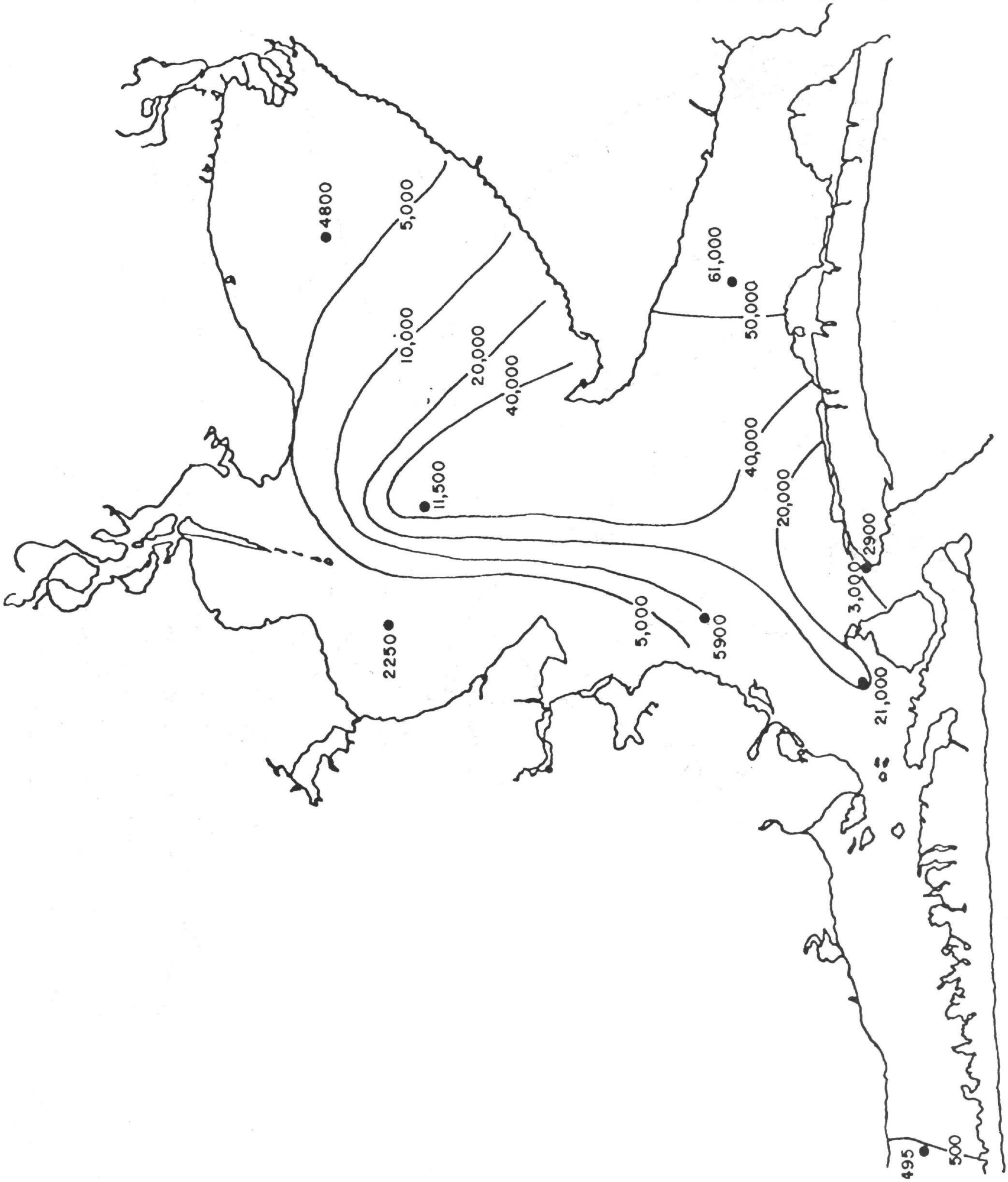
Environmental and Engineering Services



From: UTMSI, 1973, "Toxicity Studies of Galveston Bay Project"

* Contours produced from data obtained from Copeland, 1970

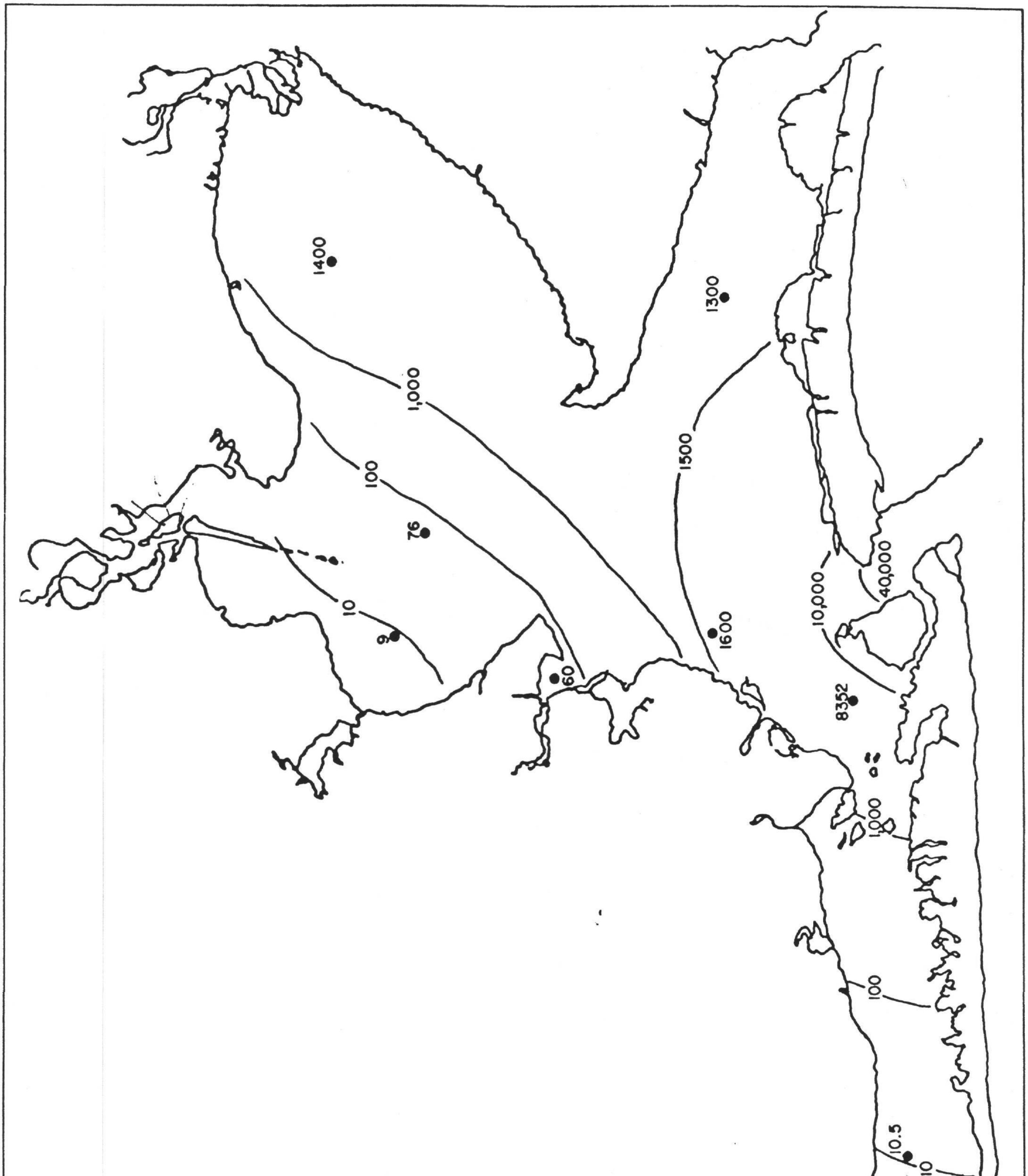
Values are in number of cells per 100 ml.

Figure 19

February, 1969 Phytoplankton Populations

Galveston Bay System

JN JONES AND NEUSE, INC.
Environmental and Engineering Services



From: UTMSI, 1973, "Toxicity Studies of Galveston Bay Project"

* Contours produced from data obtained from Copeland, 1970

Values are number of cells per 100 ml.

