Characterization of Selected Public Health Issues in Galveston Bay

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EXECUTIVE SUMMARY

The purpose of this project is to characterize public health issues associated with bay use activities such as shellfish consumption and contact and non-contact recreation. The major objectives of this characterization study are:

1. Review and summarize activities associated with shellfish bed closures,

2. Identify and characterize sources of bacterial contamination,

3. Review and characterize areas of Galveston Bay which have exceeded water quality standards for contact and non-contact recreation, and

4. Assess the incidence of known pathogenic organisms such as Vibrio Vulnificus.

The characterization includes consideration of indicator organisms and known pathogenic organisms and covers all identified water quality segments of Galveston Bay.

The report is an analysis of existing data obtained from agencies involved with public health protection and regulation--the Texas Department of Health (TDH) and the Texas Water Commission (TWC) as well as information provided by Galveston and Harris counties, the City of Houston, and numerous other sources. There are six major sections in this report. The first is is an introduction which provides an overview of the project. The second section briefly introduces and compares indicator organisms used by various agencies, and their relation with pathogens. The EPA and Texas water quality criteria for indicator organisms are reviewed as well as a brief historical review of the National Shellfish Sanitation Program (NSSP). A more detailed analysis of the TDH implementation of the NSSP is the subject of Section 3.0. Section 4.0 focuses on sources of bacterial input to Galveston Bay. The objective is to analyze and quantify to the extent practical the contribution of indicator organisms to Galveston Bay from a range of sources. Section 5.0 is an analysis of available indicator organism data, including spatial and temporal patterns. Section 6.0 describes an investigation of the possible relationship between indicator organism levels and known pathogenic microorganisms in Galveston Bay. Among the pathogens, Vibrios are of primary concern because of their medical significance and their ability to be transmitted through various contact and noncontact recreational activities as well as the consumption of seafood.

The major conclusions, described in more detail in each section, include:

1. While many changes have taken place over the years in shellfish harvesting regulation, there have been no major changes in the areas closed to shellfish

harvesting. Analyses on the coliform data show that many areas classified as "polluted" or closed to shellfish harvesting do not have high long-term mean indicator levels. The classification is generally a result of either a small portion of the data exceeding higher values, generally after rains, or a judgement made about the potential for upland facilities to introduce pathogens.

2. All open bay areas of Galveston Bay conform to current Texas water quality criteria for contact recreation. The only areas whose overall long-term median FC levels exceed the 200 col/dL contact recreation criteria are inland areas: Houston Ship Channel, Houston area bayous (Greens, Sims, Hunting, Brays, Buffalo, Clear Creek), Dickinson Bayou and Bastrop Bayou Tidal.

3. From admittedly noisy coliform bacteria data, which are available back to roughly 1950, no change could be detected over time that could be associated with watershed development activities.

4. As an indicator of the possible presence of human wastes and thus diseases associated with human waste, the total and later FC bacteria tests have a long and quite successful history. However, over the last several decades, it is becoming increasingly obvious that the tests have numerous limitations. These include frequent "false positives" - essentially naturally occurring bacteria which "pass" the test, failure to correlate with pathogens directly measured in some studies, and failure to provide an alert for naturally occurring pathogenic microorganisms.

5. Among the sources of indicator bacteria loadings to the Galveston Bay, wet weather runoff contributes the most significant amount. However, due to the die-off rate of bacteria, high concentrations in the bay tend to be localized and of short duration.

6. No significant correlation between indicator bacteria levels and incidents of Vibrio diseases could be found in the data.

1.0 INTRODUCTION

The purpose of this project is to characterize public health issues associated with bay use activities such as shellfish consumption and contact and non-contact recreation. The major objectives of this characterization study are:

1. Review and summarize activities associated with shellfish bed closures,

2. Identify and characterize sources of bacterial contamination,

3. Review and characterize areas of Galveston Bay which have exceeded water quality standards for contact and non-contact recreation, and

4. Assess the incidence of known pathogenic organisms such as Vibrio Vulnificus.

The characterization includes consideration of indicator organisms and known pathogenic organisms and covers all identified water quality segments of Galveston Bay. Existing data that were employed in this work included:

Texas Department of Health (TDH)

- Indicator bacteria data computer files and paper listings,
- Shellfish classification maps showing each change in Shellfish harvesting area boundaries, and
- Files of Vibrio and other pathogen identifications;

Texas Water Commission (TWC)

- Machine readable copy of Statewide Monitoring Network (SMN) data (coliforms, temperature, salinity) for selected stations in the bay, along with paper copy of above for data checking, and
- Paper listing of files for all permitted point sources discharging to the listed bay segments.

There are six major sections in this report. The first is this introduction which provides an overview of the project. The second section briefly introduces and compares indicator organisms used by various agencies, and their relation with pathogens. In addition, the Environmental Protection Agency (EPA) and Texas water quality criteria for indicator organisms are reviewed. A brief historical review of the National Shellfish Sanitation Program (NSSP) concerning the use of indicator organisms for the classification of shellfish growing waters is also included in Section 2.

Section 3 of this report summarizes the TDH implementation of the requirements of the NSSP for segments in Galveston Bay. The objective is to review current and historical regulations and shellfish classification boundaries. The review included:

1. TDH regulatory procedures (NSSP),
2. historical maps showing prohibited shellfish growing areas,
3. trends of bay areas in terms of prohibited, conditionally approved, and approved growing areas,
4. differences in prohibited areas with change from total to fecal coliform as regulatory criteria,
5. current classifications of bay areas,
6. TDH monitoring and management practices,
7. a comparison of measurement techniques for coliform bacteria, and
8. comparison of the Texas program with those in other coastal states.

Section 4 focuses on sources of bacterial input to Galveston Bay. The objective is to analyze and quantify to the extent practical the contribution of indicator organisms to Galveston Bay from a range of sources. The sources considered include:

1. permitted wastewater discharges,
2. wastewater collection system leaks, overflows and excursions,
3. partially treated wastewaters from failed septic systems, and
4. runoff from watershed areas.

Section 5 documents results from analyzing both total and FC data from the TDH, TWC and predecessor agencies, including the Texas Water Quality Board (TWQB, the old Galveston Bay Project) for the Galveston Bay system. This section starts with a brief description of the sub-segmentation of the Galveston Bay segments into quadrilaterals. Statistical and regressional analyses on the historical coliform data and comparisons are described with various indicator bacteria criteria. The relationship between total and FC was investigated based on long-term geometric means of the data. Finally, the collected coliform data are used to investigate possible temporal trends for several representative quadrilaterals in the open bay areas.

Section 6 describes an investigation of the possible relationship between indicator organism levels and known pathogenic microorganisms in Galveston Bay. Among the pathogens, Vibrios are of primary concern because of their medical significance and their ability to be transmitted through various contact and noncontact recreational activities as well as the consumption of seafood. The first part of this section is a description of Vibrio bacteria. Next, data obtained from TDH on the incidents of Vibrio infections in Texas were analyzed and reported. The relationship between these incidents and FC data was then explored. Finally, brief investigation was performed to determine the existence of data about other known diseases which are associated with shellfish consumption.

There are two appendices attached to this report. The first is a copy of the available historical shellfish classification maps published by TDH. The second is a detailed description of indicator organism testing procedures. The shellfish classification maps in ARC-INFO format are provided to the GBNEP in diskettes under separate cover.

2.0 INDICATOR ORGANISMS AND WATER QUALITY CRITERIA

2.1 INTRODUCTION OF INDICATOR BACTERIA

The goal of public health regulation is to limit human exposure to pathogens in water. It would be the best if pathogens can be monitored directly. Ideally, monitoring programs to support public health protection specifically for activities such as shellfish consumption and contact recreation, would measure pathogens directly. Instead, indicator organisms have been used for regulatory purposes, especially for recreational and shellfish growing waters.

Cabelli (1977) noted that the best indicator organism should be the one whose densities correlate best with health hazards associated with one or several given types of pollution sources. He also listed the requirements for an indicator as follows:

A. The indicator should be consistently and exclusively associated with the source of the pathogens.

B. It must be present in sufficient numbers to provide an accurate density estimate whenever the level of each of the pathogens is such that the risk of illness is unacceptable.

C. It should approach the resistance to disinfectants and environmental stress, including toxic materials deposited therein, of the most resistant pathogen potentially present at significant levels in the sources.

D. It should be quantifiable in recreational waters by reasonably facile and inexpensive methods and with considerable accuracy, precision, and specificity.

These requirements provide a basis to compare available indicators for water quality monitoring.

The objective of this session is to give a brief description of the indicator organisms and their relations with pathogens. The organisms discussed include total and FC, E. coli, fecal streptococcus, and enterococcus, which have been used as indicators in either EPA guidance or state water quality standards. In addition, the EPA 1986 water quality criteria for bacteria, the Texas water quality criteria for contact and noncontact recreational waters, and the water quality criteria for shellfish growing waters by the National Shellfish Sanitation Program (NSSP) are also discussed in this section.

2.1.1 Total and Fecal Coliform

By definition (Standard Methods, 1989), the total coliform (TC) group comprises all aerobic and facultative anaerobic, gram-negative, nonspore-forming, rod-shaped bacteria that ferment lactose with gas and acid formation within 48 hours at 35°C. Fecal coliform (FC) are defined as those coliforms which respond at an elevated temperature of 44.5°C. Thus a more accurate name for organisms which show positive on the FC test would be heat tolerant coliforms.

Among the coliform group, there are four genera in the Enterobacteriaceae family, Escherichia, Klebsiella, Citrobactor, and Enterobacter (Metcalf and Eddy, 1991). Some of these genera are common in the intestinal tract of mammals (e.g. Escherichia coli and others are common in soil and on the surface of plants e.g. Klebsiella).

In addition to other kinds of bacteria, each person produces from 100 to 400 billion coliform organisms per day (Metcalf and Eddy, 1991). Since historically the primary public health concern has been diseases transmitted through human wastes, the absence of coliform organisms is taken as an indication that a sample is free of disease-producing organisms. After being isolated and associated with the fecal wastes of warm-blooded animals in late 1800s and early 1900s (Cabelli, 1977), coliforms have been used as indicators for indexing health hazards in drinking and recreational waters.

Coliforms have also shown a measure of correlation with pathogens. For example, Geldreich (1978) found that for FC concentrations less than 200/dL, (100 mL = 1 dL) Salmonella occurrences ranged from 6.5 to 31%. However, at FC concentrations greater than about 1000/dL, the frequency of Salmonella occurrence doubled. For recreational lakes and streams with FC levels from 1 to 200/dL, Salmonella occurred in 28% of the water samples. When FC were about 1000/dL, Salmonella occurrence was 96%.

On the other hand, there are many bacterial species of the four main genera which are common in soil and on the surface of plants which respond positively to the TC or FC test (Dufour 1977; Cabelli, et al., 1982). FC positive results have been found in numerous food processing industry wastes (EPA, 1986) and fish growing ponds (De La Cruz, 1992) all with no mammalian waste sources. Elevated levels are also found in runoff from agricultural fields with very limited mammalian and avian population and have been documented to grow in higher organic strength waters (Jensen, Ritter, and Tyrawski, 1977).

A common theme of these results would appear to be elevated concentratons of organic materials from a wide range of sources can support bacterial populations, a portion of which are capable of responding positively to the TC and FC tests. This would indicate that the TC/FC test does not meet Cabelli's first requirement for a good indicator organism -- consistent and exclusive association with a pathogen source.

2.1.2 Escherichia Coli

Escherichia coli is a member of the coliform bacteria population that may be used to indicate fecal sources. It is a normal and dominant inhabitant of the mammalian digestive tract. However, disease-causing strains of E. coli specie have been isolated from tap water, drinking water sources, and mountain streams (Standard Methods, 1989). Examination of pathogenic E. coli is not easy due to the uncertainty in determining the pathogenic nature of isolated E. coli strains. There is no biochemical marker that can separate pathogenic from non-pathogenic strains and the relationship between serotype and pathogenicity is questionable (Standard Methods, 1989).

The use of E. coli as an indicator organism is somewhat restricted by the fact that (Tchobanoglous and Schroeder, 1985) (1) E. coli is not a single species, (2) certain genera of the coliform group such as Proteus and Aerobacter are normally found outside the human intestinal tract in soil, (3) other organisms found in water that do not represent fecal pollution possess some of the characteristics attributed to E. coli, and (4) E. coli identical to that found in humans is also found in the intestinal tract of other warm-blooded animals. However, primarily because studies had shown that E. coli was a much better indicator of disease risk than was FC, EPA (1986) has recommended that E. coli be used as a criteria for classifying waters for fresh water contact recreation.

2.1.3 Fecal Streptococcus

The fecal streptococcus (FS) group consists of a number of species of the genus Streptococcus. They are characterized as gram-positive, cocci bacteria which are capable of growth in brain-heart infusion broth. In the laboratory they are defined as all the organisms which produce red or pink colonies within 48 hours at 35 $\pm$ 1.0°C on KF-streptococcus medium (Standard Methods, 1989). The normal habitat of FS is the gastrointestinal tract of warm-blooded animals so that the presence of them is an indication of contamination of fecal wastes.

FS have been used together with FC to differentiate human fecal contamination from that of other warm-blooded animals. A ratio of FC to FS greater than four was considered indicative of human fecal contamination, while a ratio of less than 0.7 was suggestive of contamination by nonhuman sources (Standard Methods, 1989). This differentiation has been questioned (Dutka and Kwan, 1980) because of variable survival rates of fecal streptococcus group species. Also, disinfection of wastewaters have a significant effect on the ratio of these indicators, which may result in misleading conclusions regarding the source of contaminants. The ratio is also affected by the methods for enumerating FS.

The KF membrane filter procedure has a false-positive rate ranging from 10 to 90% in marine and fresh waters (Standard Methods, 1989). Due to all these reasons, the FC versus FS ratio is of questionable utility in differentiating human and nonhuman sources of positive coliform test results.

2.1.4 Enterococcus

The enterococcus group includes two strains of the FS that is most human specific. These are S. faecalis and S. faecium (Metcalf and Eddy, 1991). They can be differentiated from other streptococci by their ability to grow in 6.5% sodium chloride, at pH 9.6, and at both 10°C and 45°C. Studies at marine and fresh water bathing beaches indicated that swimming-associated gastroenteritis was related directly to the quality of the bathing water and that enterococci were the most efficient bacterial indicator of water quality (Standard Methods, 1989; EPA, 1986). In fact, S. faecalis has the advantage over E. coli in that it survives better in the aquatic environment (Slanetz and Bartley, 1965). This may be the reason that enterococcus is the only indicator for marine waters selected by EPA in its 1986 water quality criteria.

2.1.5 Discussion on Indicator Organisms

For a number of historical reasons described above, the coliform group has been employed as an indicator of the possible presence of disease producing organisms. Initially, the TC test was most widely used. Since the late 1970's, the FC test has generally supplanted the TC test as being somewhat more specific to mammalian wastes.

While the FC test is undoubtedly an improvement over the TC test, it is by no means the ideal indicator organism. Among the problems with the FC test is that it is subject to false positive results from organisms which are not of enteric origin. EPA studies involving contact recreation found that the FC test results were not highly related to the presence of pathogen concentrations measured. Based on these studies, EPA (1986) recommended that the FC test be replaced by either E. coli or enterococci for classification of waters for contact recreation as described in Section 2.2.3. Texas has not acted on that EPA recommendation.

Another weakness of the FC test, and perhaps any indicator organism test geared to human waste, is that there are some bacterial pathogens which are unrelated to human wastes. To the degree that naturally occurring microbial pathogens become a significant public health concern, completely new test procedures may have to be developed.

While the FC test has its limitations and problems, it also has many attributes. Perhaps the most significant attribute is that as a regulatory tool, it has worked long and well. In the case of shellfish quality regulation, coliform testing has been used successfully for well over fifty years. For the foreseeable future, the FC test will continue to be the basis for much of the regulatory decision making regarding both shellfish harvesting and contact recreation.

2.2 DISCUSSION OF FEDERAL AND STATE WATER QUALITY CRITERIA

The objective of this section is to review the current EPA and Texas criteria for bacteria in fresh and marine waters that are applicable to the GBNEP project area. The focus is on coliform and other indicator bacteria used for water quality criteria.

2.2.1 General Texas Water Quality Criteria for Bacteria

According to Section 307.4.(i) of the Texas Surface Water Quality Standards (TWC, 1991), the general water quality criterion for bacteria is that a FC concentration of not more than 200 colonies per 100 mL (1 dL) shall apply to all water bodies not specifically listed in Appendix A of Section 307.10. As described in the following sections, this criterion is the same as the 1976 EPA water quality criteria.

2.2.2 Texas Water Quality Criteria for Designated Segments

Based on site-specific uses, the TWC established water quality standards for bacteria. For recreation waters, it is divided into two categories - contact and noncontact recreation. Recreational activities involving a significant risk of ingestion of water, including wading by children, swimming, water skiing, diving, and surfing, are defined as contact recreation. Activities involving no significant ingestion risk such as boating are defined as noncontact recreation. The Texas State Water Quality criteria for both contact and noncontact recreation waters are:

1. Contact Recreation

    a. FC content shall not exceed 200 colonies per dL as a geometric mean based on a representative sampling of not less than five samples collected over not more than 30 days.

    b. FC content shall not equal or exceed 400 colonies per dL in more than 10% of all samples, but based on at least five samples, taken during any 30-day period. If 10 or fewer samples are analyzed, no more than one sample shall exceed 400 colonies per dL.

2. Noncontact Recreation

a. FC content shall not exceed 2,000 colonies per dL as a geometric mean based on a representative sampling of not less than five samples collected over not more than 30 days.

b. FC content shall not equal or exceed 4,000 colonies per dL in more than 10% of all samples, but based on at least five samples, taken during any 30-day period. If 10 or fewer samples are analyzed, no more than one sample shall exceed 4,000 colonies per dL.

In addition, criteria for specific segments are established based on designated uses.

Most of the GBNEP segments fall under the 200 FC/dL general criterion. The exceptions are:

River Basin	Segment Number	Water Quality Criterion (FC/dL)
San Jacinto	1006, 1007	2,000
Galveston Bay	2421, 2422, 2423, 2424, 2432, 2433, 2434, 2435, 2439	14

The criterion of 2,000 FC/dL is for the Houston Ship Channel which is not designated for contact recreation. The criterion of 14 is for the bay areas where shellfish growth is a designated use.