Figure 20

April, 1969 Phytoplankton Populations

Galveston Bay System

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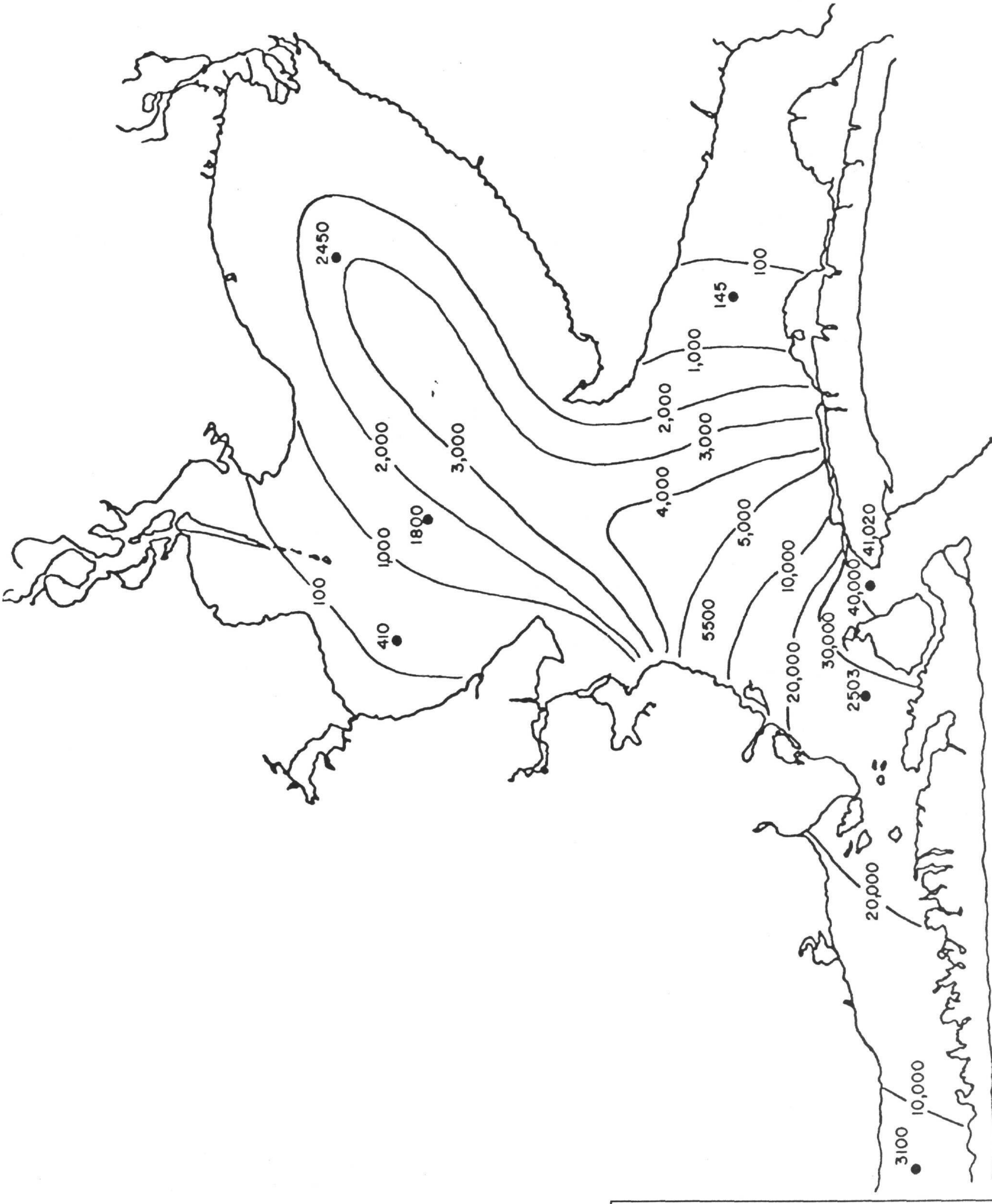

From: UTMSI, 1973, "Toxicity Studies of Galveston Bay Project"

* Contours produced from data obtained from Copeland, 1970

Values are in number of cells per 100 ml.

Figure 21

July, 1969 Phytoplankton Populations

Galveston Bay System

JN JONES AND NEUSE, INC.
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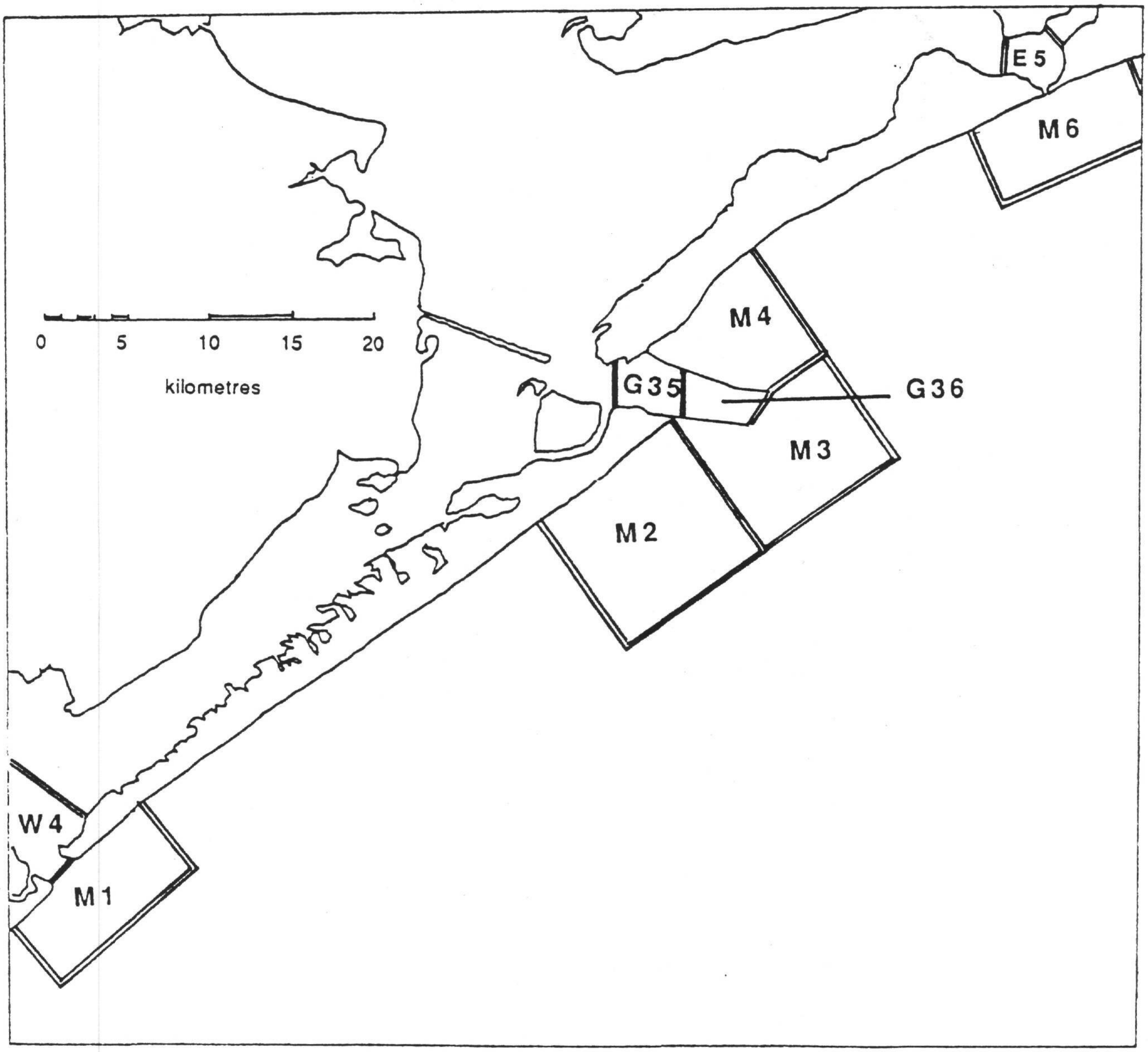
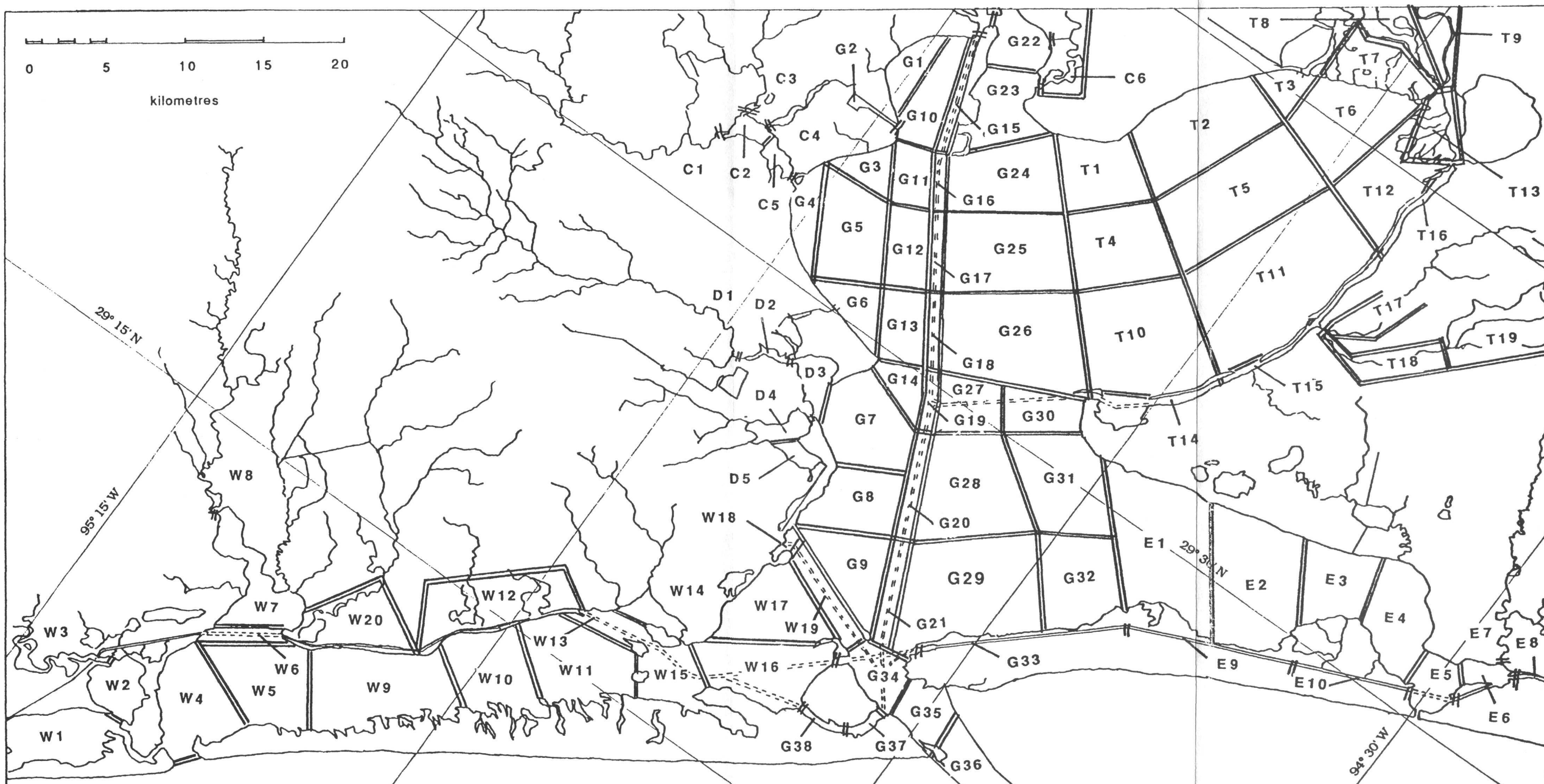


From: Ward, 1991, "Hydrographic Segmentation for Galveston Bay"

Figure 22
Hydrographic Segmentation Map
Near-shore Gulf of Mexico
Galveston Bay Area

JN JONES AND NEUSE, INC.
Environmental and Engineering Services



From: Ward, 1991, "Project Memorandum - Hydrographic Segmentation for Galveston Bay"

Figure 23

Hydrographic Segmentation Map

Galveston Bay

JN JONES AND NEUSE, INC.
Engineering and Environmental Consultants

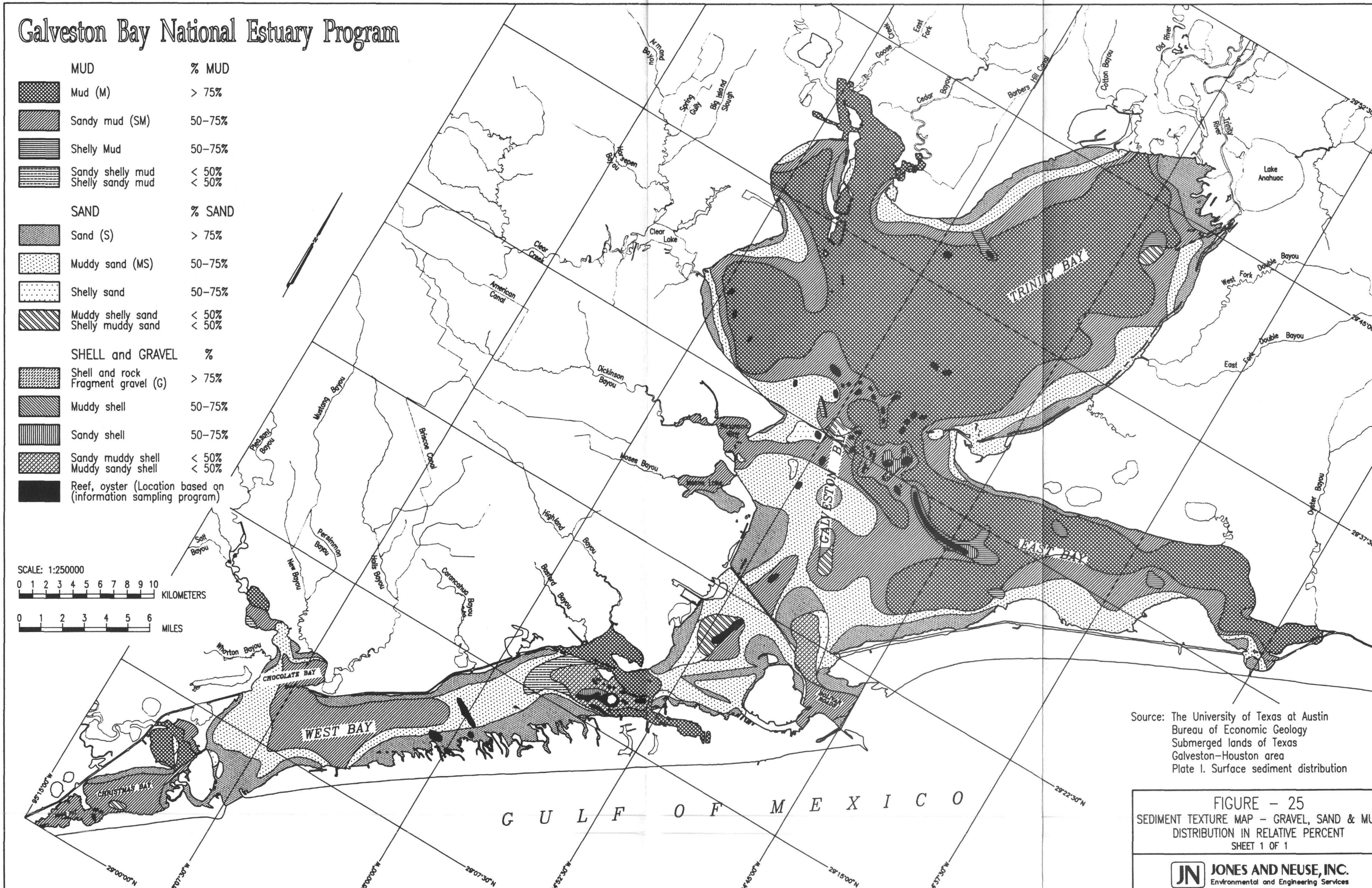


FIGURE – 25
SEDIMENT TEXTURE MAP – GRAVEL, SAND & MUD DISTRIBUTION IN RELATIVE PERCENT
SHEET 1 OF 1

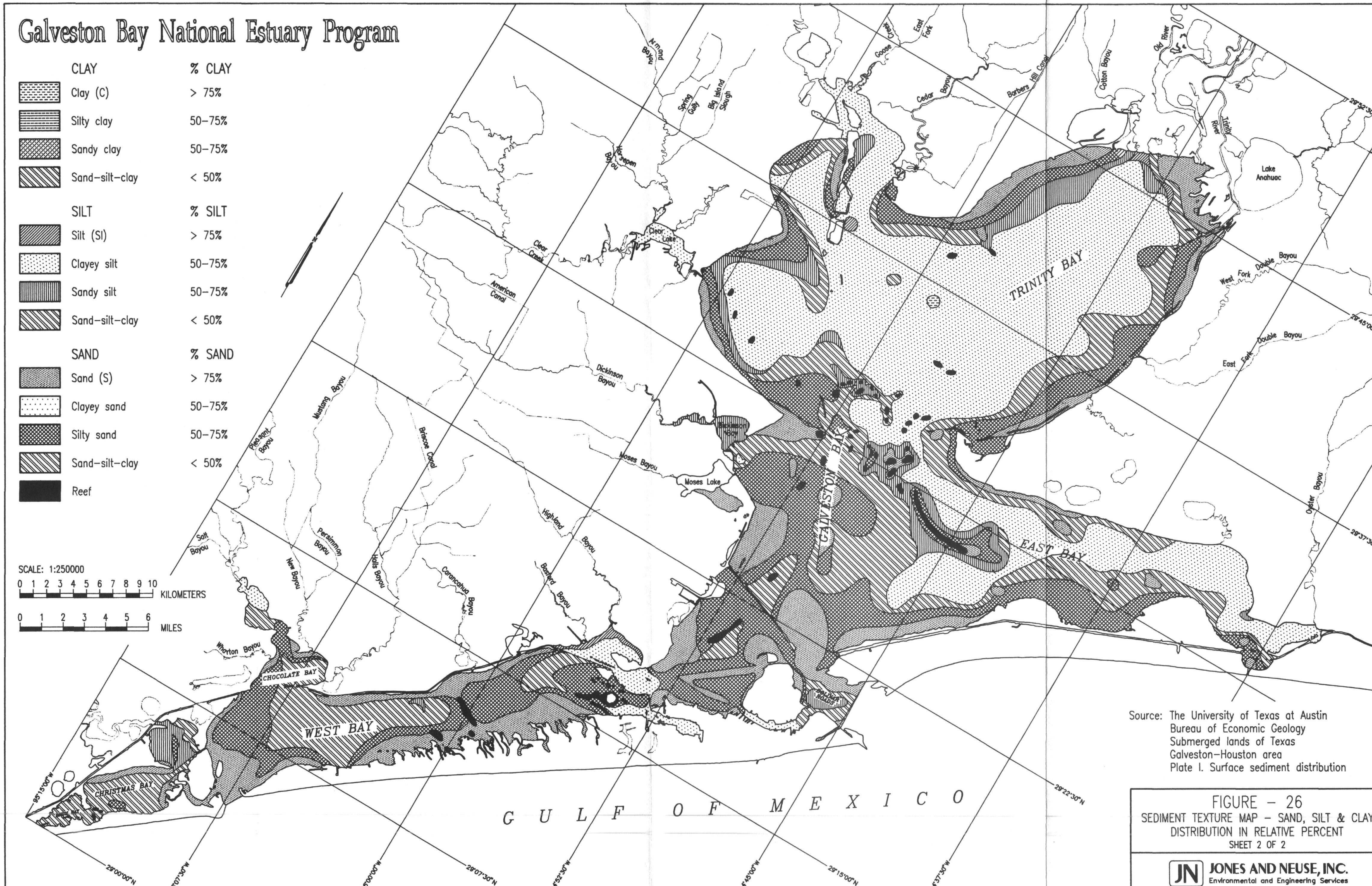


FIGURE – 26
SEDIMENT TEXTURE MAP – SAND, SILT & CLAY DISTRIBUTION IN RELATIVE PERCENT
SHEET 2 OF 2

Galveston Bay National Estuary Program

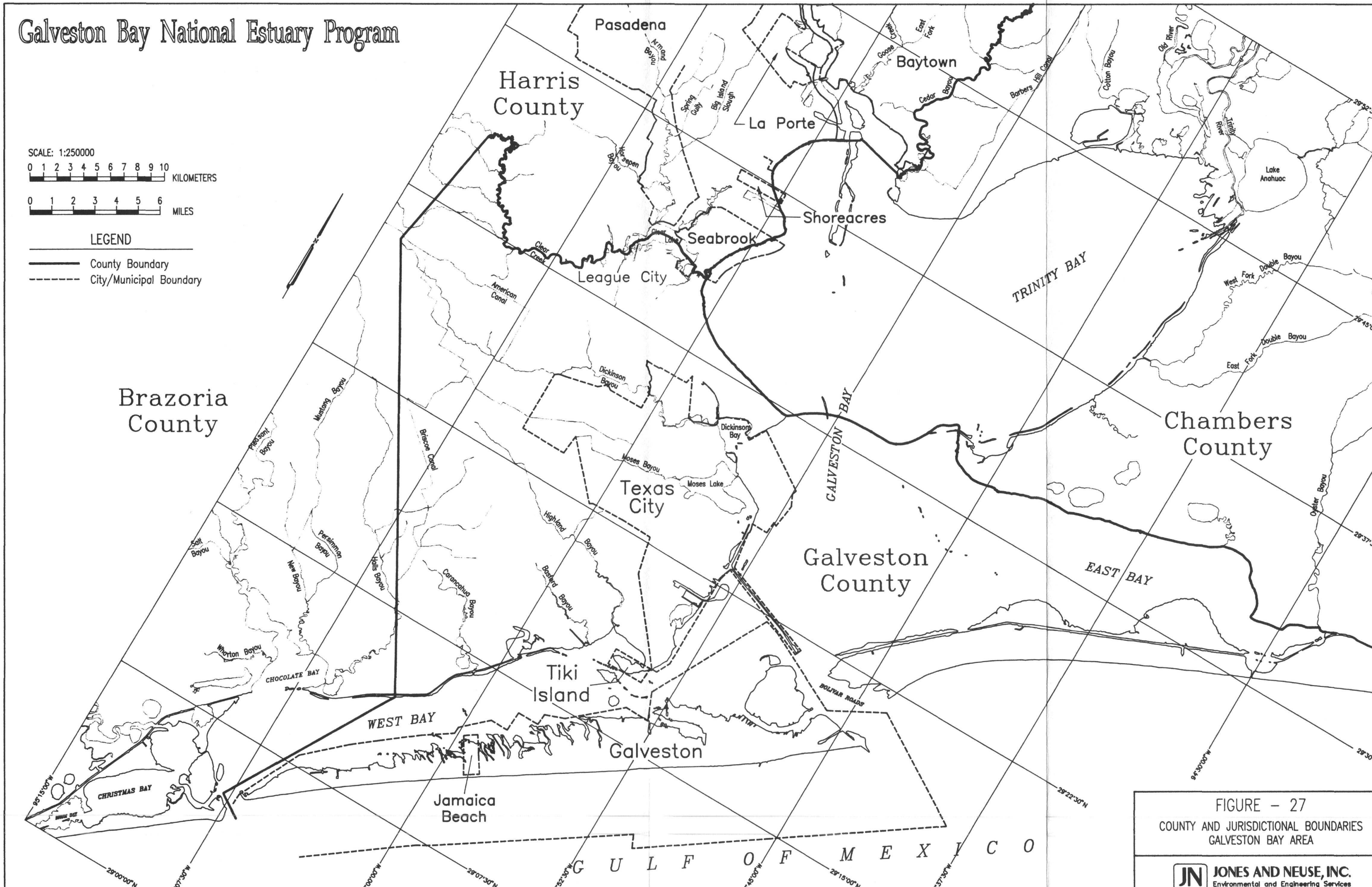


FIGURE – 27
COUNTY AND JURISDICTIONAL BOUNDARIES
GALVESTON BAY AREA

JN JONES AND NEUSE, INC.
Environmental and Engineering Services

4.0 SEGMENTATION DETERMINATION

This section details the procedure employed to assess both the existing segmentation in the Galveston Bay system and those segment boundaries proposed for inclusion in the final segmentation scheme.

4.1 Decision Matrix

Several segmentation schemes currently exist for Galveston Bay, particularly with respect to natural resources data. Both State and Federal natural resource agencies collect data for the management of resources within Galveston Bay. These segmentation schemes have evolved under differing criteria including monitoring designations, regulatory requirements, anthropogenic factors, natural resource distributions, and physical characteristics such as hydraulics. The focus of this project is to devise a segmentation scheme that accounts for as many of these needs and influences as possible while producing a manageable segmentation scheme.

To facilitate the conceptualization and visualization of the information employed in development of a segmentation scheme, a decision matrix was constructed. The decision matrix is basically a spreadsheet or ledger with rows comprised of the existing and proposed segments and boundaries. The columns in the matrix are the criteria for which the segments are evaluated. Ideally, the matrix would be based upon independent objective criteria which could be easily quantified. However, the characteristics traditionally measured and evaluated for a ecologically-complex living system such as an estuary are quite interrelated. As a result, the amount of