2.2.3 EPA Water Quality Criteria for Bacteria

A. EPA Criteria for Bathing (Full Body Contact) Recreational Waters

Before 1986, the EPA water quality criteria (EPA, 1976) for bacteria were the same as, and the basis for, the TWC criteria described previously. In 1986, based on the results of a large prospective epidemiological study conducted for EPA by Cabelli, et al. (1982), the current federal bacteriological water quality criteria were derived. The following is a summary of the 1986 EPA criteria.

B. EPA Criteria for Fresh Waters

EPA (1986) recommends that, based on a statistically sufficient number of samples (generally not less than 5 samples equally spaced over a 30-day period), the geometric mean of the indicated bacterial densities should not exceed one or the other of the following:

E. coli	126 per dL; or
enterococci	33 per dL;

no sample should exceed a one sided confidence limit (C. L.) calculated using the following as guidance:

designated bathing beach	75% C. L.
moderate use for bathing	82% C. L.
light use for bathing	90% C. L.
infrequent use for bathing	95% C. L.

based on a site-specific log standard deviation, or if site data are insufficient to establish a log standard deviation, then using 0.4 as the log standard deviation for both indicators.

C. EPA Criteria for Marine Waters

Based on a statistically sufficient number of samples (generally not less than 5 samples equally spaced over a 30-day period), the geometric mean of the enterococci densities should not exceed 35 per dL; no sample should exceed a one sided confidence limit using the following as guidance:

designated bathing beach	75% C. L.
moderate use for bathing	82% C. L.
light use for bathing	90% C. L.
infrequent use for bathing	95% C. L.

based on a site-specific log standard deviation, or if site data are insufficient to establish a log standard deviation, then using 0.7 as the log standard deviation for both indicators.

2.2.4 Discussion of EPA 1986 Criteria

According to EPA (1986), the major limitations of the new criteria are that the observed relationships between indicator and pathogens may not be valid if the size of the population contributing the fecal wastes becomes too small or if epidemic conditions are present in a community. In both cases the pathogen to indicator ratio, which is approximately

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no sample should exceed a one sided confidence limit (C. L.) calculated using the following as guidance:

designated bathing beach	75% C. L.
moderate use for bathing	82% C. L.
light use for bathing	90% C. L.
infrequent use for bathing	95% C. L.

based on a site-specific log standard deviation, or if site data are insufficient to establish a log standard deviation, then using 0.4 as the log standard deviation for both indicators.

C. EPA Criteria for Marine Waters

Based on a statistically sufficient number of samples (generally not less than 5 samples equally spaced over a 30-day period), the geometric mean of the enterococci densities should not exceed 35 per dL; no sample should exceed a one sided confidence limit using the following as guidance:

designated bathing beach	75% C. L.
moderate use for bathing	82% C. L.
light use for bathing	90% C. L.
infrequent use for bathing	95% C. L.

based on a site-specific log standard deviation, or if site data are insufficient to establish a log standard deviation, then using 0.7 as the log standard deviation for both indicators.

2.2.4 <u>Discussion of EPA 1986 Criteria</u>

According to EPA (1986), the major limitations of the new criteria are that the observed relationships between indicator and pathogens may not be valid if the size of the population contributing the fecal wastes becomes too small or if epidemic conditions are present in a community. In both cases the pathogen to indicator ratio, which is approximately constant in a large population, becomes unpredictable and therefore, the criteria may not be reliable under these circumstances.

The presence of indicator bacteria, in rural areas, shows the presence of warm blooded animal fecal pollution. Therefore, EPA recommends the application of the above criteria unless sanitary and epidemiological studies show the sources of the indicator bacteria to be non-human and that the "indicator densities are not indicative of a health risk to those swimming in such waters" (EPA, 1986).

The 1976 EPA criteria for swimming waters were based on FC because they were more fecal specific and less subject to variation than TC which were more heavily influenced by storm water runoff. However, based on the observed strength of the relationship between the rate of gastroenteritis and the indicator density, the 1986 EPA criteria adopted E. coli or enterococci as new indicator organisms. EPA also found that no general correlation between E. coli and FC densities could be obtained across different beaches. This finding caused EPA to believe that E. coli or enterococci were superior to the FC test. Thus, EPA strongly recommended states to begin the transition process to the new indicators.

The maximum allowable geometric mean enterococci density of 33/dL for fresh waters and 35/dL for marine waters were obtained by assuming an acceptable swimming-associated rate of gastroenteritis of 8/1000 swimmers for fresh waters and 19/1000 swimmers for marine waters. These acceptable rates are equal to the estimated rate of illness at 200 FC organisms/dL. In other words, EPA based its recommended criteria levels on its best estimate of the risk level that currently exists and society accepts.

While these new EPA criteria would seem to be a technical improvement, there has been some criticism. For example, Fleisher (1991) cited flaws in the marine recreation criteria such as averaging waters of different salinities and lack of sufficient controls on local sources of variation. Whatever the outcome on these very technical points, they would not seem to alter the fundamental conclusions regarding the relatively poor performance of the FC test and the availability of better procedures.

2.3 HISTORICAL WATER QUALITY CRITERIA FOR SHELLFISH GROWING WATERS

According to Hunt (1977), following the shellfish borne outbreak of typhoid fever during the 1924-1925 oyster harvest season the Report of the Committee on Sanitary Control of the Shellfish Industry in the United States was submitted to the Surgeon General, U.S. Public Health Service, giving rise to the current NSSP. The criteria for shellfish growing waters were stated in this report as "the waters should ordinarily not show the presence of Bacillus coli in 1 cc amounts, tests for B. coli being made in 10 cc, 1 cc, and 0.1 cc amounts, according to the Standard Methods". From 1928 to 1944, according to Hunt

(1977), although studies recommended that E. coli should be the index of pollution for both shellfish and shellfish waters, the NSSP disregarded the recommendation as unsatisfactory.

In 1946, based on studies performed by many researchers, the first official shellfish growing area microbiological standard was published in the Manual of Recommended Practice for Sanitary Control of the Shellfish Industry. The standard stated that "the medium bacteriological content of samples of water ... shall not show the presence of organisms of the coliform group in excess of 70/100 mL of water ...". This switched the indicator organism from B. coli to TC.

A NSSP Microbiology Task Force met in Washington D.C. in 1973 to review shellfish growing area standards, criteria, and methodology. The Task Force concluded that "the FC group was scientifically and logistically superior to the (total) coliform or fecal streptococci indicator groups as a microbiological indicator of fecal pollution in estuarine waters" (Hunt, 1977). A study group was then formed by FDA to collect and analyze both total and FC data nationwide, with the recognition that total/FC ratios would vary according to distance from pollution source, dilution, degree of treatment, and possibly other factors. The results of the study showed that the 70 TC level was equivalent to 14 FC/dL and that there was good correlation between total and FC data. Based on this study, FDA proposed a FC criterion in 1974. Then, the current water quality criteria for shellfish growing waters using either total or FC values were developed by the NSSP. Detailed description on this most current criteria is given in Section 3.

3.0 REVIEW OF ACTIVITIES ASSOCIATED WITH SHELLFISH BED CLOSURES

The Galveston Bay estuarine system, consisting of four larger bays, Galveston, Trinity, East, and West Bays, and numerous smaller bays, creeks, and bayous, has a total surface area of about 533 square miles and is the largest estuary on the Texas coast. It also has the largest shellfish harvesting industry in Texas.

Regarding shellfish harvesting activities, the Galveston Bay system is regulated by the Division of Shellfish Sanitation Control in the TDH and enforced by the Texas Parks and Wildlife Department (TWPD). The objective of this section is to investigate the current and historical regulatory procedures for shellfish harvesting in the Galveston Bay System.

3.1 TDH REGULATORY PROCEDURES (NSSP)

The Food and Drug Administration (FDA) of the U. S. Department of Health and Human Services and the Interstate Shellfish Sanitation Conference (ISSC) updated the Manual of Operations for National Shellfish Sanitation Program (NSSP) in 1988 and revised in 1990 that governs the current regulatory procedures for shellfish growing areas. According to part I of this manual, shellfish growing areas must be classified into approved, conditionally approved, restricted, conditionally restricted, and prohibited areas by the state shellfish control authority (for Texas, this is the Division of Shellfish Sanitation Control in TDH). Furthermore, when a public health emergency resulting from, for instance, a hurricane or flooding, is declared, a closed area where the harvesting of shellfish is temporarily or "permanently" not permitted may be placed on any of these five classified area designations.

According to the NSSP manual, before a shellfish growing area can be classified, a sanitary survey must be made. Each sanitary survey shall:

1. identify and evaluate all actual and potential sources of pollution which may affect the growing area,

2. determine the distance of such sources to the growing area,

3. assess the effectiveness and reliability of sewage treatment systems, and

4. ascertain the presence of poisonous or deleterious substances.

Other environmental health factors that may affect the quality of the shellfish resources and any meteorological and hydrographic effects and geographic characteristics that may affect the distribution of pollutants over the growing area shall also be evaluated and assessed in each sanitary survey.

The Manual requires that Water samples be collected and analyzed for bacteriological quality during each sanitary survey. Sampling stations must be established to evaluate all freshwater discharges into the growing area. The sampling is to emphasize adverse meteorological, hydrographic, seasonal, and point sources of pollution to assure that the requirements for classifying growing areas are met.

The Manual also states that sanitary surveys shall be maintained on an annual basis to assure that data is current and sanitary conditions are unchanged. Also, the sanitary survey shall be reviewed and the growing area classification reevaluated at least every three years. The reevaluation shall include an analysis of laboratory results pertinent to at least the last fifteen water samples. A complete shoreline survey shall be conducted on all approved, conditionally approved, restricted, and conditionally restricted shellfish growing areas a minimum of once every twelve years.

Growing areas may be classified as approved if they are "not subject to contamination from human and/or animal fecal matter in amounts that may present an actual or potential hazard to public health". Also, approved areas must meet one of the following criteria:

1. The TC median or geometric mean Most Probable Number (MPN) (see Sec. 3.7 for a discussion of testing methods) of the water does not exceed 70 per dL and not more than 10 percent of the samples exceed an MPN of 230 per dL for a 5-tube decimal dilution test (or an MPN of 330 per dL for a 3-tube decimal dilution test). This TC standard need not be applied if it can be shown by detailed study verified by laboratory findings that the coliform are not of direct fecal origin and do not indicate a public health hazard. In addition, the standard may not be applicable in a situation where an abnormally larger number of pathogens might be present.

2. The FC median or geometric mean MPN of the water does not exceed 14 per dL and not more than 10 percent of the samples exceed an MPN of 43 per dL for a 5-tube decimal dilution test (or an MPN of 49 per dL for a 3-tube decimal dilution test).

The determination that the approved area classification standards are met shall be based upon a minimum of fifteen samples collected from each station in the approved area. These stations shall be located adjacent to actual or potential sources of pollution. Sample collection shall be timed to represent adverse pollution conditions.

Essentially, for an area to be approved for shellfish growing, it must have relatively low values in coliform sampling data and not be "subject to" potential sources of contamination such as wastewater treatment plants, fresh water discharges from rivers, homes or groups of boats.

Growing areas that are subject to intermittent microbiological pollution may be classified as conditionally approved. These areas shall be able to meet the approved area classification criteria, shown by a sanitary survey, for a reasonable period of time. The factors determining these periods must be known, predictable, and not so complex as to preclude a reasonable management approach. Also, the conditionally approved areas must be evaluated at least once each year.

An area may be classified as restricted when a sanitary survey indicates a limited degree of pollution. Such areas must not be so contaminated with fecal material, poisonous or deleterious substances that consumption of shellfish might be hazardous after controlled purification or relaying. Relaying or depuration involves placing shellfish harvested from a restricted area into an approved area for a period of time prior to sale. For restricted areas to be used for harvest of shellfish for controlled purification, the bacteriological quality of every sampling station in those portions of the area exposed to fecal contamination during adverse pollution conditions shall meet one of the following standards:

1. The TC median or geometric mean MPN of the water does not exceed 700 per dL and not more than 10 percent of the samples exceed an MPN of 2,300 per dL for a 5-tube decimal dilution test (or an MPN of 3,300 per dL for a 3-tube decimal dilution test).

2. The FC median or geometric mean MPN of the water does not exceed 88 per dL and not more than 10 percent of the samples exceed an MPN of 260 per dL for a 5-tube decimal dilution test (or an MPN of 300 per dL for a 3-tube decimal dilution test).

Sanitary surveys of restricted areas shall be conducted, maintained, and reevaluated in the same manner and frequency as for approved areas.

After a sanitary survey shows that an area will meet the restricted area classification criteria for a reasonable period of time, such area can then be classified as conditionally restricted. The factors determining these periods must be known, predictable, and not so complex as to preclude a reasonable management approach. Also, the conditionally restricted areas must be evaluated at least once each year.

A growing area shall be classified as prohibited if there is no current sanitary survey or evaluation to support the classification of approved, conditionally approved, restricted, or conditionally restricted. As stated in the NSSP manual, growing areas shall be classified as prohibited if the sanitary survey or other monitoring program data indicate that:

1. Pollution sources may unpredictably contaminate the shellfish, or

2. The area is contaminated with poisonous or deleterious substances whereby the shellfish may be adulterated, or

3. The area is polluted with fecal waste to such an extent that shellfish may contain excessive filth or be vectors of disease-causing microorganisms, or

4. The area contains shellfish wherein the concentration of paralytic shellfish poison (PSP) equals or exceeds 80 micrograms per 100 grams of edible portion of raw shellfish, or when neurotoxic shellfish poison is found in detectable levels.

Growing areas adjacent to sewage treatment plant outfalls and other waste discharges of public health significance shall also be classified as prohibited.

Although the NSSP manual provides five classifications to shellfish growing waters, Texas waters are currently classified into only three categories, namely approved, conditionally approved, and polluted. The criteria used for these classifications are the same as those in the NSSP manual with the polluted areas being the same as the prohibited areas. The term "polluted" is mandated by State Law, Health and Safety Code, Subchapter B, Section 436.011. It is somewhat inappropriate since the great majority of areas so classified are based on a judgement as to proximity to waste sources, etc., with no evidence of pollution. The TDH has made repeated efforts to have the legislation changed, but no action has been taken to date (Wiles, pers. comm. 1992).

3.2 HISTORICAL MAPS SHOWING SHELLFISH CLOSURES

As listed in Table 3-1, there have been 40 shellfish classification maps issued for Galveston Bay by TDH. Unfortunately, eight of them can not be found although EH&A has performed an intensive search. The available 32 maps, including the most current 1991 map, are shown in Appendix A and are also provided in ARC-INFO format on diskettes as requested by GBNEP.

TABLE 3-1
SHELLFISH CLASSIFICATION MAPS ISSUED BY TDH

MARINE ORDER NUMBER	DATE ISSUED	AVAILABLE AT EH&A
–	01-Apr-52	YES
–	01-Sep-53	YES
–	01-Aug-55	YES
–	01-Aug-58	YES
–	01-Oct-58	YES
–	01-Oct-60	YES
–	01-Nov-63	YES
–	01-Jun-64	YES
–	01-Jul-64	YES
–	01-Jul-65	YES
–	01-Jul-66	YES
–	01-Jul-67	YES
6	01-Jul-68	YES
10	01-Jul-69	YES
11	14-Jul-70	NO
12	01-Sep-70	YES
13	01-Nov-71	YES
14	28-Feb-72	NO
15	01-Sep-72	YES
17	07-Apr-73	YES
20	12-May-73	YES
22	01-Sep-73	YES
24	21-Feb-74	YES
26	15-Oct-75	NO
29	01-Sep-77	NO
34	16-Nov-79	NO
37	31-Oct-80	NO
42	01-Sep-81	YES
65	01-Sep-83	YES
99	01-Apr-85	NO
108	01-Sep-85	YES
117	15-Oct-86	YES
122	22-Nov-86	YES
154	1-Dec-87	NO
166	01-Jul-88	YES
175	15-Oct-88	YES
205	01-Nov-89	YES
211	15-Dec-89	YES
239	01-Nov-90	YES
299	01-Nov-91	YES

3.3 TRENDS OF BAY AREAS IN TERMS OF "POLLUTED", CONDITIONALLY APPROVED, AND APPROVED

As shown in the appendix, the pattern of regulated areas in the Galveston Bay system has varied considerably over the years. This variation can be attributed to different classification methods, testing procedures, and terminologies. In particular, the terminology used for prohibited areas has varied over the years and has included unapproved, insanitary, and polluted. With some of the older designations, the meaning of the terms is not certain (Wiles, 1992).

In 1952 and 1953, most of Trinity Bay, the northern and southwestern parts of Galveston Bay, the eastern part of East and West Bays, and Chocolate Bayou in West Bay were all classified as "unapproved oyster areas". In 1955, the unapproved area in Trinity Bay was reduced and the northern and western parts of Galveston Bay were classified as "insanitary oyster areas". This caused a significant reduction in the unapproved area in Galveston Bay. In August of 1958, the unapproved area in Trinity Bay was increased and the insanitary area in Galveston Bay was classified back to unapproved areas with a significant increase in such areas. In October of 1958, the central part of Galveston Bay was reclassified into conditionally approved oyster areas while the previous unapproved areas were renamed to be insanitary areas. This classification remained the same in 1960, 1963, June and July of 1964, and 1965.

In 1966, the previous insanitary area was termed polluted area. As compared to the classification in 1965, there was a reduction in the polluted/insanitary areas in Trinity Bay and north of Galveston Bay and a slight reduction in the conditionally approved area. The same 1966 classification was maintained for 1967 and 1968. In 1969, the polluted areas in northern Trinity and Galveston Bays were reduced while the polluted areas in southern Trinity Bay were increased. These changes were the direct results of the comprehensive sanitary survey performed by TDH in 1969. This same 1969 classification remained unchanged for 1970.