correlation between the criteria in the decision matrix is considerable. For instance, the array of parameters measured to characterize water quality are to a large degree dependant upon other physical, anthropogenic, and hydrodynamic factors included in other criteria such as circulation patterns, bathymetry, and the quantity and quality of the waste loads to which the area is subject.

As a result, the decision matrix is largely qualitative in nature. Considerable effort was expended to score the matrix as objectively as possible. Much of the information synthesized for scoring each criteria is qualitative in nature and nonuniformly distributed in both time and space. As a result, some intuition was required in the scoring of the matrix. The effect of individual bias was minimized, to the extent possible, by employing a "committee" decision process for scoring the matrix among the members of the project team.

The decision matrix is shown in Table 4. The criteria employed in the matrix are discussed in sections 4.2.2 through 4.2.12 of this report. Except for a few exceptions discussed in the following section, most criteria were scored "H" for high, "M" for medium, and "L" for low indicating the positioning of particular areas along the gradient represented by a criterion relative to its potential impact upon segmentation.

4.2 Criteria

4.2.1 Simplicity

Obviously, any segmentation scheme that included boundaries to satisfy any and all conceivable criteria would result in a profusion of small segments. Management of the segment boundaries and their locations would be as big a difficulty as management of the estuary, a goal to which the segmentation scheme is intended to complement rather than confound. The criterion of simplicity is implicit in this analysis rather than explicit since this criterion applies across the segmentation scheme as a whole rather than to individual criteria. An effort was made to subdivide the system into as few segments as would adequately serve the purposes of this study and satisfy the criteria.

4.2.2 Jurisdictional and Administrative Boundaries

Within the criteria headings of the decision matrix, a distinction has been made between jurisdictional and administrative boundaries. Jurisdictional boundaries are defined as territorial limits that, at least approximately, define an entity's jurisdiction. Examples of jurisdictional boundaries are county boundaries and city limits (less the variable nature of