In 1971, the polluted areas remained the same as in 1969 but the conditionally approved area located in central Galveston Bay was reclassified to be approved area. This classification remained unchanged in 1972. In May of 1973, the entire area north of a line drawn from the Houston Ship Channel Marker #53 to the Smith Point was reclassified as polluted areas. This includes all of Trinity and most of Galveston Bays. The reason for this closing might be excessive rainfall. Four months later, in September of 1973, the areas closed in May were opened and the classification was again the same as the one in 1972, except for the eastern part of West Bay where the polluted area was slightly increased.

In 1974, the polluted areas in Trinity and Galveston Bays were increased due to excessive rainfall. From 1975 to 1980, although there were at least four shellfish classification maps issued by TDH, none of them was found. In 1981, the only available map was for West Bay only which had the same classification as the 1973 map. In 1983, the polluted areas in Trinity and Galveston Bays were significantly reduced. In 1985, the polluted area in Trinity Bay was expanded further offshore and hence increased the size. This classification remained the same in 1986.

In 1988, the classification map introduced significant change. First, the classification criteria revised in 1986 and updated in 1988 by NSSP were adopted and the areas were reclassified into approved, conditionally approved, and polluted areas. Second, a comprehensive sanitary survey was performed by TDH in 1988. This was the first survey since 1969 on the Galveston Bay system. The results of this survey reclassified the bay waters significantly. For East and West Bays, all classifications remained the same. However, for Trinity and Galveston Bays, significant changes in classification areas can be seen. First, conditionally approved areas were added into the classification for the first time since 1970. Second, the polluted areas were significantly reduced.

In 1989, the shellfish classification map showed that the polluted areas were increased and the conditionally approved areas were reduced in both Trinity and Galveston Bays. The 1990 and 1991 maps show no change in these classification for Trinity, Galveston, and East Bays, except for the southwest corner of Galveston Bay near the Dollar Reef Markers where the polluted area was reduced. For West Bay, although a comprehensive sanitary survey was performed in 1988, the classification maps remained unchanged in 1989 and 1990. In fact, the classification for West Bay had not been changed for more than 10 years. However, the polluted areas in the eastern part of West Bay were increased in the 1991 map.

3.4 DIFFERENCES IN CLOSURE AREAS WITH CHANGE FROM TOTAL TO FECAL COLIFORM AS REGULATORY CRITERIA

Up to the mid to late 1970's, the TDH was using TC MPN data as criteria for classification of shellfish growing waters (Wiles, 1992). Then, both total and fecal MPN test data were used until about 1983. From 1983 on, only FC data have been used.

As can be seen from Appendix A, the classification maps for September of 1973 and September of 1983 are identical. This result indicates that no significant change can be observed when classification criteria changed from total to FC values. Also, although a slight change in polluted areas occurred in September of 1985 as compared to September of 1983, this change in polluted areas may be due to other reasons than the change in classification criteria.

However, the 1988 map indicated significant changes in the classification of shellfish growing areas. These changes include the addition of conditionally approved area and the reduction in polluted areas compared with the 1986 classification. Although NSSP revised its Manual of Operation in 1986 which may have some effect on this 1988 classification, the significant changes in the 1988 classification map are mostly due to the results of the comprehensive sanitary survey performed by TDH in 1988. Thus, a conclusion can be drawn that the change from total to FC testing did not produce a significant change in the classification results.

3.5 CURRENT CLASSIFICATIONS OF BAY AREAS

The most current classifications of Galveston Bay areas were issued by TDH on November 1, 1991 according to Marine Order MR-299. This map is shown in Figure 3-1. As in 1990, the eastern portion of East Bay was classified as polluted. In Galveston Bay, the southwestern, western, northwestern, and northern portions were classified as polluted areas. As for Trinity Bay, the northern, northeastern and eastern portions were classified as polluted areas. Also, all areas within a 50 yard radius of recreational cabins located in the Bays were closed for shellfish harvesting.

For West Galveston Bay areas, the eastern portion and most of Chocolate Bay were classified as polluted areas. Also, all residential subdivision channels and harbor areas up to a radius of 300 yards offshore from the shoreline where the channels become land bound and all areas within a 50-yard radius of recreational cabins located in the bay were closed for shellfish harvesting.

There were three areas in Galveston Bay that were classified as conditionally approved areas. These areas are subject to classification changes based upon meteorological conditions. The first conditionally approved area, Area 1 in Figure 3-1, is located west of the Houston Ship Channel. When seven-day rainfall at San Leon or the closest available National Weather Service rain gauge exceeds 2 inches, this area is closed for shellfish harvesting. The other two areas, Area 2 in Galveston and Area 3 in Trinity Bay, are managed together based on river stage and rainfall. When either the Trinity River exceeds 9 ft at Moss Bluff or when seven-day rainfall exceeds 2 inches at the Baytown National Weather Service rain gauge or the nearest available official rain station, these two areas are closed. The only difference between areas 2 and 3 is that the decision on reopening is made independently based on sampling data. All other areas in the Galveston Bay system not specifically defined above were classified as approved for the harvesting of shellfish.

When comparing this 1991 classification with the 1990's, the following results can be observed. First, the 1990 and 1991 classifications are the same for Trinity, Galveston, and East Bay areas. Second, the 1991 classification includes more polluted area in the east

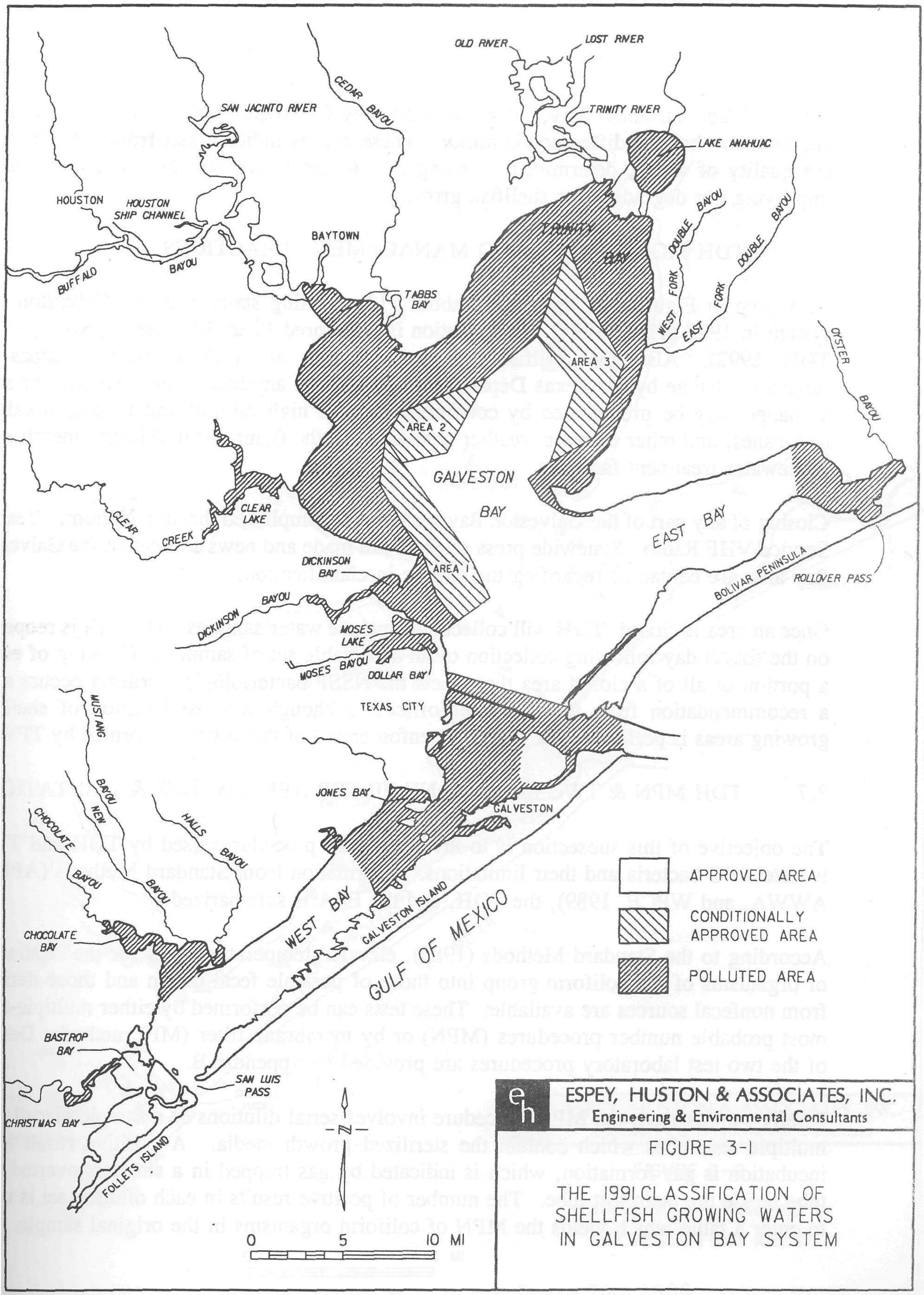

FIGURE 3-1

THE 1991 CLASSIFICATION OF SHELLFISH GROWING WATERS IN GALVESTON BAY SYSTEM side of West Galveston Bay, near the West Bay Shellfish Marker #1, than the 1990 classification but the difference is minor. These results indicate that from 1990 to 1991 the quality of water, determined by using FC, in the Galveston Bay system is neither improving nor degrading for shellfish growing.

3.6 TDH MONITORING AND MANAGEMENT PRACTICES

As shown in Figure 3-2, there were about 112 sampling stations in the Galveston Bay system in 1988 (TDH, 1988). Each station is monitored 12 to 30 times per year (Wiles, TDH, 1992). Also, the shellfish classification status of all Texas estuarine areas are subject to change by the Texas Department of Health at anytime. The necessity for such a change may be precipitated by conditions such as high rainfall and runoff, flooding, hurricanes, and other extreme weather conditions or the failure or inefficient operation of wastewater treatment facilities.

Closing of any part of the Galveston Bay system is accomplished through National Weather Service VHF Radio. Statewide press releases are made and news sources in the Galveston Bay area are contacted regarding the change in classification.

Once an area is closed, TDH will collect and analyze water samples. The area is reopened on the fourth day following collection of an acceptable set of samples. Opening of either a portion or all of a closed area that meets the NSSP bacteriological criteria occurs after a recommendation from the TDH sub-office. Although the classification of shellfish growing areas is performed by TDH, the enforcement of the law is performed by TPWD.

3.7 TDH MPN & TWC MEMBRANE FILTER APPROACHES & LIMITATIONS

The objective of this subsection is to investigate the procedures used by TDH and TWC to detect FC bacteria and their limitations. Information from Standard Methods (APHA, AWWA, and WPCF, 1989), the TDH, and the EPA is summarized.

According to the Standard Methods (1989), elevated-temperature tests for the separation of organisms of the coliform group into those of possible fecal origin and those derived from nonfecal sources are available. These tests can be performed by either multiple-tube most probable number procedures (MPN) or by membrane filter (MF) methods. Details of the two test laboratory procedures are provided in Appendix B.

Briefly summarized, the MPN procedure involves serial dilutions of a sample placed into multiple test tubes which contain the sterilized growth media. A positive result after incubation is gas formation, which is indicated by gas trapped in a smaller inverted test tube inside the main test tube. The number of positive results in each dilution set is used to enter a table which yields the MPN of coliform organisms in the original sample.

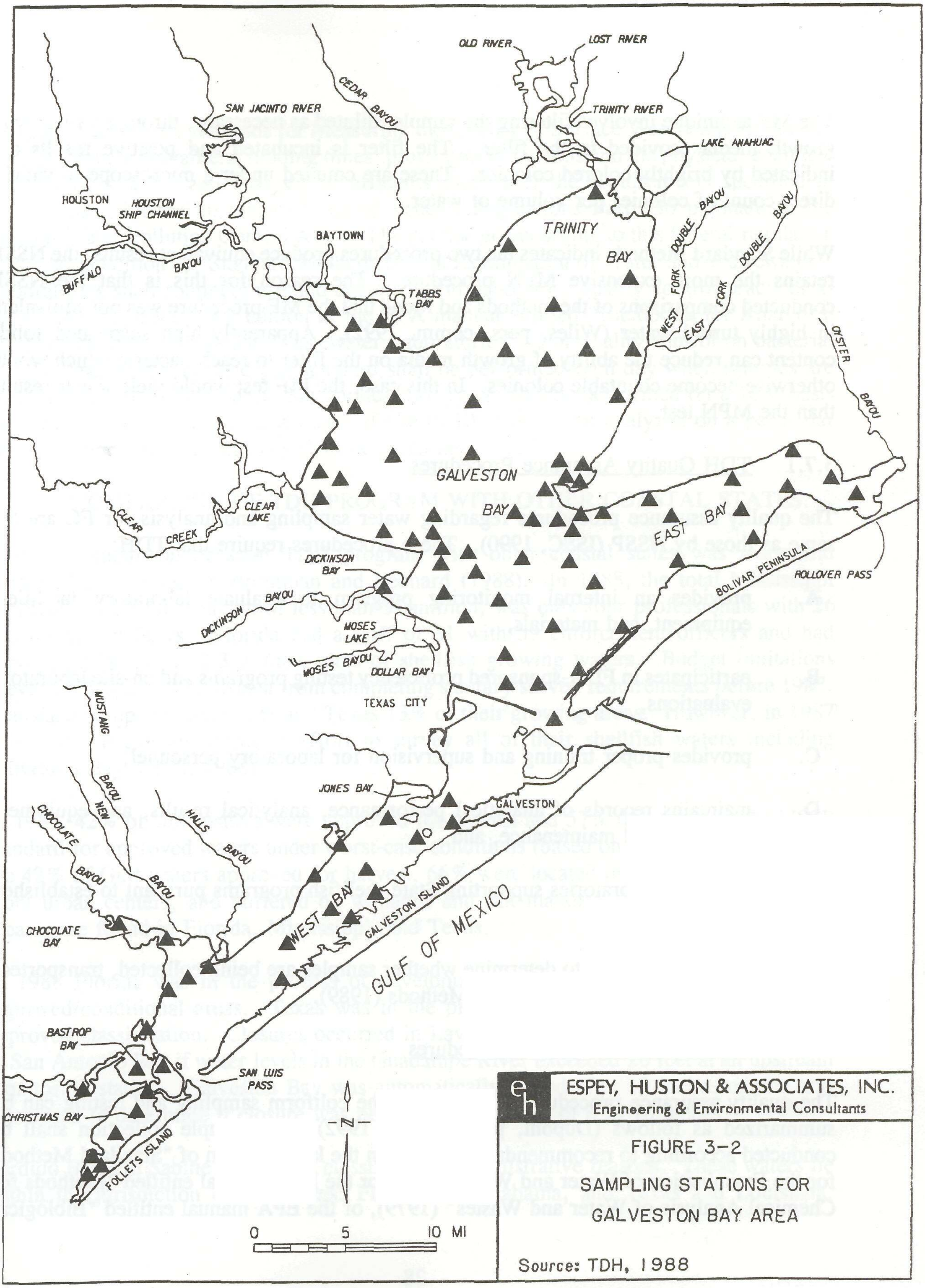

FIGURE 3-2

SAMPLING STATIONS FOR GALVESTON BAY AREA

Source: TDH, 1988

The MF technique involves filtering the sample, diluted as necessary, through a filter with growth media provided to the filter. The filter is incubated and positive results are indicated by brightly colored colonies. These are counted under a microscope to yield a direct count of colonies per volume of water.

While Standard Methods indicates the two procedures produce equivalent results, the NSSP retains the more expensive MPN procedure. The reason for this is that the NSSP conducted comparisons of the methods and found that the MF procedure was not equivalent in highly turbid water (Wiles, pers. comm. 1992). Apparently high suspended solids content can reduce the ability of growth media on the filter to reach bacteria which would otherwise become countable colonies. In this case, the MF test would yield lower results than the MPN test.

3.7.1 TDH Quality Assurance Procedures

The quality assurance procedures regarding water sampling and analysis for FC are the same as those by NSSP (ISSC, 1990). These procedures require that TDH:

A. provides an internal monitoring program to evaluate laboratory facilities, equipment, and materials,

B. participates in FDA-sponsored proficiency testing programs and on-site laboratory evaluations,

C. provides proper training and supervision for laboratory personnel,

D. maintains records of analytical performance, analytical results, and equipment operation and maintenance, and

E. evaluates laboratories supporting State shellfish programs pursuant to established NSSP guidelines.

These procedures are used to determine whether samples are being collected, transported, and analyzed consistent with Standard Methods (1989).

3.7.2 TWC Quality Assurance Procedures

The quality assurance procedures followed for the coliform sampling and testing can be summarized as follows (Dupont, pers. comm. 1992). All sample collection shall be conducted according to recommendations found in the latest edition of "Standard Methods for the Examination of Water and Wastewater", or the EPA manual entitled "Methods for Chemical Analysis of Water and Wastes" (1979), or the EPA manual entitled "Biological

Field and Laboratory Methods for Measuring the Quality of Surface Waters and Effluents" (1973). Sample containers, holding times, preservation methods and the physical, chemical and microbiological and analyses of effluents shall meet the requirements specified in regulations published in the 40 Code of Federal Regulations Part 136 pursuant to the Federal Water Pollution Control Act, and be conducted according to this federal regulation or the latest edition of "Standard Methods for the Examination of Water and Wastewater". Laboratories shall routinely use and document intralaboratory quality control practices as recommended in the latest edition of the EPA manual entitled "Handbook for Analytical Quality Control in Water and Wastewater Laboratories". For quality control on bacterial tests, at least one blank and one standard shall be performed each day when samples are analyzed. Also, it is required that duplicate analyses shall be performed on a 10% basis each day when samples are analyzed. If one to 10 samples are analyzed on a particular day, then one duplicate analysis shall be performed.

3.8 COMPARISON OF TDH PROGRAM WITH OTHER COASTAL STATES

A brief comparison between TDH program with other coastal states was made and presented here based on Broutman and Leonard (1988). In 1988, the total Mississippi shellfish staff, with a budget of less than $1 million, was only four professionals with 26 enforcement officers. Florida had a staff of 31 with 59 enforcement officers and had surveyed 50% of the 2.3 million acres of shellfish growing waters. Budget limitations prevented Texas and Louisiana from completing sanitary survey requirements before 1987. Louisiana completed only 11% and Texas 13% of their growing areas. However, in 1987 both states began an extensive effort to survey all of their shellfish waters including Galveston Bay (TDH, 1988).