Table 4
Segmentation Decision Matrix

Segment or Boundary	Jurisdictional	Administrative	Physical Boundary	Ease of Location	Inflows	Channel	Current Pattern	Water Quality	Sediment Distribution	Biological	Anthropogenic Influence	Exceptional Resource
Upper Galveston Bay Area												
TWC 2421 Upper Galveston Bay		Y	M	M				M	M	H	M	
NMFS Area 3 Upper Galveston Bay		Y	M	M				M	M	H	M	
NMFS Area 3.1 SW Upper Galveston Bay		Y	L	L				M	L	M	M	
NMFS Area 3.2 W Upper Galveston Bay		Y	L	L				H	L	H	H	
NMFS Area 3.3 N Upper Galveston Bay		Y	M	L				H	L	H	H	
NMFS Area 3.4 SE Upper Galveston Bay		Y	L	L				M	M	M	M	
TDH Area 1 Conditionally Approved Area		Y	L	L				M	L	M	M	
TDH Galveston/Trinity Bay Closed Area		Y	L	L				M	L	H	M	
TDH Area 2 Conditionally Approved Area		Y	L	L				M	M	M	M	
UTCRWR Seg. G1			M	L				H	L	H	H	
UTCRWR Seg. G3			L	L				M	M	H	H	
UTCRWR Seg. G4			M	L				M	L	H	M	
UTCRWR Seg. G5			L	L				M	M	H	L	
UTCRWR Seg. G6			L	L	H				L		M	
UTCRWR Seg. G10			L	M				H	L	H	H	
UTCRWR Seg. G11			L	M				H	M	H	H	
UTCRWR Seg. G12			L	M				M	M	M	M	
UTCRWR Seg. G13			L	M				M	M	M	M	
UTCRWR Seg. G15			L	H		H		M	M	H	H	
UTCRWR Seg. G16			H	H		H		M	M	H	H	
UTCRWR Seg. G17			H	H		H		M	M	H	H	
UTCRWR Seg. G18			H	H		H		M	M	H	H	
UTCRWR Seg. G22			H	H				H	U	H	H	
UTCRWR Seg. G23			M	H				M	U	H	H	
UTCRWR Seg. G24			L	M				M	H	H	H	
UTCRWR Seg. G25			L	L				M	M	M	M	
UTCRWR Seg. G26			L	M				L	L	L	L	
Clear Lake Area												
TWC 2425 Clear Lake		Y	H	H				H	U	M	H	
UTCRWR Seg. C1			H	H				H		M	H	
UTCRWR Seg. C2			H	H				H	U	M	H	
UTCRWR Seg. C4			H	H				H		M	H	
UTCRWR Seg. C5			H	H				H	U	M	H	
TWC 1101 Clear Creek Tidal		Y	H	M				H		M	H	
Armand Bayou Area												
TWC 1113 Armand Bayou Tidal		Y	H	H				L		M	H	Y
UTCRWR Seg. C3			H	H				L		M	H	Y
Bayport Channel												
TWC 2438 Bayport Channel		Y	H	H		H	H	M		M	H	
UTCRWR Seg. G2			H	H		H	H	M		M	H	

Table 4 (cont.)
Segmentation Decision Matrix

Segment or Boundary	Jurisdictional	Administrative	Physical Boundary	Ease of Location	Inflows	Channel	Current Pattern	Water Quality	Sediment Distribution	Biological	Anthropogenic Influence	Exceptional Resource
Trinity Bay Area												
TWC 2422 Trinity Bay		Y	H	H	H			M	M	H	H	
NMFS Area 2 Trinity Bay		Y	H	H	H			M	M	H	H	
NMFS Area 2.1 Lower Trinity Bay		Y	L	M	M			M	M	H	H	
NMFS Area 2.2 Central Trinity Bay		Y	L	L	H			M	M	H	H	
NMFS Area 2.3 Upper Trinity Bay		Y	M	M	H			H	M	H	H	
TDH Area 3 Conditionally Approved Area		Y	L	L				M	H	M	M	
UTCRWR Seg. T1			L	L	M			M	M	H	H	
UTCRWR Seg. T2			L	L	M			M	M	H	H	
UTCRWR Seg. T3			L	L	H			M	L	H	H	
UTCRWR Seg. T4			L	L	M			L	U	L	M	
UTCRWR Seg. T5			L	L	M			L	U	M	M	
UTCRWR Seg. T6			L	L	H			H	U	H	H	
UTCRWR Seg. T10			L	L	M			M	M	M	H	
UTCRWR Seg. T11			L	L	M			M	M	M	H	
UTCRWR Seg. T12			L	L	H			M	M	H	H	
UTCRWR Seg. T14			H	H	M	H		M	M	H	M	
UTCRWR Seg. T15			H	H	M	H		M	M	H	M	
UTCRWR Seg. T16			H	H	M	H		M	M	H	M	
Cedar Bayou Area												
TWC 0901 Cedar Bayou Tidal		Y	H	H	M			H		M	H	
UTCRWR Seg. C6			H	H	M			H		M	H	
Trinity River												
TWC 0801 Trinity River Tidal		Y	H	H	H			H		H	H	
UTCRWR Seg. T7			H	L	H			H		H	H	
UTCRWR Seg. T8			H	M	H			H		H	H	
UTCRWR Seg. T9			H	H	H			H		H	H	
UTCRWR Seg. T13			H	L	H			H		H	H	
Double Bayou Area												
UTCRWR Seg. T17			H	H								
UTCRWR Seg. T18			H	M								
UTCRWR Seg. T19			H	M								

Table 4 (cont.)
Segmentation Decision Matrix

Segment or Boundary	Jusisdictional	Administrative	Physical Boundary	Ease of Location	Inflows	Channel	Current Pattern	Water Quality	Sediment Distribution	Biological	Anthropogenic Influence	Exceptional Resource
West Bay Area												
TWC 2424 West Bay		Y	H	H				M	L	H	M	
NMFS Area 1 West Bay		Y	H	H				M	L	H	M	
NMFS Area 1.1 Southeastern West Bay		Y	L	L				M	L	H	M	
NMFS Area 1.2 Northeastern West Bay		Y	L	L				M	L	H	H	
NMFS Area 1.3 East Central West Bay		Y	M	L				L	M	L	L	
NMFS Area 1.4 Central West Bay		Y	M	L				L	M	L	L	
NMFS Area 1.5 Western West Bay, Christmas Bay & Drum Bay		Y	M	H				L	M	L	L	
TDH Eastern West Bay Closed Area		Y	M	H				H	L	H	H	
UTCRWR Seg. W4			M	M				L	M	L	L	
UTCRWR Seg. W5			L	L				M	M	M	M	
UTCRWR Seg. W9			M	L				L	M	L	L	
UTCRWR Seg. W10			M	M				L	M	L	L	
UTCRWR Seg. W11			M	M				M	M	L	M	
UTCRWR Seg. W12			H	L				M		H	H	
UTCRWR Seg. W13			M	H				M	H	H	H	
UTCRWR Seg. W14			H	H				M	U	H	H	
UTCRWR Seg. W15			M	M		M		M	L	H	H	
Chocolate Bay Area												
TWC 2432 Chocolate Bay		Y	H	H			H	M	L	H	H	
NMFS Area 1.6 Chocolate Bay		Y	H	H			H	M	L	H	H	
TDH Chocolate Bay Closed Area		Y	H	H			H	M	L	H	H	
UTCRWR Seg. W6			M	H		H	H	M	M	H	H	
UTCRWR Seg. W7			H	H			H	M	L	H	H	
TWC 1107 Chocolate Bayou Tidal		Y	H	H				M		M	H	
UTCRWR Seg. W8			H	H				M		M	H	
Bastrop Bay/Oyster Lk.												
TWC 2433 Bastrop Bay/Oyster Lake		Y	H	H			H	L	H	L	L	
UTCRWR Seg. W2			H	H			H	L	H	L	L	
TWC 1105 Bastrop Bayou Tidal		Y	H	M				H		H	H	
UTCRWR Seg. W3			H	M				H		H	H	
Christmas Bay Area												
TWC 2434 Christmas Bay		Y	H	H			H	L	H	L	L	Y
UTCRWR Seg. W1			H	H			H	L	H	L	L	Y
Drum Bay Area												
TWC 2435 Drum Bay		Y	H	H				L	U	L	L	E

Table 4 (cont.)
Segmentation Decision Matrix

Segment or Boundary	Jurisdictional	Administrative	Physical Boundary	Ease of Location	Inflows	Channel	Current Pattern	Water Quality	Sediment Distribution	Biological	Anthropogenic Influence	Exceptional Resource
Lower Galveston Bay Area												
TWC 2439 Lower Galveston Bay		Y	M	M				M	L	H	H	
NMFS Area 5 Lower Galveston Bay		Y	M	M				M	L	H	H	
NMFS Area 5.1 SW Lower Galveston Bay		Y	H	H				M	L	H	H	
NMFS Area 5.2 W Lower Galveston Bay		Y	M	M				M	L	L	L	
NMFS Area 5.3 NW Lower Galveston Bay		Y	L	L				M	L	H	H	
NMFS Area 5.4 E Lower Galveston Bay		Y	L	L				M	L	L	L	
NMFS Area 5.5 Bolivar Roads		Y	M	M								
UTCRWR Seg. G7			L	M				M	L	H	H	
UTCRWR Seg. G8			L	M				M	M	H	H	
UTCRWR Seg. G9			M	M				M	L	L	L	
UTCRWR Seg. G14			L	M				M	L	H	H	
UTCRWR Seg. G19			L	H		H		M	M	M	H	
UTCRWR Seg. G20			L	H		H		M	M	M	H	
UTCRWR Seg. G21			L	H		H		M	M	M	H	
UTCRWR Seg. G27			L	L		M		M	L	L	L	
UTCRWR Seg. G28			L	L				M	L	L	L	
UTCRWR Seg. G29			L	L				M	L	L	L	
UTCRWR Seg. G30			L	L		M		M	L	M	M	
UTCRWR Seg. G31			L	L				M	L	L	L	
UTCRWR Seg. G32			L	L				M	L	L	L	
UTCRWR Seg. G33			H	H		H	H	M	M	M	M	
UTCRWR Seg. G34			H	H		M		M	L	H	H	
UTCRWR Seg. G37			H	H		H	H	M	M	H	H	
UTCRWR Seg. G38			H	H		H	H	M	M	H	H	
UTCRWR Seg. W16			M	M		M	H	M	L	H	H	
UTCRWR Seg. W17			M	M			H	M	L	H	H	
UTCRWR Seg. W18			M	H				M	H	H	H	
UTCRWR Seg. W19			H	H		H	H	M	H	H	H	
Dickinson Bay Area												
TWC 1103 Dickinson Bayou Tidal		Y	H	M				H		H	H	
UTCRWR Seg. D1			H	M				H		H	H	
UTCRWR Seg. D2			H	H			H	M	U	H	H	
UTCRWR Seg. D3			H	H			H	M	U	H	H	
Moses Lk./Dollar Bay												
TWC 2431 Moses Lake		Y	H	H			L	M	L	H	H	
UTCRWR Seg. D4			H	H			H	M	U	H	H	
UTCRWR Seg. D5			H	H			H	M	H	H	H	
Texas City Ship Channel												
TWC 2437 Texas City Ship Channel		Y	H	H		H		M		H	H	

Table 4 (cont.)
Segmentation Decision Matrix

Segment or Boundary	Jusisdictional	Administrative	Physical Boundary	Ease of Location	Inflows	Channel	Current Pattern	Water Quality	Sediment Distribution	Biological	Anthropogenic Influence	Exceptional Resource
Houston Ship Channel/ San Jacinto River Area												
TWC 1001 San Jacinto River Tidal		Y	H	M				H		H	H	
UTCRWR Seg. S1			H	M				H		H	H	
UTCRWR Seg. S2			H	H		M		H		H	H	
TWC 1005 Houston Ship Channel/ San Jacinto River		Y	H	H		H		H	M	H	V	
UTCRWR Seg. H1			H	H		H		H	M	H	V	
UTCRWR Seg. H7			H	H		H		H	M	H	V	
UTCRWR Seg. H11			H	H		H		H	M	H	V	
UTCRWR Seg. H12			H	H		H		H	M	H	V	
TWC 1006 Houston Ship Channel		Y	H	H		H		H	M	H	V	
UTCRWR Seg. H13			H	H		H		H	M	H	V	
UTCRWR Seg. H14			H	H		H		H	M	H	V	
UTCRWR Seg. H15			H	H		H		H	M	H	V	
TWC 1007 Houston Ship Channel/ Buffalo Bayou		Y	H	H		H		H	M	H	V	
UTCRWR Seg. H16			H	H		H		H	M	H	V	
UTCRWR Seg. H17			H	H		H		H	M	H	V	
UTCRWR Seg. H18			H	H		H		H	M	H	V	
UTCRWR Seg. H19			H	H		H		H	M	H	V	
UTCRWR Seg. H20			H	H				H		H	V	
Tabbs Bay												
TWC 2426 Tabbs Bay		Y	M	M				M	L	M	H	
UTCRWR Seg. H3			H	H				M	L	M	H	
San Jacinto Bay												
TWC 2427 San Jacinto Bay		Y	H	H				M	U	M	H	
UTCRWR Seg. H5			H	H				M		M	H	
UTCRWR Seg. H6			H	H				M		M	H	
Black Duck Bay												
TWC 2428 Black Duck Bay		Y	H	H				M		M	M	
UTCRWR Seg. H4			H	H				M		M	M	
Scott Bay												
TWC 2429 Scott Bay		Y	H	H				M		M	M	
UTCRWR Seg. H8			H	H				M		M	M	
Burnett Bay												
TWC 2430 Burnett Bay		Y	H	H				M		M	M	
UTCRWR Seg. H9			H	H				M		M	M	
Barbors Cut												
TWC 2436 Barbors Cut		Y	H	H				M	U	M	M	
UTCRWR Seg. H2			H	H				M	U	M	M	

Table 4 (cont.)
Segmentation Decision Matrix

Segment or Boundary	Jusisdictional	Administrative	Physical Boundary	Ease of Location	Inflows	Channel	Current Pattern	Water Quality	Sediment Distribution	Biological	Anthropogenic Influence	Exceptional Resource
East Bay Area												
TWC 2423 East Bay		Y	H	H			H	L	M	M	M	
NMFS Area 4 East Bay		Y	H	H			H	L	M	M	M	
NMFS Area 4.1 Lower East Bay		Y	M	M				L	M	L	M	
NMFS Area 4.2 Upper East Bay		Y	M	M				M	L	H	H	
TDH Eastern East Bay Closed Area		Y	M	H				H	L	H	H	
UTCRWR Seg. E1			M	M				L	M	L	M	
UTCRWR Seg. E2			M	M				L	M	L	M	
UTCRWR Seg. E3			M	M				L	M	L	M	
UTCRWR Seg. E4			M	M				M	L	H	H	
UTCRWR Seg. E5			M	M		M		M	L	H	H	
UTCRWR Seg. E6			M	M				M	L	H	H	
UTCRWR Seg. E7			H	H								
UTCRWR Seg. E8			H	H								
UTCRWR Seg. E9			H	H		H		M		M	H	
UTCRWR Seg. E10			H	H		H		M		M	H	
Boundaries												
Texas General Land Office State Land Tract System		Y										
Harris/Chambers County Galveston Bay/Tabbs Bay	Y											
Harris/Chambers County Galveston Bay/HSC	Y											
Harris/Galveston County Clear Lake	Y											
Galveston/Chambers County Upper/Lower Galveston Bay	Y											
Brazoria/Galveston County Western West Bay	Y											
City of Houston HSC/San Jacinto River	Y											
City of Baytown Goose Creek/HSC	Y											
City of La Porte Lower San Jacinto Bay	Y											
City of La Porte Upper San Jacinto Bay	Y											
City of La Porte Santa Anna Bayou	Y											
City of Shoreacres Galveston Bay	Y											
City of Seabrook Galveston Bay	Y											
City of Seabrook Clear Lake	Y											
City of Seabrook Taylor Lake	Y											
City of Pasadena Armand Bayou	Y											
City of Nassau Bay Clear Lake	Y											
City of League City Clear Lake	Y											

Table 4 (cont.)
Segmentation Decision Matrix

Segment or Boundary	Jusisdictional	Administrative	Physical Boundary	Ease of Location	Inflows	Channel	Current Pattern	Water Quality	Sediment Distribution	Biological	Anthropogenic Influence	Exceptional Resource
City of Clear Lake Shores Clear Lake	Y											
City of Texas City Galveston Bay	Y											
City of Texas City Dickinson Bayou	Y											
City of Texas City Dickinson Bay	Y											
City of Texas City Moses Lake & Dollar Bay	Y											
City of Texas City Texas City Ship Channel	Y											
City of Texas City Texas City Dike	Y											
Village of Tiki Island Jones Bay	Y											
Village of Tiki Island West Bay	Y											
City of Jamaica Beach West Bay	Y											
City of Galveston Galveston Bay	Y											
City of Galveston West Bay	Y											
City of Galveston Bolivar Roads	Y											
City of Galveston Gulf of Mexico	Y											
Texas City Dike			H	H			H					
Hanna Reef			H	M			H					
Shear Boundary along HSC			L	L			H					
Carancahua Reef			H	M			H					

extraterritorial jurisdiction). Administrative boundaries are boundaries separating subareas within an entities jurisdiction. Most of the existing segmentation encompass this function as one criterion.

4.2.3 Physical Boundaries

In terms of estuary segmentation, physical boundaries are usually shorelines or the mean high tidal limit. Since water is a fluid medium, one of the major constraints to fluid movement and circulation patterns are physical or morphological boundaries. Emphasis was placed upon defining segments, where possible, that were at least partially determined by physical boundaries.

Included as physical boundaries are geographic features such as shorelines, points, promontories, peninsulas, dikes, seawalls, breakwaters, and islands. Also included are hydrographic boundaries such as reefs and shoals. While not absolute barriers to hydraulic transport, their influence in determining circulation patterns and, concomitantly, other chemical and biological characteristics of an area is considerable.

In the context of this study, the Texas City Dike is an excellent example of a geographic boundary that greatly influences the circulation patterns in the area. Carancahua Reef is an equally good example of a hydrographic boundary that splits West Bay into two circulation cells. The cell on the west side of the reef is predominated by circulation from San Luis Pass while the circulation cell on the east side of the reef is predominated by Galveston Bay and Bolivar Roads circulation.

4.2.4 Ease of Location

Boundaries should be determinable in the field to be of maximum utility for monitoring or regulation. In segmenting an estuary the size of the Galveston Bay system, it is inevitable that some boundaries must cross expanses of open water. Preference was given to boundaries and potential boundaries that were definable from discernable landforms or landmarks.

areas adjacent. Despite it's variable nature, water quality is one of the most important criteria for segmentation, since water quality is one of the features estuarine management is intended to protect.

4.2.9 Sediment Distribution

Sediment distribution patterns are a valuable characteristic to be considered in a segmentation scheme for an estuary. Substrate characteristics play an important role in determining species distributions for benthic organisms and, to some extent, their demersal predators. Sediment distributions are reflective of many other characteristics of an area in an estuary including circulation patterns, bathymetry, turbulence and wave action, inflow characteristics, and surrounding land types and uses. Relative to characteristics of the water column, they are less dynamic. Sediment quality has been related to historical changes over many centuries.

Sediment distribution and uniformity was assessed for each existing and proposed segment. Preference was given for segments that exhibit a higher degree of sediment uniformity or a sediment distribution differing from its neighbor. The scoring in the matrix was based upon the following:

U - total uniform sediment distribution
H - high uniformity sediment distribution
M - medium uniformity sediment distribution
L - low uniformity sediment distribution.