In 1985, 42% of Gulf waters were approved for harvest and 57% did not meet the NSSP standard for approved waters under worst-case conditions (based on TC MPN values). Of the 42% of Gulf waters approved for harvest, 66% were located in coastal Louisiana, far from urban centers, and buffered by wetlands and salt marshes. Approved/conditional areas were found in Florida, Mississippi, and Texas.

In 1988 Florida was in the process of developing management plans for many of its approved/conditional areas. Texas was in the process of implementing a conditionally approved classification. Closures occurred in Lavaca Bay after three inches of rain, and in San Antonio Bay if water levels in the Guadalupe River exceeded 20 feet at an upstream monitoring station. Galveston Bay was automatically closed after 10 inches of rain and monitored to determine if closure was necessary after rains of 6 to 10 inches.

Perdido Bay and Sabine Lake were classified for administrative reasons. These waters lie within the jurisdiction of two states: Florida and Alabama, and Texas and Louisiana, respectively. Harvest is prohibited by interstate agreement to avoid problems of bistate management. Neither system contains shellfish resources of commercial importance.

Approximately half (53%) of the 3.4 million acres of harvest-limited waters in the Gulf were affected by a combination of point (sewage treatment plants (STPs), straight pipes, and industry) and nonpoint sources (septics, boating and shipping, urban runoff, agricultural runoff and feedlots, and wildlife) in 1988. The other half (47%) were affected only by nonpoint sources. Point sources alone affected less than 1% of shellfish growing waters. For example, estuaries predominantly affected by sewage treatment plants and urban runoff were the Caloosahatchee River, Tampa Bay, Pensacola Bay, Lakes Pontchartrain and Borgne, Brazos River, and Corpus Christi Bay; by combined urban and nonurban sources were St. Andrew Bay, Mississippi Sound, Galveston Bay, and Laguna Madre; by upstream sources were Apalachicola Bay, Mobile Bay, Mississippi Sound, Mississippi Delta, Atchafalaya and Vermillion Bays, and San Antonio Bay; by septics was Aransas Bay; by septics and straight pipes were Chandeleur/Breton Sounds, Terrebonne/Timbalier Bays, and Caillou Bay; by septics and boating activities were Ten Thousand Islands and Charlotte Harbor; by septics and wildlife were Apalachee and Choctawhatchee Bays; by septics and agricultural runoff was Matagorda Bay; by wildlife was Suwannee River; and by agricultural runoff was Barataria Bay.

NOAA estimates reported by the Office of Technology assessment (1987) showed that 84% of FC loads in the Gulf of Mexico coastal region were from nonpoint sources. The remaining 16% of loading was from municipal point sources (STPs). The loading from industrial point sources was negligible compared to the other two sources.

An estimated 0.4 million acres or 11% of harvest-limited waters in the Gulf were affected only by animal sources (wildlife, agriculture runoff and feedlots). In an additional 1.1 million acres or 34%, animals were a significant contributing source, along with human sources of pollution. Urban runoff, which may or may not contain human fecal material, affected 1.1 million acres or 33% of harvest-limited areas. Industrial sources were contributing factors in the closures of 0.3 million acres or 10% of these waters.

Broutman and Leonard (1988) concluded that: 1) most waters in the Gulf of Mexico did not meet standards for approved waters at all times; 2) the majority of approved waters were in the outer bays of Louisiana where salinities were high and oyster productivity was low; 3) harvest was prohibited in 29% of waters around developed areas; and 4) an additional 27% of waters might not be harvested after heavy rainfall or when river stages were high. These conditionally approved waters were the most productive in the Gulf.

3.9 CONCLUSIONS

The classification of shellfish growing areas is affected by many factors. Among these factors, rainfall runoff has the biggest effect on water quality conditions in bay waters. This can be seen from the conditionally approved areas which are managed from rainfall and/or freshwater inflow levels. No significant trend can be observed from historical classification maps. In fact, the classifications are fairly similar through time unless there is excessive rainfall which may close shellfish harvesting areas significantly for a short period. Other changes that have occurred in the historical maps are due to the comprehensive sanitary surveys which redetermine the water quality conditions and hence reclassify bay waters.

A second conclusion is that no significant changes in the classifications occurred when the criteria switched from using TC to FC. This conclusion suggest that both TC and FC work equally well as a tool to regulate the shellfish growing waters. However, as described in Section 6, no obvious relationship between coliform levels and pathogens such as the Vibrios can be observed. Thus, the validity of using only coliforms to regulate shellfish growing areas may be questionable.

4.0 INDICATOR BACTERIA INPUTS TO GALVESTON BAY

The purpose of this section is to analyze and quantify to the extent practical the contribution of indicator organisms to Galveston Bay from a range of sources. The sources to be considered are:

- Permitted wastewater discharges,
- Wastewater collection system leaks, overflows and excursions,
- Partially treated wastewater from failed septic systems, and
- Runoff from watershed areas.

As can well be imagined, these categories frequently overlap with attendant analytical difficulties. The problem is compounded by the dynamic nature of indicator organism concentrations. While these problems exist, it is nevertheless worthwhile to attempt the quantification in that the results will at least bracket expected values and provide a measure of the relative importance of the various sources.

A major component of the analysis is based on a recently completed project for the Galveston Bay National Estuary Program, "Characterization of Non-Point Sources and Loadings to Galveston Bay", by Groundwater Services, Inc. (GSI) and Rice University (1991). Additional analyses are performed using data from the City of Houston as well as data from Harris and Galveston Counties (City of Houston, 1991). The reasons for employing the Houston data are:

1. Houston is by far the largest urban area in the immediate bay watershed,

2. The treatment plants and collection systems are generally representative of the other bay communities in terms of age and design,

3. Much of the data from the City are computerized and readily available, and

4. Over the last five years the City has made major investments in identifying and repairing problems in its collection system which allows quantification of these sources to some degree.

Each of the four major topics will be discussed, emphasizing the data available. The final subsection provides an integration of various components and data sources.

4.1 PERMITTED WASTEWATER DISCHARGES

This subsection addresses domestic/municiple wastewater treatment plants (WWTPs). While it is recognized that some industrial discharges do contain FC bacteria, often in the absence of any enteric wastes (see discussion in EPA, 1986; Dufour, 1977), these inputs are considered to be relatively small in the bay area.

The domestic WWTP category is perhaps the easiest to quantify in that all permitted point sources are required to report monthly information on discharges including average and daily maximum flows and minimum residual chlorine concentrations. So long as there is a residual of chlorine in the effluent after a minimum of 20 minutes contact time (at maximum flow, the actual contact time at normal flows is typically much longer), there are essentially no FC positive test results.

While it cannot be said that all treatment plants in the Galveston Bay immediate drainage area always maintain the required chlorine residual, it can be said that failures to do so are relatively infrequent. A similar statement can be made about the frequency of bypasses from treatment plants. These points are illustrated in Table 4-1 which is a tabulation of the number of bypass events and days when the minimum chlorine residual was not achieved during the one year interval of July, 1990 through June 1991. It can be seen that over the course of a year, thirty five plants (12,775 plant-days) had a total of six days when the chlorine residual was less than 1 mg/L. Only one of these observations actually had no chlorine residual.

Similarly, only one treatment plant bypass occurred during the year. Interestingly, this bypass occurred as a result of a failure in construction work being performed on the collection system. Rehabilitation work on Houston's collection system is ongoing in several areas and will be discussed in the next section. The bypass did not result from capacity limitations. This plant and the rest of the Houston system has capacity for over twice the actual wastewater flows.

4.2 COLLECTION SYSTEM LEAKS, OVERFLOWS AND EXCURSIONS

The City of Houston has portions of its collection system which are roughly 100 years old and large areas approaching their 50 year anniversary. As growth of the City occurred, the collection system has suffered from a combination of aging processes (soil settlement, acidic corrosion, etc.) and, with redevelopment of older areas, the addition of flows greater than what was originally expected when the sewers were designed. The result was overflows or releases from the sewers, particularly during wet weather and sometimes in dry weather.

Collection system problems include both undesired inputs and releases. Inputs include illicit stormwater connections and leaks which allow entry of stormwater during wet periods. These are a concern because they result in dramatically higher sewer flows which can exceed the capacity of lines, lift stations or the receiving treatment plant. When any of these occurs, a bypass results. Releases can also occur from leaks which enter the soil

TABLE 4-1

TABULATION OF HOUSTON WASTEWATER

DISINFECTION AND BYPASS PERFORMANCE

City of Houston Plant	Number of Min Cl_2<1.0	Number of Bypass Events
Sims Bayou	0	0
Sims South	2 (0.8, 0.0)	0
Almeda Sims	1 (0.8)	0
Chocolate Bayou	0	0
Clinton Park	0	0
FWSD-23	0	0
Gulf Meadows	0	0
Homestead	0	0
West District	0	0
Southwest	0	0
WCID-47	0	0
WCID-51	0	0
Easthaven	0	0
FWSD-34	0	0
Sagemont	0	0
Southwest	2 (0.4, 0.3)	0
Northest	0	0
Intercont. Airport	0	0
Southeast	0	0
Eastex Oaks	0	0
69th Street	0	1 (7 MG)
WCID-111	0	0
White Oak	0	0
Northgate	0	0
Imerial Valley	0	0
Harris Co. MUD-123	0	0
Harris Co. MUD-139	0	0
Turkey Creek	1 (0.5)	0
Green Ridge MUD	0	0

TABLE 4-1 (Concluded)

City of Houston Plant	Number of Min Cl_2<1.0	Number of Bypass Events
Beltway	0	0
Cedar Bayou	0	0
Northborough	0	0
Harris Co. MUD-218	0	0
Keegans Bayou	0	0
Westheimer Road	0	0

Source: TWC printout 07/90 to 06/91

or connect with the storm sewer system without the effect of higher wet weather flows. Significant leaks of this type are much less common and more readily identified and fixed than wet weather overflows, but also have the capacity to have a readily detectable impact on receiving waters. Leaks to the soil which do not enter a stormsewer could in some cases enter surface waters in a way that would be difficult to detect.

Elimination of overflow points is the culmination of extensive work in monitoring flows and water levels in various portions of the system during wet weather, using these data to allow numerical modeling of the system for design conditions, using the numerical model to determine the most appropriate remedy, design of the selected remedy and construction. This is a slow and expensive process (hundreds of millions spent to date and several billion still to go). It is also one that will never be complete as collection systems continue to age.

The City of Houston has been heavily involved in work on its collection system for many years. Since 1987, the City has been reporting activities biannually to the TWC in documents called "Response Reports". In the September 1991 Report, approximately 140 overflow points were reported as eliminated. Of these, only three are reported as class A or which release during dry weather.

In addition to the work being performed by the main engineering effort of the City, the Wastewater Quality Control group has been monitoring water quality conditions in the major bayous and has identified a number of dry weather sewer releases. An important element of this work, in addition to identifying some additional leaks, was that an attempt was made to measure the flows and quality of the observed discharges.

Table 4-2 lists measured flows and water quality data (provided by Glanton, 1992) from a number of leak points monitored in the Buffalo Bayou watershed from the upper end to a point just outside of downtown (Shepherd), an area that includes some fairly old sections as well as newer ones and does not have the atypical age and density of downtown Houston. Each of these observations is from a storm sewer near Buffalo Bayou during dry weather conditions. Attention was first attracted to these locations by monitoring of coliform levels in Buffalo Bayou. A sharp increase in bayou FC levels was an indication of a sewer leak. City personnel then searched the connecting storm sewers in the area until one was found to be flowing. The flowing storm sewer was then traced until the leak was detected. Once identified, the leak was turned over to City maintenance crews for repair. The data in Table 4-2 includes observations both before and after repair.

Several observations can be made on the data in Table 4-2. The first is that a fairly small percentage exhibit the numerical characteristics of raw sewage (CBOD > 100 mg/L, NH_4-N of around 10 mg/L or greater, and coliform levels > 10^6 FC/dL). Using these criteria, only the observations at Shepherd on 3/29/89 and Adams Gully on 4/06/89 would appear

TABLE 4-2
CITY OF HOUSTON SEWER LEAK MONITORING DATA

LOCATION DATE	ID #	FLOW (GPM)	pH	NH_4-N	NO_3-N	TKN	CBOD	FC / dL*
RUMMEL CREEK								
07/17/90	OT-418	50.0	7.7	1.1	1.2		3.1	53,000
08/13/90	OU-389	200.0	7.9	0.1	0.5		3.9	1,600
11/05/91	1Y-162	0.0	8.0	0.1	0.2	0.5	1.5	270
	AVERAGE	125.0	7.9	0.4	0.6	0.5	2.8	2,840
FONDREN								
07/30/89	9R-354							220,000
08/25/89	9S-163		7.7	0.1	0.7		50.4	2,000,000
08/13/90	OU-390	100.0	8.2	2.1	0.7		12.7	3,000,000
08/21/90	OU-562							150,000
09/04/90	OW-157							21,000
10/03/90	OX-183	40.0	8.2	1.8	0.6	2.0	2.8	13,000
11/05/91	1Y-163		7.9	0.1	0.3	5.0	18.0	78,000
	AVERAGE	70.0	8.0	1.0	0.6	3.5	21.0	170,660
BERING DITCH								
04/06/89	90-45							4,300
10/23/89	9U-377							1,400
02/22/90	OM-200							85,000
04/17/90	OP-104							3,100,000
05/07/90	OR-21							8,000
07/17/90	OT-420	100.0						32,000
08/13/90	OU-391	400.0	9.5	0.1	1.3		10.8	2,000,000
08/21/90	OU-564							22,000
11/20/90	OY-256							42,000
12/06/90	OZ-177	80.0						21,000
03/07/91	1N-131	850.0						370,000
03/20/91	1N-154	850.0						TNTC
03/25/91	1N-163	850.0						320,000
04/10/91	1P-178	778.0	9.0	0.0	0.3		4.9	2,900
11/04/91	1Y-156	800.0	8.6	0.4	0.4	0.8	3.0	1,500
	AVERAGE	588.5	9.0	0.2	0.7	0.8	6.2	36,724
FARTHER POINT	120"							
10/23/89	9U-380							8,400
04/18/90	OP-114							3,600
08/16/90	OU-464	30.0	7.9	0.2	3.9	4.6	3.7	41,000
11/20/90	OY-263							1,100
11/05/91	1Y-164		8.2	0.1	0.7	0.9	2.9	3,700
	AVERAGE	30.0	8.1	0.2	2.3	2.8	3.3	5,503
SPRING BRANCH								
10/10/89	9U-263							4,700
02/06/90	OM-59							4,700
11/07/91	1Y-175		8.8	0.5	1.7	1.3	1.6	720
	AVERAGE		8.8	0.5	1.7	1.3	1.6	2,515

TABLE 4–2
CITY OF HOUSTON SEWER LEAK MONITORING DATA (CONTINUED)

LOCATION DATE	ID #	FLOW (GPM)	pH	NH_4–N	NO_3–N	TKN	CBOD	FC / dL*
ADAMS GULLY								
03/08/89	9N–67							130,000
03/20/89	9N–114		6.9	0.5	1.2		15.6	590,000
03/22/89	9N–132							93,000
03/27/89	9N–184							376,000
04/06/89	90–78		7.9	17.3			19.8	
04/19/89	90–134			6.0				2,100,000
05/26/89	9P–222		8.1	1.6	1.1		6.0	
07/13/89	9R–117			0.7	1.3		2.7	2,000,000
02/02/90	OM–21							3,300
03/23/89	ON–166							1,400
10/30/90	OX–301							8,900
05/02/91	1R–9	636.0	8.1	1.1	0.9	1.0	3.7	6,800
11/04/91	1Y–157		8.1	1.3	0.5	2.2	12.0	910
	AVERAGE	636.0	7.8	4.1	1.0	1.6	10.0	47,636
BRIARHOLLOW								
03/20/89	9N–120		7.7	0.5	0.9		12.7	140,000
05/23/90	OR–144		8.0	3.1	0.4		118.0	TNTC
05/30/90	OR–186							2,000,000
07/17/90	OT–421	50.0						9,400
08/16/90	OU–465	50.0	7.7	0.2	1.2	4.7	2.8	4,100
10/03/90	OX–185	60.0						44,000
10/30/90	OX–300							5,900
03/20/91	1N–155	150.0						24,000
03/25/91	1N–164	150.0						3,100
11/05/91	1Y–165		7.8	0.3	0.7	7.0	28.0	TNTC
	AVERAGE	92.0	7.8	1.0	0.8	5.9	40.4	25,994
SANDMAN								
04/06/89	90–69	15.0						110,000
04/24/89	90–193	150.0						TNTC
05/23/89	9P–205							520,000
10/03/90	OX–184	15.0	8.5	0.2	2.7	1.4	1.5	940
10/30/90	OX–308							1,600
05/07/91	1R–155	10.0	7.6	6.3	0.4	6.9	7.6	90,000
11/07/91	1Y–176		8.4	2.4	2.6	4.7	2.9	16,000
	AVERAGE	47.5	8.2	3.0	1.9	4.3	4.0	22,327
SHEPHERD								
03/29/89	9N–189	50.0	7.8	16.5	0.8		53.0	TNTC
03/23/90	ON–167	5.0						740
10/30/90	OX–309							23,000
11/07/91	1Y–177		8.4	0.6	2.0	3.1	8.4	12,000
	AVERAGE	27.5	8.1	8.6	1.4	3.1	30.7	5,889

TABLE 4–2
CITY OF HOUSTON SEWER LEAK MONITORING DATA (CONTINUED)

LOCATION DATE	ID #	FLOW (GPM)	pH	NH_4–N	NO_3–N	TKN	CBOD	FC / dL*
WILLOWICK								
03/08/89	9N–70							7,400
03/30/89	9N–197							1,740,000
04/03/89	90–18	80.0						1,600
04/24/89	90–182							TNTC
05/24/89	9P–211							52,000
07/13/89	9R–115			0.2	1.8		3.8	5,200
10/02/89	9R–26							9,600
02/12/90	OM–103							450
03/24/90	14							250,000
05/23/90	OR–145							2,700,000
07/17/90	OT–422	100.0						250,000
08/09/90	OU–313	120.0	8.3	0.1	1.3	0.9	3.4	6,900
10/01/90	OX–177	60.0						14,000
10/30/90	OX–303							34,000
04/10/91	1P–177							8,900
05/02/91	1R–8	219.0	7.8	1.6	0.8	7.2	6.4	810,000
05/14/91	1R–170	274.0						3,800
08/27/91	1R–228							6,600
10/02/91	1X–154	275.0	7.6	0.2	1.2	0.8	3.0	83,000
11/04/91	1Y–158		7.9	2.6	0.2	4.8	10.0	TNTC
	AVERAGE	161.1	7.9	0.9	1.1	3.4	5.3	28,919
OVERALL AVERAGE		**237.4**	**8.1**	**2.1**	**1.1**	**3.1**	**13.4**	**16,086**

* CALCULATIONS ARE OF GEOMETRIC MEAN WITH 1 dL = 100 mL

to be raw sewage and even in these cases the CBOD values are well below 100 mg/L. On the other hand, there are a larger group of observations which have FC levels in excess of one million counts per dL.