4.2.10 Biological

The biological criterion in the decision matrix is a compendium of biological information available from a number of sources. The criterion reflects an assessment of reported biological problems in the area such as fish kills, TDH closed areas, TWC aquatic life uses, and, where available, species assemblage data. As such, it represents an admittedly crude biological risk assessment based upon available information. The criterion was scored high, medium, and low. As an example, areas that reported by TWC as not meeting "fishable" criteria were automatically scored high.

4.2.11 Anthropogenic Influence

This criterion is a qualitative assessment of human-induced input to the area. The bulk of the information utilized was from the TWC records and documents pertaining to point and non-point sources in the area. In addition, on-shore population density and land uses, dredge spoil locations, channelization and ship traffic, and locations of oil production areas were considered. The criteria was scored high, medium, and low as were most other criteria with the addition of "V" for areas of very high impact.

4.2.12 Exceptional Resource

This criterion was included to account for areas that have been designated as coastal preserves or that exhibit characteristics that, due largely to their relatively unimpacted state, may exhibit exceptional aquatic life uses or be potential coastal preserves. The criteria was scored with a "Y" for areas that are coastal preserves and "E" for areas of apparent exceptional resource value.

4.3 Proposed Segmentation

Of the existing segmentation schemes reviewed, the TWC scheme and the CRWR scheme, which was a hydrographic subdivision of the TWC scheme satisfied the criteria the best. This is not particularly surprising, since the TWC segmentation scheme encompasses a number of criteria and uses including administrative and monitoring. The TWC segmentation scheme subdivides the study area for this project into 29 segments as shown in Figures 3 and 4. The results of this study subdivide the area into 44 segments described subsequently. The resulting segmentation is shown on Figures 28 and 29.

4.3.1 Lower Galveston Bay Area

As indicated in Figure 28, the lower Galveston Bay area was subdivided into four segments labeled LG1 through LG4. The most prominent change was the designation of LG3. The LG3 segment is a one kilometer wide segment that encloses the Houston Ship Channel as it passes through lower Galveston Bay. There are several prominent reasons this segment was designated. The comparatively deep Houston Ship Channel is a flow conduit in Galveston Bay and influences circulation and salinity patterns. Inspection of Figure 10 from the TWDB reveals that modeling predicts a shear boundary that coincides with the Houston Ship Channel and divides the Bay into sections of average inflow velocities and average outflow velocities driven by the Coriolis effect in the Bay. In addition, the area is one with high anthropogenic influence from shipping, dredging, and outflow from the heavily impacted upper Channel.

Segments LG1 and LG2 lie to either side of segment LG3. There are significant differences between LG1 and LG2, mostly due to human impact. LG1 is part of the area in Lower Galveston Bay that is closed to oystering by the TDH, whereas LG2 is predominantly open to oystering. LG1 receives more direct industrial impact from onshore land uses than does LG2. In addition, LG2 is adjacent to the Abshier wildlife management area.

The northern boundaries of segments LG1, LG2, and LG3 were established to coincide with the TWC boundary between upper and lower Galveston Bays. This boundary location can be justified for several reasons including salinity pattern variations modeled by the TDWR described in section 3.5.2, and a jurisdictional boundary defined by the chambers and Galveston County lines. The NMFS established a boundary here used to report commercial fishery statistics prior to 1976 (Section 3.10).

Segment LG4 encompasses Bolivar Roads, an area of relatively high tidal velocities and direct marine influence. Pelican Island and the Port Bolivar Peninsula create a hydrographic barrier between segment LG4 and the remainder of the lower Glaveston Bay segments. Figure 28 also indicates that the area to the west of the Texas City Dike was included in West Bay rather than Galveston Bay. From a hydrographic standpoint, the area is more related to West Bay than Galveston Bay due to the placement of the manmade barrier of the Texas City Dike.

4.3.2 Upper Galveston Bay Area

The upper Galveston Bay area was segmented into six segments. Segments UG3 and UG6 encompass the Houston Ship Channel and were created for the same reasons as LG3 described previously. The segment boundary between UG3 and UG6 (as well as between UG6 and LG3) was established to take into account any water quality or biological differences that might be invoked due to it's proximity to adjacent segments. Segments UG1 and UG2 were divided from the body of upper Galveston Bay largely because they receive direct inflow from the upper reaches of the Houston Ship Channel. They were divided from each other along Atkinson Island which forms a partial hydraulic barrier. Dredge spoil piles along the eastern edge of segment UG3 enhance the barrier between the Houston Ship Channel and segment UG2.

Segments UG4 and UG5 are divided by the Houston Ship Channel segment UG6. Segment UG4 is either closed or only conditionally approved for shellfish harvesting by the TDH. The adjacent shore of segment UG4 is highly populated and developed. Segment UG5 has virtually no shoreline and is influenced heavily by its connection to Trinity Bay. The eastern boundary of segment UG5 corresponds to that established by the TWC. It's position can be based partially on salinity patterns predicted through modeling as described in Section 3.5.3 This boundary also matches one of several established by the Center for Research in Water Resources (CRWR) for the purpose of tracking typical plumes of run-off from the Trinity River described in more detail in Ward, 1991.

4.3.3 Trinity Bay Area

The TWC segmentation scheme includes Trinity Bay as a single segment. Trinity Bay has been divided into three segments along the inflow gradient of the Trinity River. The various inflow studies from the TWDB indicate the Trinity River inflow as the predominant freshwater inflow to the Galveston Bay system. Both NMFS and CRWR have divided Trinity Bay into approximately the same segments. The boundary between TB1 and TB2 coincides with the boundaries between the GLO land tracts, 51/50, 52/49, 53/48, 54/47, 55/46, 56/45, 57/44, 58/43, 59/42, and 60/41 in Trinity Bay. The boundary between TB2 and TB3 coincides with the boundaries between the GLO land tracts, 18-19D/22-23C, 18-19C/22-23C, 18-19B/22-23B, 18-19A/22-23A, 17-20A/21A, 20B/21B, 20C/21C, and the northeastern border of 20D in Trinity Bay. In addition, the TWC definition of the Trinity River tidal segment from its confluence with Trinity Bay to the tidal limit was preserved and is identified in Figure 28 as TR1. The western boundary of segment TB1 was established for salinity and run-off plume modeling as sited in previous Section 4.3.2. Each of the transverse boundaries chosen for Trinity Bay approximate those used by the CRWR for plume modeling.

4.3.4 East Bay

The TWC segmentation includes East Bay as a single segment. East Bay was divided into two segments EB1 and EB2 along the boundary of the TDH closed area. Consideration was given to redefining the border between East Bay and lower Galveston Bay (segments EB1 and LG2) along Hanna Reef. Hanna Reef, as a hydrographic feature, directs flow into and out of East Bay. However, the existing TWC boundary was relocated in the past to account for the influence of Hanna Reef, and parts of the proposed segment boundary would have been difficult to locate in the field. The TWC segment 2423 encompassing East Bay was preserved as segment EB1.

4.3.5 West Bay

Probably the most significant changes in segmentation were made to West Bay. The area encompassed by segment WB1 was previously part of lower Galveston Bay in the TWC segmentation scheme. The partial occlusion of the inter-bay circulation patterns by Pelican Island and the Texas City Dike make this area hydraulically more related to West Bay than Galveston Bay. The boundary between WB1 and WB2 was originally intended to be the IH 45 Causeway. However, the boundary was relocated to the Deer Island/Tiki Island area at the suggestion of TWC staff that have many years experience in sampling and monitoring the area. (Kirkpatrick, 1991, personal communication) The Deer Island/Tiki Island area is shallower, has many small islands and spoil banks, and is probably more of a hydraulic constraint than the causeway.

West Bay was divided approximately in half along Carancahua Reef (or Caranachua Reef) since it forms a predominant hydraulic boundary. Segment WB3 encompasses the western end of West Bay to the west of Carancahua Reef. The TWC boundaries for Christmas Bay, Drum Bay, Bastrop Bay, and Chocolate Bays were preserved and are identified in Figure 28 as WB4, WB5, WB6, and WB7, respectively.

4.3.6 Moses Lake/Dollar Bay Area

TWC Segment 2431 that includes Moses Lake and Dollar Bay was preserved as segment ML1 as shown in Figure 28.

4.3.7 Clear Lake Area

TWC Segments 2425 (Clear Lake), 1101 (Clear Creek), and 1113 (Armand Bayou), contained in the Clear Lake watershed were preserved as segments CL1, CL2, and CL3, respectively. These are shown in Figure 28.

4.3.8 Tidal Bastrop Bayou and Chocolate Bayou

The two tidal TWC segments, Bastrop Bayou (Segment 1105) and Chocolate Bayou (Segment 1107), were preserved and identified in Figure 28 as BB1 and CB1, respectively. Bastrop Bayou enters Bastrop Bay and Chocolate Bayou enters Chocolate Bayou.

4.3.9 Houston Ship Channel Area

The three TWC segments (1005,1006, and 1007) that comprise the upper Houston Ship Channel were preserved and are identified in Figure 29 as HC1, HC2, and HC3, respectively. The San Jacinto River tidal segment from immediately below IH 10 in Harris County to the tidal limit was maintained and is indicated in Figure 29 as SJ1.