Several possible explanations are proposed which may be playing a role in the observations. The first is that a substantial portion of the leaks into the stormwater system may be freshwater. This would have the effect of diluting the wastewater chemical characteristics and also explain why in some cases there was still flow after the known sewer leak was repaired. A second factor may be the treatment effect which occurs during wastewater's flow down the stormsewer to the sampling point. During dry conditions, wastewater would have substantial time in what amounts to a linear trickling filter treatment plant. However, without disinfection at the end of the hypothesized treatment plant, FC levels would still be quite high. Another factor is that wastewater which leaves the sanitary sewer and reaches a storm sewer will have a substantial opportunity for settling of solids in the sanitary sewer. The sewage which reaches a storm sewer will thus be substantially weaker in strength than raw wastewater.

Whatever the explanation for the difference from the expected characteristics of raw sewage, it is submitted that these data are the best available to characterize the effect of collection system leaks under dry flow conditions. With a total of ten locations identified, the average of each flow measurement per location was computed. This was 237.4 gpm. The total of the average dry weather releases were 1,779 gpm. The geometric mean FC concentration was computed from the data available for each site. The geometric average of the site geometric means was 16,086 colonies/dL, with a range from 2,840 to 170,660. With the sewer service area of Buffalo Bayou between Addicks and Shepherd approximated by the difference in the two watershed areas (358 at Shepherd and 293 at Addicks or 65 sq mi), an estimate of dry weather FC input from sewer leakage per day per sq. mi. of sewered area can be derived.

1,779 gal/min/65 sq.mi. * 37.85 dL/gal * 1,440 min/day * 16,086 FC/dL = 2.4 E 10 FC/sq.mi./day

To the extent that this area is representative of other sewered areas around Galveston Bay, a rough quantification of dry weather sewer leak inputs of indicator bacteria is possible.

The City also maintains records of pump station excursions. These are estimates of releases which occur from events such as extremely high flows, mechanical breakdowns or power losses (which are generally associated with extreme storm conditions). Records provided by the Wastewater Quality Control branch include events for the years 1989 through June, 1991. The data included with each event the date, duration and estimated volume based on the size of the lift station and duration. The duration was determined through records of pump downtime and/or water level in the wet well. Over the thirty month period, approximately 500 individual events were monitored. The total release volume for 1989 was 52.8 MG, for 1990 12.2 MG and for the first six months of 1991, 26.0 MG. A high proportion of these events were associated with very wet periods (May 17-18 '89, 7"-13" of rain; June 23-28,'89, Tropical Depression Allison; August 1,'89, Tropical Storm Chantel). With 1990 being considerably dryer than 1989, the amount of lift station overflow was much smaller.

To provide a basis for projecting the Houston data to the entire bay, the entire cumulative monitored lift station flow of 91.0 MG is divided by the City's collection system area (536.3 sq. mi.) and number of days in the record (912) to yield an average daily lift station release per square mile of service area of 186 gallons/day/sq.mi. This flow is primarily stormwater mixed with some smaller proportion of sanitary sewage. The exact proportion will vary considerably but will probably be at least five parts stormwater to one part sewage. It is not uncommon for treatment plants to encounter storm inflows of six to ten times dry weather flow. To estimate the FC loading from lift station excursions requires an estimate of the FC concentration of this water. CoH personnel have sampled raw, dry-weather sewage on a number of occasions. The average of these FC observations is 10^7 col/dL (Garrett, 1992). With this value, an estimate of stormwater diluted sewage of 500,000 col/dL would seem quite conservative. Using this value, an excursion estimate is:

186 gal/sq.mi./day * 37.85 dL/gal * 500,000 col/dL = 3.52 E 9 col/sq.mi./day

On a per year basis, this would be 1.28 E 12 col./sq.mi./yr.

While lift station excursions during wet weather are a significant contributor, they are by no means all of the wet weather overflow points. Over the last seven+ years, many modifications and improvements have been made to eliminate or greatly reduce overflows. However, due to the nature of these points, it is very difficult to quantify total annual release volumes. The City does not maintain a database of other overflow point releases, and there is no way that these could be quantified within the constraints of this project without such a database.

For comparison, another estimate is derived from a study of nonpoint source loads to the Houston Ship Channel (HSC) watershed conducted for the TWC in the mid-1980's by Winslow and Associates in conjunction with Alan Plummer and Associates (WAI, 1986). This study calculated loadings to the HSC of a range of conventional pollutants (but no indicator bacteria) for urban runoff, sewer overflows, and wet weather WWTP overflows The basic finding of the study was that urban runoff contributed the great majority c oxygen demanding load to the HSC, and that overflows accounted for about 10% of th CBOD and 5 to 6% of the load for other conventional parameters.

While the WAI study did not quantify indicator bacterial loads, it did estimate loads from sanitary sewer wet weather overflow events. The calculations were based on 163 identified potential overflow points, a probability of an overflow given a rain event, and a number of rain events per year to yield a calculated 8,188 overflows per year within the 825 sq. mi. HSC basin. These values would indicate that each identified location overflowed 50 times per year. The calculated flow from each location was 121,614 cubic feet, 0.91 MG or 3,444 cubic meters per event.

Event mean concentrations (EMCs) reported for overflow sampling events suggests that stormwater accounts for the majority of the overflow volume. For example, the $CBOD_5$ EMC was 48.5 mg/L and the NH_4-N was 3.83 mg/L, on the order of 3-5 times higher than urban runoff and much lower than wastewater. To estimate the FC loading from this overflow volume, the same conservative concentration of 500,000 col/dL used for lift station excursions will be employed. The estimated indicator bacteria loading from wet weather sewer overflows in colonies per sq. mi. per year is:

8,188 events/yr * 3,444 m^3/event * 10,000 dL/m^3 * 5 E 5 col/dL / 825 sq. mi. = 1.71 E 14

On a per day basis this is 4.7 E 11. Comparing this to the dry weather estimate above, it is about 20 times greater, as would be expected.

4.3 SEPTIC SYSTEM FAILURES

To date, very little work has been done in quantifying either the volume or characteristics of partially treated wastewater from failing septic systems. A rough, very conservative and heavily qualified estimate is developed here based on discussions with Galveston and Harris County personnel involved in septic system regulation and tabulations of the number of shoreline systems.

Before reviewing the information obtained, a brief definition of terms is provided. A typical septic or subsurface disposal system consists of a tank or tanks in series followed by a subsurface drainfield. Household wastewater first enters the septic tank where solids settling and anaerobic decay are provided. Water leaves the septic tank through baffles (to avoid solids carryover) and enters the drainfield where it seeps into the ground. If for some reason, the drainfield becomes clogged, this water will back up to the surface. The amount of this partially treated water that leaves the property will depend on the degree of blockage and soil moisture conditions.

The quality of such partially treated wastewater can be expected to be highly variable due to differences in septic tank detention time (function of tank size, solids accumuation in the tank and loading rate) and the amount of soil that the water passes through or over before it enters surface waters. Soil type can also be an important factor. Coarse sandy soils can allow water to move off the site and to the surface with little detention time or treatment. On the other hand, overland flow through vegetated soils can provide very good treatment similar to a land application wastewater treatment system. However, even if septic wastewater is actually well treated before it reaches the bay (except for facilities directly on the bay) the effluent on the surface produces unacceptable nuisance and public health considerations.

In discussions with the Harris County Sanitarian's office, some rough estimates of the number of septic systems and system problems were discussed. The County began issuing permits for new subsurface disposal systems in 1978. Since that time there have been approximately 13,000 permits issued. However, this is only a portion of the total number of systems in the County. A substantial number of systems existed prior to 1978, and a substantial number still exist in incorporated areas of the County. County personnel estimated that the total number of septic systems in Harris County was on the order of 100,000.

Currently the Sanitarian's office receives between 30 and 45 complaints per month regarding subsurface systems. Of these, 25 to 30 typically involve some type of violation. A violation in this context means water is coming to the surface in some fashion. This might be an easily observable flow off of the property or just a small ponded location on the property. Of the 25 to 30 violations, roughly 5 to 10 involve only washing machine discharges which are not hooked into the septic system. Using these ranges, the actual number of sanitary waste releases to the surface observed by Harris County is thus in the range of 15 to 25 per month. Most of these are corrected in short order but some remain unfixed for some time due to various reasons. Because these reported violations may not include all septic system problems, the upper end of all ranges is employed. Using 25 failures per month and 100,000 total systems gives a rate of 0.025% per month that would result in some release of water to the surface.

Harris County also has performed some visual inspections in unincorporated areas. In the northeast portion of the county which includes several hundred thousand residences, some of which are sewered and some not, inspectors found a total of 1,922 instances where leakage might be occurring. These instances ranged from directly observed water flowing from the ground into an adjacent ditch to simple vegetation changes indicating a possible leak. Some of these leaks or possible leaks could have involved either potable water lines or sewer lines so it is impossible to draw firm conclusions. However, it does suggest that the number of marginal septic systems might be higher than the number reported through the complaint mechanism. The county representative also noted that the majority of the 1,922 instances were observed in a few specific areas in northeast Houston which were old and had very high population densities on small lots.

Galveston County Health District (Entringer, 1992) estimates there are approximately 4,500 structures in Galveston County served by septic systems, 95% of which are single family residences. According to Mr. Entringer, the County has investigated approximately 70 complaints since October of 1990, a period of 15 months. With a monthly rate of 4.67 complaints and 4,500 systems, this amounts to a monthly rate of 0.1% per month, not greatly different from the 0.025% rate estimated for Harris County. Entringer also notes that of the 70 complaints, very few "discharged wastewater directly in Galveston Bay or its tributaries".

Another important aspect in dealing with failing septic systems is that with the very small flows involved, any release located away from the immediate bay itself would, under dry weather and low flow conditions, be substantially degraded before it reached the bay. Under wet conditions, the small flows would render the release undetectable in the much larger volume of runoff, which generally has a substantial indicator bacteria concentration. Accordingly, only septic systems directly fronting on the bay are considered.

Septic systems close to the bay were tabulated by the TDH in their Sanitary Surveys of Galveston and West Galveston Bays (1988). A count of the systems identified in these reports yielded 5,275 in Galveston Bay and 2,893 in West Galveston Bay, for a total of 8,168 near-bay systems. While it is recognized that many of these residences are only occupied seasonally, it will be assumed that they are all in use year round. Taking the upper rate observed in Galveston County of 0.1% per month would indicate that at any one time, roughly eight systems will be having a problem of some type sufficient to produce a complaint. While Entringer notes that very few of the complaint systems actually release wastewater to the bay, it will be very conservatively assumed that each releases water at a typical single family wastewater flow rate of 150 gallons/day. To simplify and allow quantification of a very conservative estimate, it is also assumed that the water released is raw sewage with an FC concentration of 2 E 6 col/dL, rather than the much lower value one would expect after anaerobic decay in a septic tank. With these very conservative assumptions, a septic tank coliform loading estimate is:

8 systems * 150 gal/day/system * 37.85 dL/gal * 2 E 6 col/dL = 9.1 E 10 col/day

On a per year basis, this would be 3.3 E 13 colonies which could, with worst-case assumptions, reach the bay. Even with the very conservative assumptions, this source will be shown to be quite small relative to other sources.

4.4 RUNOFF INPUTS OF FC BACTERIA

Groundwater Services, Inc. (GSI) and Rice University conducted a characterization of non-point source (NPS) loadings to Galveston Bay. Their objective was to conduct a geographic analysis and priority ranking of possible non-point sources and loads to

Galveston Bay. The primary elements for the non-point analysis included watershed hydrology, load estimates, ranking of subwatersheds, upper watershed influences, and mapping. The following is a summary of the non-point source loadings of FC to Galveston Bay developed by GSI.

The study on NPS loadings to Galveston Bay performed by GSI started by dividing the entire drainage basin of Galveston Bay into 21 watersheds based on drainage and topographic characteristics. These watersheds were further divided into 100 subwatersheds based on major watershed boundaries, subwatershed size, USGS watershed boundaries, and land uses. A watershed was defined as the drainage of a major stream flowing into Galveston Bay, and a subwatershed was a smaller area with generally uniform land use characteristics encompassing the vicinity of a tributary to a major stream.

Land use information was established and categorized by GSI based on interpreted satellite imagery. Their study found the following landuse distribution for the Galveston Bay drainage area below lakes Livingston and Houston: 10% high-density urban, 9% residential, 23% open/pasture, 22% agricultural, 1% barren, 15% wetlands, 1% water, and 18% forest areas.

Event mean concentrations (EMC), were estimated from a variety of local and nationwide data sources. The major sources for EMC data were the Rice University NPS Studies, the USGS Houston Urban Runoff Program Data, and the Texas Water Commission/Winslow Associates Houston Ship Channel NPS Study. Other sources included data from the EPA Nationwide Urban Runoff Program (NURP), the Priority Pollutant Survey from the NURP Program, the USGS Austin NPS study, and various agricultural NPS studies. FC EMCs employed by GSI were:

Land Use Category	FC EMCs (colonies/dL)	Relative Accuracy
High Density Urban	22,000	Good
Residential	22,000	Good
Agricultural	2,500	Fair
Open/Pasture	2,500	Fair
Barren	1,600	Fair
Wetlands	1,600	No Data
Water	0	No Data
Forest	1,600	Good

With these EMC values, three rainfall cases were formulated and the total NPS loads associated with each case were computed. The rainfall amounts from the three cases (an average year, a wet year with a 10-year return period, and an individual storm with 4.5 inch uniform rainfall) were transformed into runoff using the Soil Conservation Service method (SCS, 1986). The computed NPS loading of FC for each of the three cases are:

Case	FC Loads to Bay (*E15 colonies)
1. Average Year	355
2. Wet Year	531
3. Individual Storm	55

In addition, the computed NPS load of FC from each land use for the average year (case 1) are:

Land Use Category	FC Loads (*E15 colonies)
High Density Urban	208
Residential	101
Agricultural	18
Open/Pasture	17
Barren	0
Wetlands	4
Water	0
Forest	7

As for the spatial variation of the NPS loadings of FC, the computed coliform (and other substance) loads associated with the case 1 average year are listed in Table 4-3, which is Table 7.1c reproduced from the GSI report.

Several conclusions were drawn by GSI from this study. The first was that the precise sources of NPS loads were relatively difficult to determine due to their widespread, diffuse nature. The second was that the results from the three cases indicated that a significant portion of the annual loads occurred during a few of the largest rainfall events during the year. The third conclusion was that high density urban land use areas were the main contributor of NPS loads to the bay. For FC, this land use category contributed 59% of the total annual NPS loads from all categories. The last conclusion from this study was that the highly urbanized areas in Houston, Baytown, Texas City, and Galveston showed the highest loads per unit area for FC.

TABLE 4-3

AVERAGE YEAR TOTAL NON-POINT SOURCE (NPS) LOADS PER AREA BY WATERSHED

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NPS Loads by Unit Area										
Watershed	Area (sq mi)	Runoff Volume (thousand acre-ft)	Total Suspended Solids (kg/ha)	Total Nitrogen (kg/ha)	Total Phosphorus (kg/ha)	Biochemical Oxygen Demand (kg/ha)	Oil and Grease (kg/ha)	Fecal Coliform (bil. col/ha)	Dissolved copper (1/1000 kg/ha)	Pesticides (1/1000 kg/ha)
Project Area	4,238	3,010	438	5.85	1.0	24.0	12.9	323	9.9	0.7
Addicks Reservoir	134	82	618	5.60	1.0	19.7	10.7	264	9.0	0.6
Armand/Taylor Bayou	77	70	584	8.41	1.4	34.1	25.5	564	12.8	1.1
Austin/Bastrop Bayou	213	121	380	4.44	0.8	16.1	4.2	158	8.0	0.4
Barker Reservoir	122	71	**1,022**	5.73	1.0	18.2	6.7	182	8.6	0.4
Brays Bayou	127	147	867	12.30	2.3	50.0	**50.6**	**1,018**	17.0	1.9
Buffalo Bayou	105	116	795	12.40	2.4	51.2	46.7	1,008	16.4	1.9
Cedar Bayou	211	153	469	5.86	1.1	22.5	6.3	230	10.5	0.5
Chocolate Bayou	170	95	434	4.27	0.8	14.3	2.9	125	8.0	0.3
Clear Creek	182	138	474	6.39	1.1	25.1	14.4	346	10.7	0.7
Dickinson Bayou	101	60	317	4.97	0.8	19.7	7.2	222	8.5	0.5
East Bay	288	193	348	5.21	0.9	21.0	6.1	223	9.1	0.5
Greens Bayou	209	184	559	9.20	1.7	38.9	25.4	630	13.0	1.2
North Bay	25	25	621	10.06	1.8	41.6	33.9	740	14.6	1.4
San Jacinto River	68	65	454	7.12	1.2	30.7	13.2	391	11.4	0.8
Ship Channel	166	198	787	11.56	2.1	47.3	44.6	914	16.5	1.7
Sims Bayou	93	91	660	9.76	1.7	39.6	32.2	697	14.4	1.3
South Bay	78	68	503	6.87	1.2	27.8	30.5	572	10.5	1.1
Trinity Bay	317	225	312	4.34	0.7	18.0	3.4	151	8.6	0.4
Trinity River	**1,099**	**572**	217	3.08	0.4	15.0	1.9	95	7.4	0.3
West Bay	344	212	335	4.55	0.8	18.0	9.6	237	7.9	0.5
White Oak Bayou	110	128	840	**12.78**	**2.4**	**52.5**	46.9	1,012	**17.1**	**1.9**
Median	134	121	503	6.39	1.1	25.1	13.2	346	10.5	0.7
Maximum	1,099	572	1,022	12.78	2.4	52.5	50.6	1,018	17.1	1.9
Minimum	25	25	217	3.08	0.4	14.3	1.9	95	7.4	0.3

Note:

1. Boldface/underline indicates highest watershed load for the parameter.
2. Source: Non-point source characterization Project, GSI, 1991.

One limitation of the study is the lack of information on the FC inputs from wetland areas. The GSI study employed an EMC of 1,600 col/dL, the same as for barren land and lower than agricultural or open land. While there has been little monitoring effort directed at FC concentrations from wetland areas, TDH personnel report that bay waters adjacent to wetland areas show rapid increases in FC levels following even moderate rains (Wiles, 1992). Similar observations and documentation were presented for tidal wetlands in Jensen, et. al. (1980). It is believed that had a more representative EMC been employed (higher than agricultural land), the relative contribution of wetlands to the baywide FC load would be more accurately portrayed. However, this would still undercount the actual contribution of wetlands to observed bay FC levels, simply because of their proximity to the bay relative to urban land areas.

4.5 DISCUSSION AND ANALYSIS

Comparing numbers on the urban loadings, it is reassuring to find some measure of agreement and some indication of progress. The agreement observed is between the calculated wet-weather load from the TWC/WAI study, using a perhaps generous FC EMC of 500,000 col/dL, and the GSI urban areal FC load. As calculated earlier using the WAI base, the areal load was 1.7 E 14 col/sq.mi./yr. The urban areas of Houston, represented by Brays and Buffalo bayous have areal loads of on the order of 1 E 12 col/ha per average year (Table 4-3). Converting the hectares to square miles yields 2.59 E 14 col/sq.mi/yr, in close agreement with the WAI-based value. This should not be considered too surprising since the GSI calculation was based in part on WAI and other data collected during a similar period.

The indication of progress is that current wet-weather loads, based on the lift station excursion data, are on the order of 1.3 E 12 col/sq.mi./yr, roughly two orders of magnitude less. While lift stations are certainly not the only wet-weather overflow points remaining, they are one of the major places where extreme flows can escape. At some point in the future, these should be the only major wet-weather overflow points for precipitation events which do not exceed the collection system design criteria. The dry-weather FC loads are smaller still by roughly two additional orders of magnitude.

Based on the data developed, treatment plants operating normally are not a significant source of FC bacteria. While treatment plant bypasses do occur, based on the Houston sample, they do not occur with sufficient regularity or magnitude to warrent quantification. Overflows and other collection system releases will continue to be a significant wet weather source, but the data available suggests that it will be considerably less in the future than was quantified in the GSI/Rice study using mainly data from the early 1980s.

Inputs from malfunctioning septic systems will be detectable only in the immediate locale and then only during wet weather when other sources will likely dominate. For example, the very conservative (probably by several orders of magnitude) estimate of near-bay failing septic system inputs, is roughly 500 times smaller than GSI's calculated inputs from agricultural land alone. While septic system contributions of indicator bacteria to the bay are undoubtedly insignificant relative to other sources, they still pose nuisance and public health concerns and have the potential to infect shellfish in the immediate vicinity of the system. The fact that septic systems appear to be a minor contributing factor should not be taken as a justification for reduced monitoring or problem correction efforts.

Based on the above discussion, EH&A believes that the GSI calculated FC load to the bay, which implicitly incorporates all of the sources discussed, is approximately correct. EH&A has only two reservations about this calculated load. One is the EMC value employed for urban and residential areas. This was developed from data collected at a time when bypasses and overflows in the Houston area may have been worse than they are today. On the other hand FC concentrations in urban/residential runoff are substantial even when an area is new and presumably has a tight collection system. Also, collection system work in other communities around the bay has not been nearly as extensive as in the Houston area. The second reservation is that the EMC value employed for wetlands is substantially lower than is actually the case. However, these are nothing more than reservations with no quantative basis for changes. Given the next point, there is little to be gained by refining the GSI FC loads.

While a quantification of indicator bacteria input to surface waters is a useful exercise, it is only part of the total picture. This is because coliform bacteria generally die off rapidly when introduced to surface waters (Mitchell and Chamberlain, 1974; Bellaire, et. al, 1977; Thomann and Mueller, 1987). The die off can reduce very high levels in the immediate vicinity of a wash off point to normal background levels in a matter of days.

In addition, FC inputs into many tributary streams may never reach Galveston Bay. This is particularly true in the highly urbanized streams of the Houston area feeding into the Houston Ship Channel, which provides a relatively long residence time before entering the bay. In short, while calculated FC loads to the bay are large, high concentrations in the bay tend to be localized and of short duration. This phenomona is illustrated by the TDH management plan for the conditional areas of Galveston Bay. These areas are closed following heavy rains (or high Trinity River inflows) but are reopened in a relatively short time, determined by post-rain monitoring.

The difference between actual data and calculated concentrations based on wash off inputs, without considering die off and hydraulic factors can be appreciated in Table 4-4. This table compares the average year FC runoff-based concentrations (from Table 7.1b of the GSI report) with actual geometric mean FC data for various areas where comparable segment definitions exist. It can be seen that reasonably similar FC concentrations exist for the two methods on some of the Houston area bayous. For example, the geometric

TABLE 4-4
COMPARISION OF MEASURED FC LEVELS AND
FC CONCENTRATIONS CALCULATED FROM RUNOFF

Watershed*	Area* (sq. miles)	Runoff* Volume (thousand acre-ft)	Calculated* Average FC Concentration (col/dL)	Measured Long Term** Geometric Mean FC (col/dL)
GBNEP	4,238	3,010	9,576	---
Addicks Reservoir	134	82	9,122	---
Armand/Taylor Bayou	77	70	12,991	35
Austin/Bastrop Bayou	213	121	5,858	79
Barker Reservoir	122	71	6,557	---
Brays Bayou	127	147	18,558	12,159
Buffalo Bayou	105	116	19,178	3,848
Cedar Bayou	211	153	6,686	151
Chocolate Bayou	170	95	4,703	80
Clear Creek	182	138	9,590	458
Dickinson Bayou	101	60	7,876	418
East Bay	288	193	6,983	4
Greens Bayou	209	184	15,003	4,157
North Bay	25	25	15,365	---
San Jacinto River	68	65	8,671	132
Ship Channel	166	198	16,157	1,494
Sims Bayou	93	91	15,039	627
South Bay	78	68	13,691	---
Trinity Bay	317	225	4,475	7
Trinity River	1,099	572	3,833	45
West Bay	344	212	8,081	7
White Oak Bayou	110	128	18,332	---

*Source: Table 7.1b (GSI, 1992)
**Geometric average of quadrilaterals from Table 5-2

mean of the Brays Bayou data is 12,159 FC/dL while the calculated mean from runoff data is 18,588 FC/dL. Buffalo and Greens bayous appear at least qualitativly similar. However, when comparing the open bay areas such as East, West or Trinity bays, there is no relation whatsoever. For example, East Bay's input based value is 6,983 FC/dL while its actual long-term geometric mean is 4 FC/dL. Clearly, a simple quantification of inputs sheds little light on the actual FC concentrations that will be experienced in the bay itself. However, quantification of factors such as source dynamics, die off rates (a function of light intensity, substrate concentration, etc.) and mixing processes is well beyond the scope of this project.

5.0 ANALYSES OF COLIFORM DATA

Both TC and FC data from the TDH, TWC and predecessor agencies, including the TWQB, (the old Galveston Bay Project) for the Galveston Bay system have been collected and analyzed. The analyses include a check on the frequency and extent of areas exceeding water quality criteria, examination of temporal trends for selected stations, and investigation on the relationship between TC and FC data. The results of these analyses are documented in this section.

5.1 DATA DESCRIPTION

5.1.1 Segmentation of Galveston Bay System

Before coliform data were analyzed, it was noted that some existing TWC water quality segments might be too big to have unique characteristics. For example, Segment 2439 covers lower Galveston Bay including part of the Texas City Harbor and Houston Ship Channels, where water quality varies significantly inside the segment. If coliform data from all stations in Segment 2439 were averaged and analyzed together, the result might not be very meaningful.

According to Ward (1991), there should be two broad objectives for imposing a segmentation system on an estuary. The first objective is administrative; the segmentation may be based on political and geographic boundaries. The second objective is analytical with segmentation criteria being delineation of regions of relative homogeneity in properties. Based on these considerations, and a need to remain consistent with the existing TWC segments, Ward (1991) subdivided TWC segments into quadrilaterals which are listed in Table 5-1. Figure 5-1 shows the quadrilaterals for the open bay areas. The collected coliform data were analyzed based on quadrilaterals developed by Ward. Note that Ward has also developed a set of segments which emphasis homogeneity. These are not employed in this analysis but are used in a data analysis by Ward (1992).

5.1.2 Sources and Types of Coliform Data

There are three major coliform data sources: TWC, TDH, and TWQB. Dr. G. Ward of The University of Texas at Austin has collected, checked, and analyzed these data and has provided these data to EH&A. As part of the QA/QC procedures, EH&A also obtained coliform data directly from TWC and compared them with data provided by Dr. Ward to confirm the identity of the data before they were analyzed.

All three data sources have both TC and FC records. Both TDH and the TWQB data are MPN observation while the MF observations are reported by TWC. Another difference should be noted in the data collecting time. TDH may be more likely to collect data after

TABLE 5–1
QUADRILATERALS IN GALVESTON BAY SYSTEM

Segment	Description
TWC Segment 0801A –	Trinity River Tidal
TWC Segment 0802 –	Trinity River Below Lake Livingston
TWC Segment 0901B –	Cedar Bayou Tidal
TWC Segment 0902A –	Cedar Bayou Above Tidal
TWC Segment 0902B –	Cedar Bayou Above Tidal
TWC Segment 1001B –	San Jacinto River Tidal
TWC Segment 1005B –	Houston Ship Channel/San Jacinto River
TWC Segment 1005C –	Houston Ship Channel/San Jacinto River
TWC Segment 1005D –	Houston Ship Channel/San Jacinto River
TWC Segment 1005E –	Houston Ship Channel/San Jacinto River
TWC Segment 1005G –	Houston Ship Channel/San Jacinto River
TWC Segment 1005I –	Houston Ship Channel/San Jacinto River
TWC Segment 1006A –	Houston Ship Channel
TWC Segment 1006B –	Houston Ship Channel
TWC Segment grnsc –	Greens Bayou C
TWC Segment grnsd –	Greens Bayou D
TWC Segment 1007A –	Houston Ship Channel/Buffalo Bayou
TWC Segment 1007C –	Houston Ship Channel/Buffalo Bayou
TWC Segment 1007D –	Houston Ship Channel/Buffalo Bayou
TWC Segment simsb –	Sims Bayou
TWC Segment brays –	Brays Bayou
TWC Segment huntb –	Hunting Bayou
TWC Segment 1013 –	Buffalo Bayou Tidal
TWC Segment 1014 –	Buffalo Bayou Above Tidal
TWC Segment 1101A –	Clear Creek Tidal
TWC Segment 1101B –	Clear Creek Tidal
TWC Segment 1102 –	Clear Creek Above Tidal
TWC Segment 1103 –	Dickinson Bayou Tidal
TWC Segment 1104 –	Dickinson Bayou Above Tidal
TWC Segment 1105A –	Bastrop Bayou Tidal
TWC Segment 1105B –	Bastrop Bayou Tidal
TWC Segment 1105C –	Bastrop Bayou Tidal
TWC Segment 1105D –	Bastrop Bayou Tidal
TWC Segment 1107 –	Chocolate Bayou Tidal
TWC Segment 1113A –	Armand Bayou Tidal
TWC Segment 2421A –	Upper Galveston Bay
TWC Segment 2421B –	Upper Galveston Bay
TWC Segment 2421C –	Upper Galveston Bay
TWC Segment 2421D –	Upper Galveston Bay
TWC Segment 2421E –	Upper Galveston Bay
TWC Segment 2422A –	Trinity Bay
TWC Segment 2422B –	Trinity Bay
TWC Segment 2422C –	Trinity Bay
TWC Segment 2423 –	East Bay
TWC Segment 2424A –	West Bay
TWC Segment 2424B –	West Bay

TABLE 5-1
QUADRILATERALS IN GALVESTON BAY SYSTEM
(CONTINUED)

Segment	Description
TWC Segment 2424C	– West Bay
TWC Segment 2424D	– West Bay
TWC Segment 2424E	– West Bay
TWC Segment 2425	– Clear Lake
TWC Segment 2426A	– Tabbs Bay
TWC Segment 2426B	– Tabbs Bay
TWC Segment 2427	– San Jacinto Bay
TWC Segment 2428	– Black Duck Bay
TWC Segment 2429	– Scott Bay
TWC Segment 2430	– Burnett Bay
TWC Segment 2431	– Moses Lake
TWC Segment 2432	– Chocolate Bay
TWC Segment 2433A	– Bastrop Bay/Oyster Lake
TWC Segment 2433B	– Bastrop Bay/Oyster Lake
TWC Segment 2434	– Christmas Bay
TWC Segment 2435	– Drum Bay
TWC Segment 2436	– Barbours Cut
TWC Segment 2437	– Texas City Ship Channel
TWC Segment 2438	– Bayport Channel
TWC Segment 2439A	– Lower Galveston Bay
TWC Segment 2439B	– Lower Galveston Bay
TWC Segment 2439C	– Lower Galveston Bay
TWC Segment 2439D	– Lower Galveston Bay
TWC Segment 2439E	– Lower Galveston Bay
TWC Segment 2439F	– Lower Galveston Bay
TWC Segment 2439G	– Lower Galveston Bay
TWC Segment 2439H	– Lower Galveston Bay

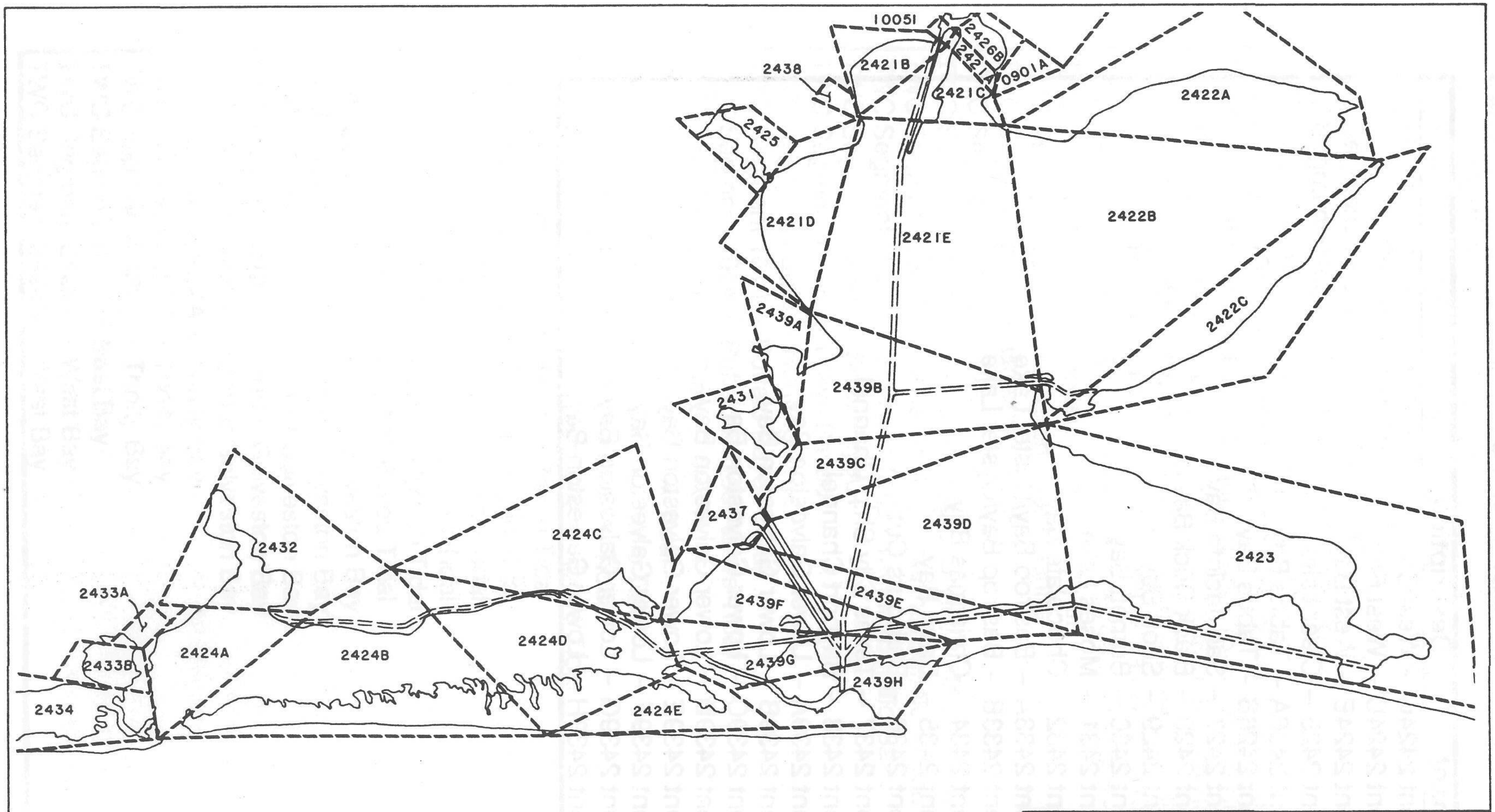

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FIGURE 5-1
QUADRILATERALS
FOR GALVESTON BAY AREAS

rainfalls since their mandate is to characterize coliform levels under "adverse pollution conditions". The TWC and earlier TWQB monitoring have no such requirement. Because of these differences the data will be reported separately. However, no attempt will be made to quantify the possible differences.