As indicated in Figure 29, most of segments enclosing the lateral bays along the Houston Ship Channel have been preserved. The exception is the addition of LB7 which contains Old River. This segment was included since it forms an alternate hydraulic channel between two other segments, HC1 and HC2.

4.3.10 Texas City Ship Channel

The TWC segment 2437 was preserved and identified in Figure 28 as TC1.

4.3.11 Dickinson Bay/Dickinson Bayou

Dickinson Bay, included in TWC Lower Galveston Bay segment 2439 was delineated as a separate segment DB1 due to a salinity gradient predicted by modeling (TDWR 1981). In addition, a hydrographic barrier is created by oyster reefs as shown in Figure 5.

The TWC segment 1103 which identifies the tidal portion of Dickinson Bayou was preserved as segment DB2.

4.3.12 Bayport Channel (Tidal)

The TWC segment 2438 was preserved as segment BC1.

4.3.13 Cedar Bayou (Tidal)

The TWC segment 0901 was preserved as segment CD1.

4.3.14 Intracoastal Waterway

The approximately 18 mile section of the Intracoastal Waterway passing through the Bolivar Peninsula has been added as segment IW1. The isolated character of this waterbody would create water quality and biological variations that are distinct from the other portions of the bay.

Galveston Bay National Estuary Program

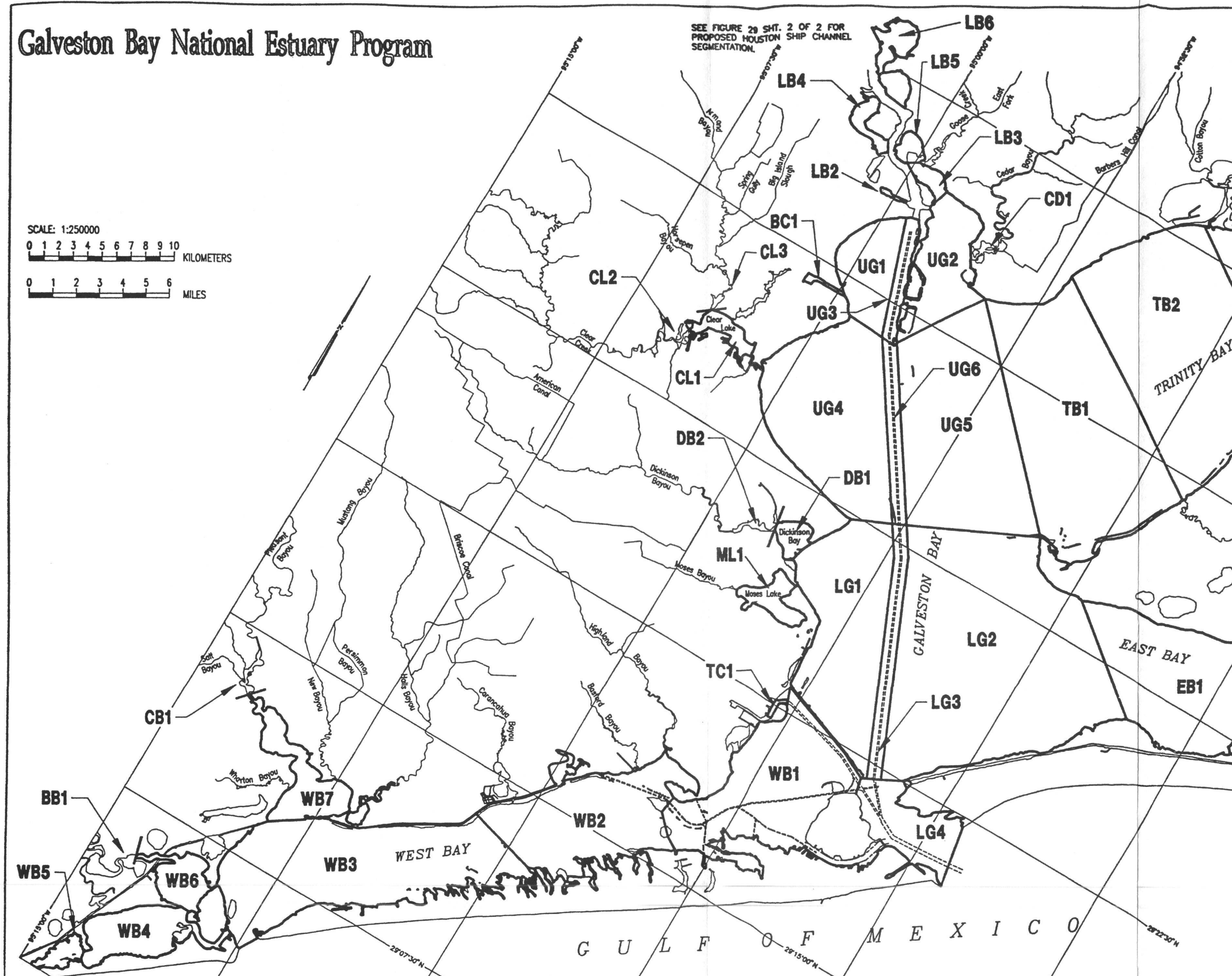


FIGURE – 28
PROPOSED SEGMENTATION FOR GALVESTON BAY, GALVESTON EAST, WEST & TRINITY BAY
SHEET 1 OF 2

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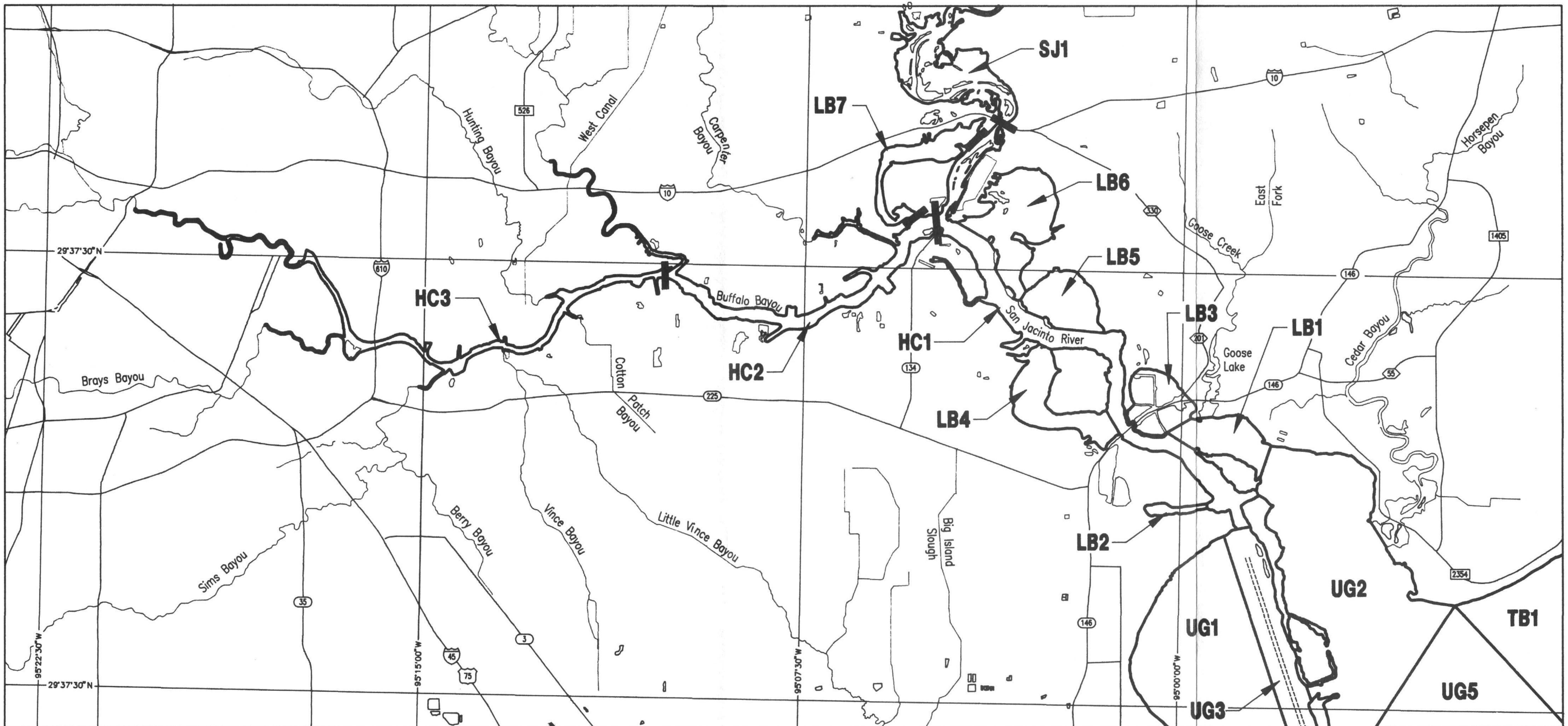
Galveston Bay National Estuary Program

SEE FIGURE 28 SHT. 1 OF 2 FOR GALVESTON BAY AREA SEGMENTATION.



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0 1 2 3 4 5 6 7 KILOMETERS

0 1 2 3 4 MILES

FIGURE – 29
PROPOSED SEGMENTATION
HOUSTON SHIP CHANNEL
SHEET 2 OF 2

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Environmental and Engineering Services

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