The periods of records for data from the three sources are not the same. For TWQB data, they range about from 1965 to 1975 with the greatest sampling intensity during the first GB project. For TDH data, they cover the period from 1950 to present. The TWC data start in about 1980 and continue to present. These differences in time frames provide a comparison among data from the three sources which is illustrated in the following trend analysis section.

TC and FC data also occupy different time frames. The TC data range from about 1950 to 1985. The FC data started in about 1965 up to present. The relationship between TC and FC data is investigated in Section 5.3.

5.2 STATISTICS ON COLIFORM DATA FOR GALVESTON BAY SYSTEM

Table 5-2 presents a statistical summary of FC data for all quadrilaterals in the Galveston Bay system. The first column of Table 5-2 is a list of the quadrilaterals. The second and third columns give the beginning and the ending dates of the available FC data. As can be seen in Table 5-2, most quadrilaterals started having FC data in 1968.

The fourth and fifth columns in Table 5-2 are the total number of FC data and their geometric mean for each quadrilaterals. These mean values represent a long term average of the FC level and can be viewed as a good indication for the average water quality condition in each quadrilateral. From these long-term average values, it can be seen that there are 22 quadrilaterals satisfying the criteria for approved shellfish growing waters, 14 FC/dL. These 22 quadrilaterals cover the open bay 1105c, 2421c, 2421e, 2422a, 2422b, 2422c, 2423, 2424a, 2424b, 2424c, 2424d, 2431, 2433b, 2434, 2435, 2437, 2439a, 2439b, 2439c, 2439d, 2439e, and 2439f (see Figure 5-1). Using the 200 FC/dL criterion for contact recreation, there are 50 quadrilaterals which meet the criterion. In fact, there are only 23 quadrilaterals whose long term mean FC values exceed the contact recreation criteria. These are mainly the urban bayous and waterways in the Houston area: 901b, 1005b, 1005c, 1005d, 1005e, 1005g, 1006a, 1006b, grnsc, grnsd, 1007a, 1007c, 1007d, simsb, brays, huntb, 1013, 1014, 1101a, 1102, 1103, 1104, and 1105a. Thus, from a long term view point, the above areas are not appropriate for recreational activities. Figure 5-2 shows a map of the open bay areas of the Galveston Bay system with the long-term FC geometric mean values.

The sixth column in Table 5-2 lists the number of observations among the total that exceeds the 14 FC/dL criterion, and the seventh column gives the associated percentages.

TABLE 5–2
ANALYSIS OF FECAL COLIFORM DATA

TWC River Segment	Record Period Begin YYMMDD	Record Period End YYMMDD	Total Available Data No.	Total Available Data Mean*	Data Exceeded 14 col./100 mL No.	Data Exceeded 14 col./100 mL % Exc	Data Exceeded 14 col./100 mL Mean*	Data Exceeded 200 col./100 mL No.	Data Exceeded 200 col./100 mL % Exc	Data Exceeded 200 col./100 mL Mean*
TWC801a	710914	900828	126	67	104	82.5	106	29	23.0	686
TWC802	720412	871215	127	30	80	63.0	81	21	16.5	445
TWC901b	710629	900828	71	262	66	93.0	343	43	60.6	827
TWC902a	730823	900312	60	167	51	85.0	265	26	43.3	948
TWC902b	900828	900828	1	80	1	100.0	80	0	0.0	0
TWC1001b	710726	900118	127	132	107	84.3	210	48	37.8	929
TWC1005b	680716	701020	106	3107	101	95.3	4086	91	85.8	6778
TWC1005c	671001	900813	285	367	256	89.8	557	161	56.5	2057
TWC1005d	720516	720516	1	790	1	100.0	790	1	100.0	790
TWC1005e	720516	720516	1	1300	1	100.0	1300	1	100.0	1300
TWC1005g	680716	720516	104	353	90	86.5	638	59	56.7	2310
TWC1005i	690514	910717	292	37	184	63.0	85	40	13.7	832
TWC1006a	720504	900813	197	1381	190	96.4	1559	162	82.2	2564
TWC1006b	680716	900711	425	1985	406	95.5	2543	336	79.1	5182
TWCgrnsc	730801	870928	120	4506	119	99.2	4836	113	94.2	5820
TWCgrnsd	720808	870928	84	3835	82	97.6	4192	78	92.9	5096
TWC1007a	680716	900813	694	8421	651	93.8	11979	618	89.0	15767
TWC1007c	680716	900813	532	7618	513	96.4	9363	494	92.9	11236
TWC1007d	680716	870928	128	21655	124	96.9	27986	117	91.4	39042
TWCsimsb	711026	870928	62	627	49	79.0	1322	33	53.2	6256
TWCbrays	711026	870928	88	12159	86	97.7	14613	84	95.5	16361
TWChuntb	730801	870928	69	2708	66	95.7	3338	62	89.9	4346
TWC1013	720808	890328	89	18597	89	100.0	18597	89	100.0	18597
TWC1014	730801	890328	205	3848	188	91.7	5360	169	82.4	8783
TWC1101a	701030	890608	77	724	71	92.2	1040	57	74.0	1939
TWC1101b	730919	900910	248	198	216	87.1	315	121	48.8	1178
TWC1102	671001	900910	308	682	294	95.5	834	232	75.3	1522
TWC1103	640305	900710	327	301	309	94.5	370	199	60.9	894
TWC1104	671001	900710	88	580	85	96.6	657	77	87.5	805
TWC1105a	671001	820217	42	419	42	100.0	419	31	73.8	664
TWC1105b	730920	901116	66	153	57	86.4	236	32	48.5	646
TWC1105c	720614	910430	41	11	15	36.6	88	4	9.8	835
TWC1105d	710623	730523	5	56	3	60.0	276	1	20.0	4600
TWC1107	701021	901218	78	80	58	74.4	165	21	26.9	1329
TWC1113a	740409	860206	18	35	11	61.1	114	4	22.2	462
TWC2421a	690514	910717	83	15	38	45.8	85	5	6.0	1095
TWC2421b	680716	910813	274	26	150	54.7	136	54	19.7	1016
TWC2421c	691104	910717	119	8	36	30.3	44	4	3.4	304
TWC2421d	680716	910813	778	15	349	44.9	97	105	13.5	612
TWC2421e	680402	910813	1345	7	324	24.1	51	39	2.9	658
TWC2422a	680820	910717	367	9	129	35.1	58	20	5.4	334
TWC2422b	680402	910717	1281	4	183	14.3	42	19	1.5	384
TWC2422c	680716	910702	314	9	105	33.4	111	35	11.1	568
TWC2423	680716	910729	933	4	139	14.9	50	18	1.9	490

TABLE 5-2
ANALYSIS OF FECAL COLIFORM DATA (CONTINUED)

TWC River Segment	Record Period		Total Available Data		Data Exceeded 14 col./100 mL			Data Exceeded 200 col./100 mL		
	Begin YYMMDD	End YYMMDD	No.	Mean*	No.	% Exc	Mean*	No.	% Exc	Mean*
TWC2424a	680716	910424	298	6	65	21.8	129	27	9.1	645
TWC2424b	710712	910424	363	4	23	6.3	28	0	0.0	0
TWC2424c	730124	910424	283	7	81	28.6	47	8	2.8	575
TWC2424d	680716	910424	912	6	215	23.6	44	21	2.3	497
TWC2424e	730508	901213	491	22	272	55.4	83	66	13.4	600
TWC2425	701030	901210	452	64	313	69.2	157	133	29.4	764
TWC2426a	720516	790516	24	23	9	37.5	90	4	16.7	397
TWC2426b	690514	910717	125	20	60	48.0	90	14	11.2	894
TWC2427	730911	900711	64	34	35	54.7	95	10	15.6	766
TWC2428	730911	900828	52	54	31	59.6	164	14	26.9	520
TWC2429	730911	900711	61	66	50	82.0	100	13	21.3	665
TWC2430	730911	900711	60	56	41	68.3	125	15	25.0	616
TWC2431	680923	900815	278	13	97	34.9	118	37	13.3	632
TWC2432	710623	901218	77	15	28	36.4	97	9	11.7	534
TWC2433a	730124	910424	54	17	26	48.1	109	9	16.7	1016
TWC2433b	720614	910430	84	6	11	13.1	82	2	2.4	885
TWC2434	710623	910430	164	3	7	4.3	49	1	0.6	350
TWC2435	720614	910430	55	5	5	9.1	32	0	0.0	0
TWC2436	730214	900711	55	34	32	58.2	88	4	7.3	1448
TWC2437	710622	910729	125	10	28	22.4	57	5	4.0	632
TWC2438	731105	900719	60	19	22	36.7	64	5	8.3	657
TWC2439a	690520	910813	264	10	89	33.7	115	27	10.2	775
TWC2439b	680402	910813	2250	5	378	16.8	51	59	2.6	388
TWC2439c	680402	910813	603	4	73	12.1	40	7	1.2	363
TWC2439d	680402	910729	618	5	108	17.5	48	10	1.6	440
TWC2439e	680716	910729	150	3	11	7.3	31	0	0.0	0
TWC2439f	680716	910729	231	9	63	27.3	189	29	12.6	1066
TWC2439g	680716	910729	390	80	234	60.0	566	140	35.9	3740
TWC2439h	820921	901113	16	18	5	31.3	114	1	6.3	1000

* Mean = Geometric Mean in colonies/100 mL

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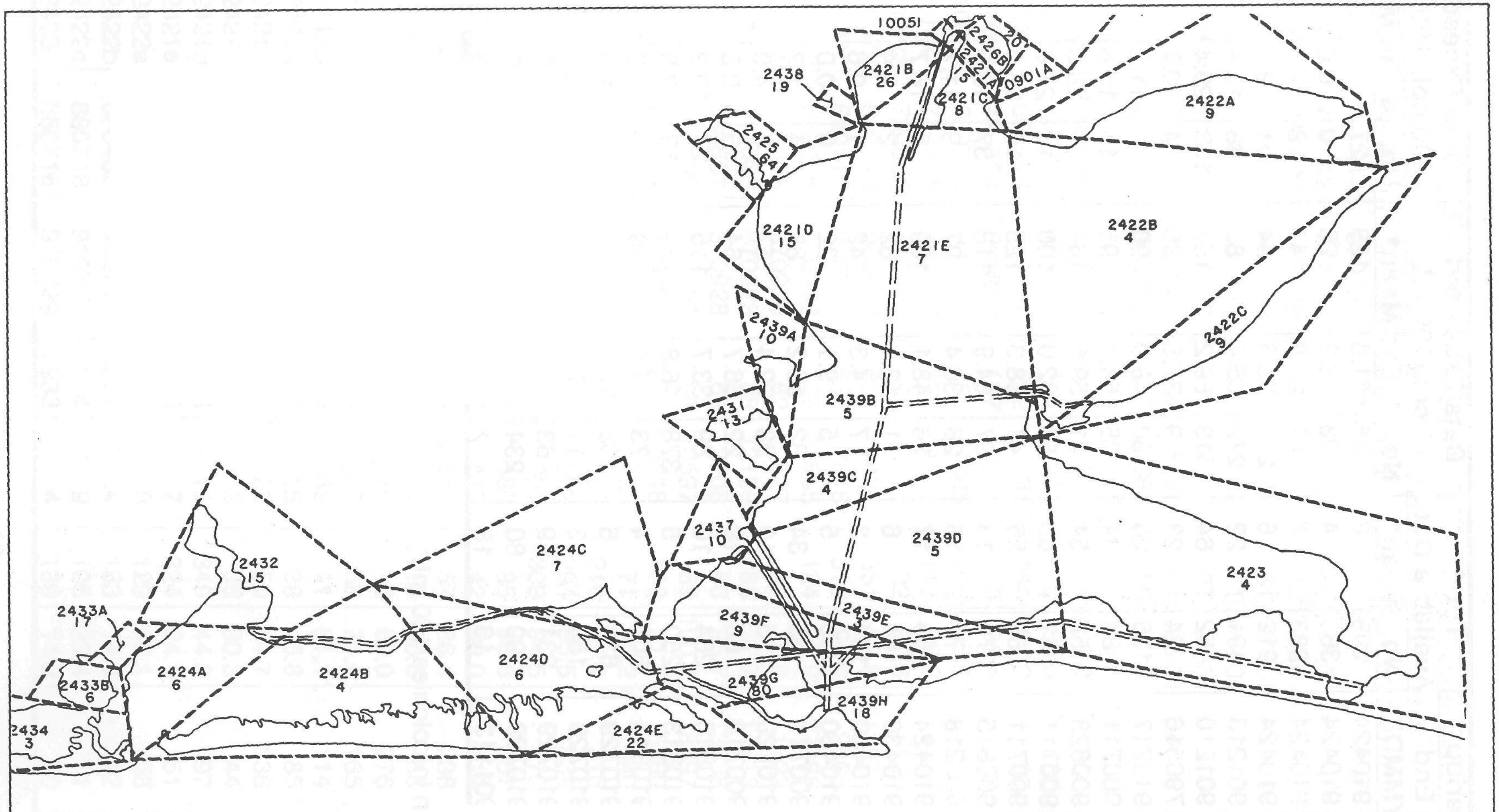

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FIGURE 5-2

LONG-TERM MEAN FECAL COLIFORM LEVELS IN GALVESTON BAY

The eighth column lists the geometric mean of those data which exceed the 14 criterion for each quadrilateral. The seventh column shows that there are 5 quadrilaterals, namely 902b, 1005d, 1005e, 1013, and 1105a, where the all the data are in excess of 14 FC/dL. However, it must be noted that three of these only have one data value.

While many of the urban bayous have relatively high FC levels, the open bay areas where most of the shellfish reefs are located, i.e. Segments 2421 to 2439, there are nine quadrilaterals with more than 50 percent of their data in excess of the 14 criterion. The remaining 29 quadrilaterals in the open bay areas all have less than 50% of data exceeding the criterion. Figure 5-3 shows the open bay area quadrilaterals with the percentage of data in excess of the 14 FC/dL criterion.

A similar analysis was performed on the data using the 200 FC/dL criterion for recreational waters. The resulting tabulations are listed in the last three columns of Table 5-2. Figure 5-4 shows a map of the open bay areas with the percentage in excess of the 200 FC/dL criterion. As can be seen, there are four quadrilaterals, 0902b, 2424b, 2435, and 2439e, where none of the data exceed the 200 criterion. While 0902b only has one observation the rest have a significant number. At the other extreme, segment 1013, Buffalo Bayou Tidal has all its data exceeding the contact recreation criterion. Five other quadrilaterals have more than 90% of their data exceeding the 200 criterion. However, they all are riverine segments and most of them are located in the Houston area.

5.3 RELATIONSHIP BETWEEN TC AND FC

As a general rule, the TC levels are about five times higher than FC (Kenner, 1978) although a wide spread exists in this ratio. To investigate this ratio, the geometric means of TC and FC data for each quadrilaterals are computed in Table 5-3 with the ratio listed in the last column. As can be seen from the table, the values of the long-term average TC to FC range from 0.8 to 75.1 with an average of 10.6, not 5. In addition to those possible reasons described in Section 2.3, the causes of the wide variations in this ratio include that the data are from different sources, measured by different organizations, measured at different weather conditions, and within different recording periods.

Regression analyses were conducted on the long-term geometric mean TC and FC values. The resulting equation for a linear scale is

$$TC = 3{,}009 + 6.68 * FC$$

with $R^2 = 0.666$. In other words about 66.6% of the TC data variance is explained by FC data and the TC/FC ratio is 6.68. On the other hand, regression on the logarithmic scale gives that

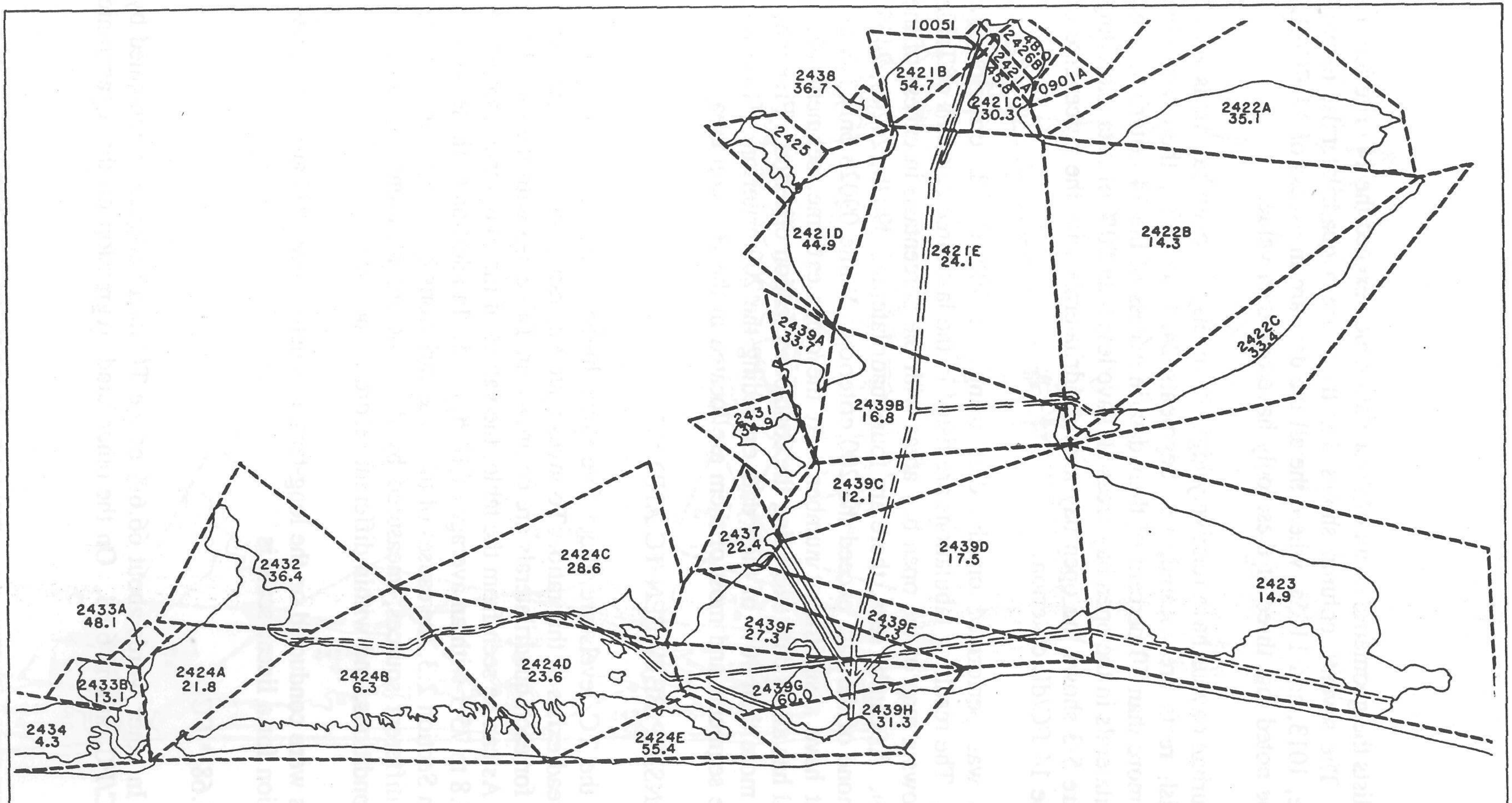

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FIGURE 5-3
PERCENTAGES OF LONG-TERM MEAN
FECAL COLIFORM LEVELS EXCEEDING
14 COLONIES/100mL CRITERION
IN GALVESTON BAY

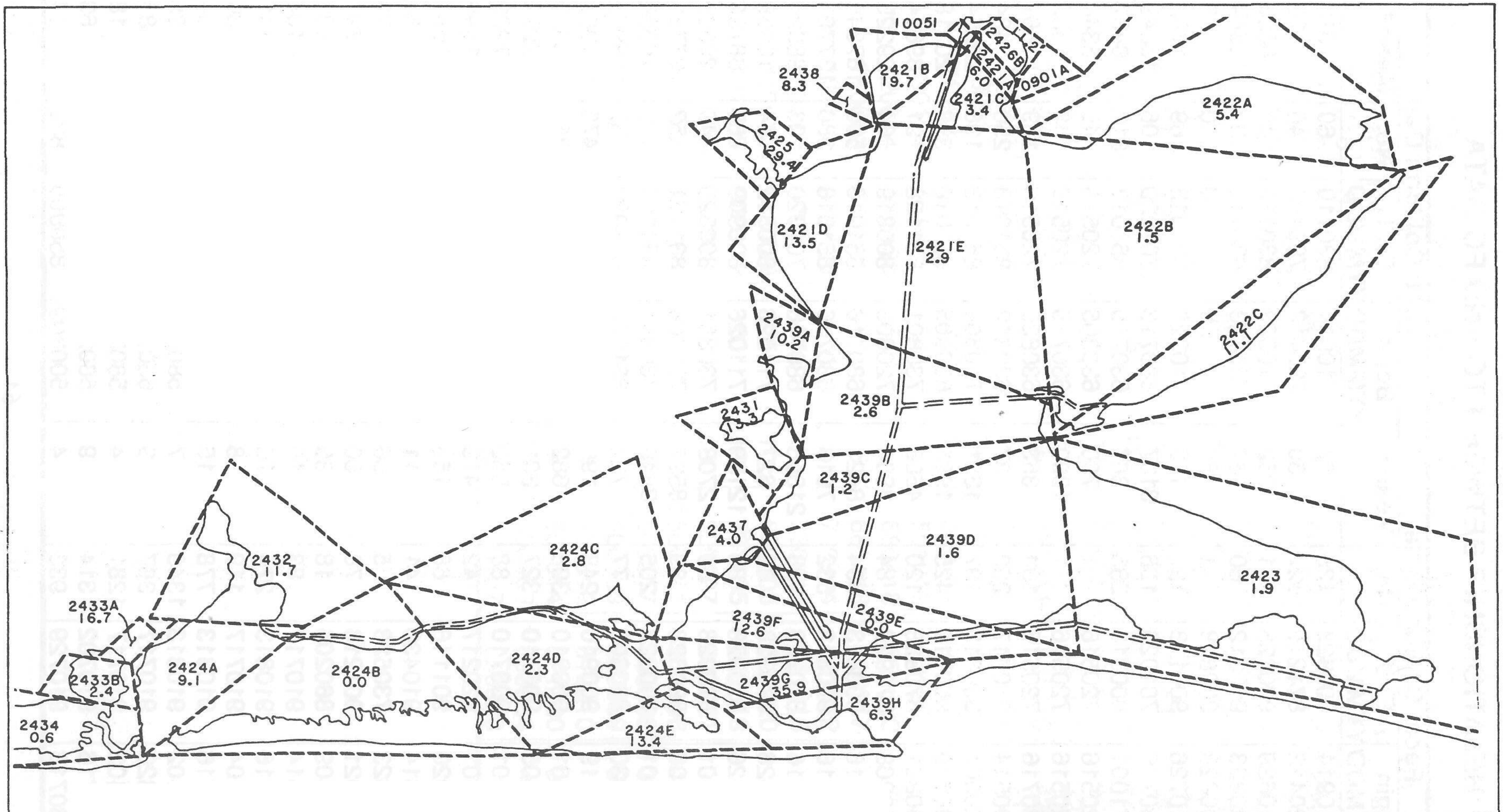

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FIGURE 5-4
PERCENTAGES OF LONG-TERM MEAN FECAL COLIFORM LEVELS EXCEEDING 200 COLONIES/100mL CRITERION IN GALVESTON BAY

TABLE 5-3
RELATIONSHIP BETWEEN TC AND FC DATA

TWC River Segment	Fecal Coliform Data				Total Coliform Data				Ratio
	Begin YYMMDD	End YYMMDD	No.	Mean*	Begin YYMMDD	End YYMMDD	No.	Mean*	
TWC801a	710914	900828	126	67	710914	830110	60	1013	15.1
TWC802	720412	871215	127	30	720412	790103	46	136	4.5
TWC901b	710629	900828	71	262	710629	830110	45	8623	32.9
TWC902a	730823	900312	60	167	730823	830110	38	12544	75.1
TWC902b	900828	900828	1	80	0	0	0	0	0.0
TWC1001b	710726	900118	127	132	710726	851018	69	1782	13.5
TWC1005b	680716	701020	106	3107	680716	701020	106	15849	5.1
TWC1005c	671001	900813	285	367	630715	851018	312	6487	17.7
TWC1005d	720516	720516	1	790	630805	720516	45	3344	4.2
TWC1005e	720516	720516	1	1300	630715	720516	48	1556	1.2
TWC1005g	680716	720516	104	353	630820	720516	139	1661	4.7
TWC1005i	690514	910717	292	37	630312	851018	250	484	13.1
TWC1006a	720504	900813	197	1381	720504	851018	138	20254	14.7
TWC1006b	680716	900711	425	1985	630805	851018	398	20118	10.1
TWCgrnsc	730801	870928	120	4506	730801	831128	91	39614	8.8
TWCgrnsd	720808	870928	84	3835	720808	800819	64	29223	7.6
TWC1007a	680716	900813	694	8421	680716	851018	506	167340	19.9
TWC1007c	680716	900813	532	7618	680716	851018	380	137785	18.1
TWC1007d	680716	870928	128	21655	680716	701020	103	98924	4.6
TWCsimsb	711026	870928	62	627	711026	800812	44	10056	16.0
TWCbrays	711026	870928	88	12159	711026	800909	68	88796	7.3
TWChuntb	730801	870928	69	2708	730801	800826	49	29565	10.9
TWC1013	720808	890328	89	18597	720808	831121	52	97731	5.3
TWC1014	730801	890328	205	3848	730801	831121	159	16556	4.3
TWC1101a	701030	890608	77	724	631120	841023	68	9976	13.8
TWC1101b	730919	900910	248	198	630402	851009	476	1966	9.9
TWC1102	671001	900910	308	682	630528	890926	351	15526	22.8
TWC1103	640305	900710	327	301	630605	830726	455	2276	7.6
TWC1104	671001	900710	88	580	640217	830726	79	7229	12.5
TWC1105a	671001	820217	42	419	671001	820217	42	11599	27.7
TWC1105b	730920	901116	66	153	730920	830824	40	5681	37.1
TWC1105c	720614	910430	41	11	680501	810317	23	57	5.2
TWC1105d	710623	730523	5	56	710623	730523	5	79	1.4
TWC1107	701021	901218	78	80	631016	830825	85	794	9.9
TWC1113a	740409	860206	18	35	630418	810224	76	503	14.4
TWC2421a	690514	910717	83	15	631218	810427	62	104	6.9
TWC2421b	680716	910813	274	26	630508	810427	327	141	5.4
TWC2421c	691104	910717	119	8	630717	850806	100	30	3.8
TWC2421d	680716	910813	778	15	580224	850806	618	54	3.6
TWC2421e	680402	910813	1345	7	580224	850806	1011	35	5.0
TWC2422a	680820	910717	367	9	630717	850807	384	84	9.3
TWC2422b	680402	910717	1281	4	580226	850516	1168	18	4.5
TWC2422c	680716	910702	314	9	580226	810406	332	69	7.7
TWC2423	680716	910729	933	4	500309	850909	832	14	3.5

TABLE 5-3
RELATIONSHIP BETWEEN TC AND FC DATA (CONTINUED)

TWC River Segment	Fecal Coliform Data				Total Coliform Data				Ratio
	Begin YYMMDD	End YYMMDD	No.	Mean*	Begin YYMMDD	End YYMMDD	No.	Mean*	
TWC2424a	680716	910424	298	6	630724	801203	304	10	1.7
TWC2424b	710712	910424	363	4	630724	851003	284	6	1.5
TWC2424c	730124	910424	283	7	500320	850923	190	14	2.0
TWC2424d	680716	910424	912	6	500320	890112	549	15	2.5
TWC2424e	730508	901213	491	22	500809	850923	320	66	3.0
TWC2425	701030	901210	452	64	630312	851021	780	668	10.4
TWC2426a	720516	790516	24	23	630820	790516	54	549	23.9
TWC2426b	690514	910717	125	20	630521	851018	92	158	7.9
TWC2427	730911	900711	64	34	730911	851018	40	1004	29.5
TWC2428	730911	900828	52	54	730911	850411	32	933	17.3
TWC2429	730911	900711	61	66	730911	851018	42	1840	27.9
TWC2430	730911	900711	60	56	730911	851018	41	990	17.7
TWC2431	680923	900815	278	13	500831	830504	212	91	7.0
TWC2432	710623	901218	77	15	500414	851022	111	65	4.3
TWC2433a	730124	910424	54	17	501012	801203	24	14	0.8
TWC2433b	720614	910430	84	6	680418	851022	72	26	4.3
TWC2434	710623	910430	164	3	680418	810317	83	5	1.7
TWC2435	720614	910430	55	5	700914	851022	39	18	3.6
TWC2436	730214	900711	55	34	730214	851018	38	490	14.4
TWC2437	710622	910729	125	10	630805	821220	96	50	5.0
TWC2438	731105	900719	60	19	731105	850213	25	352	18.5
TWC2439a	690520	910813	264	10	500227	821221	149	27	2.7
TWC2439b	680402	910813	2250	5	500111	850806	1435	19	3.8
TWC2439c	680402	910813	603	4	500317	850909	385	16	4.0
TWC2439d	680402	910729	618	5	500309	850909	639	15	3.0
TWC2439e	680716	910729	150	3	580312	810310	166	10	3.3
TWC2439f	680716	910729	231	9	500914	821220	342	37	4.1
TWC2439g	680716	910729	390	80	500809	850624	427	460	5.8
TWC2439h	820921	901113	16	18	820427	850923	14	29	1.6
								Average =	10.6

* Mean = Geometric Mean in colonies/dL

$$\text{Log(TC)} = 0.55 + 1.136 * \text{Log(FC)}$$

or

$$\text{TC} = 10^{0.55} * \text{FC}^{1.136} = 3.55 * \text{FC}^{1.136}$$

with $R^2 = 0.861$. This result indicates that the relationship between TC and FC is not linear, with an exponent of 1.136, and that about 86.1% of the TC data variance is related to the FC data. None of these results give a TC/FC ratio of 5.

The relationship between the TC/FC ratio and the geometric mean of the FC data can be observed in Figure 5-5 which shows that for areas with a FC geometric mean greater than about 20, there is extreme scatter. It can be concluded that for areas which have fairly low FC data, such as approved shellfish harvesting areas, the ratio of five is quite reasonable. For areas which have high mean FC levels, the ratio of five is not valid.

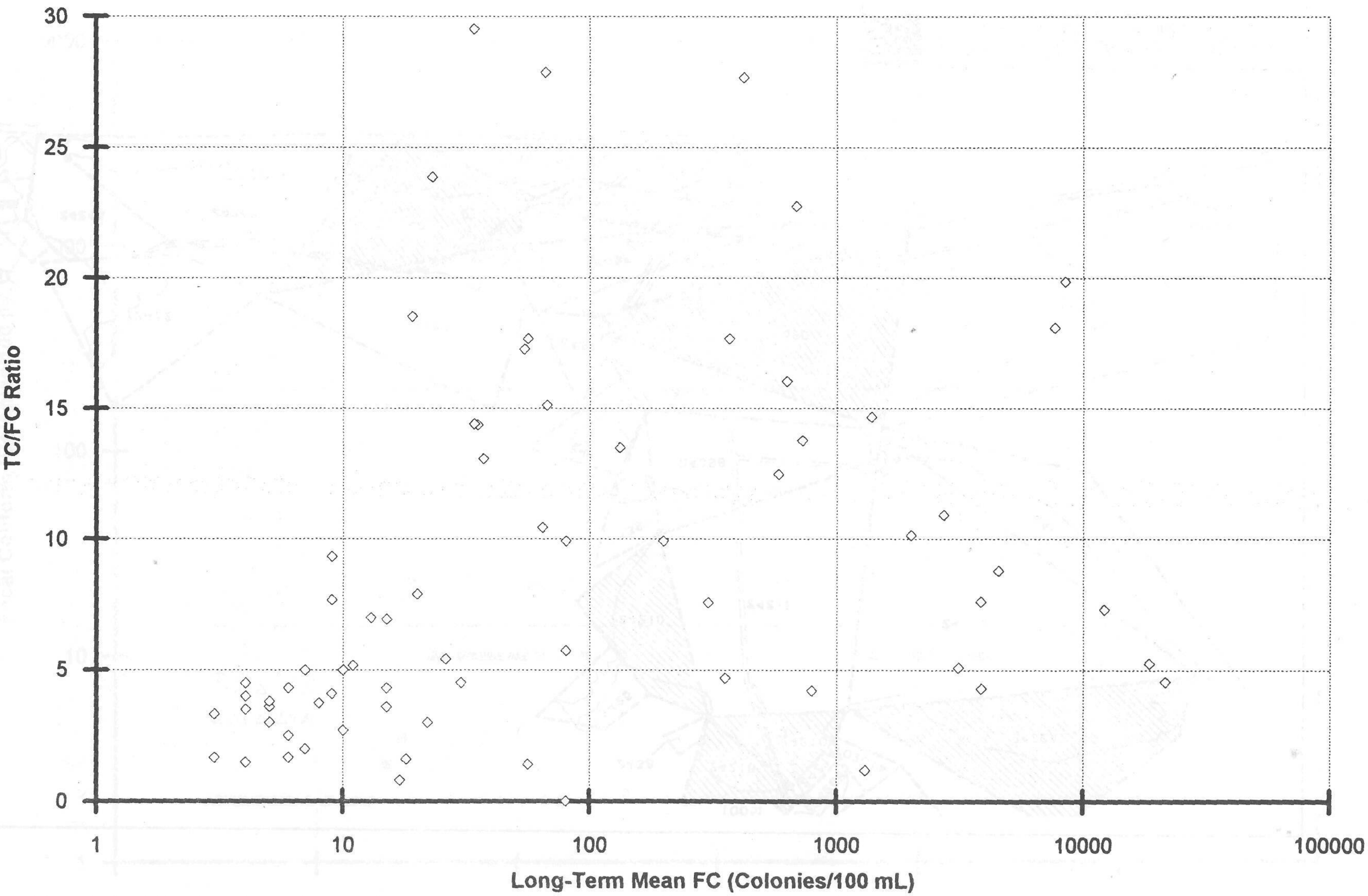
While the TC/FC ratio does not appear valid for areas with high FC levels, it is approximately correct for other areas. One advantage to using the TC data is that it allows the period of record to be extended markedly. To take advantage of this longer period of record where appropriate, and to place the two data types in approximately the same scale, a "pseudo" FC is employed. This is simply the TC data divided by five. These will be presented in the following trend analysis.

5.4 TEMPORAL TRENDS

In order to study temporal trends of the data, representative quadrilaterals are selected for more detailed analysis. These are highlighted in Figure 5-6. The criteria for selection are that they have been frequently monitored over a long period and that they cover a range of watershed development activity. Among these, 2439d in East Bay is considered a control area since little development has occurred. Its watershed is primarily agricultural with a limited residential development. Quadrilaterals 2421b and 2421c in upper Galveston Bay near the mouth of Houston Ship Channel and 1005i at the channel mouth are more likely to have changed water quality condition due to urbanization of the western bay area. Also, quadrilaterals 2421d, western side Galveston Bay near Seabrook, 2422a located at upper Trinity Bay, and 2424d at the east end of West Bay, are selected for trend analyses because of their locations, periods of record, and total number of observations available. As listed in Table 5-3, the FC geometric means for quadrilaterals 1005i, 2421b, 2421c, 2421d, 2422a, 2424d, and 2439d are 37, 26, 8, 15, 9, 6, and 5 respectively. Although the first two of these FC mean values exceed 20, which indicates a TC/FC ratio other than 5, TC data for these two quadrilaterals are transformed to pseudo FC so that a rough comparison can be made.

The first dataset considered was the control area, 2439d, in Galveston Bay near East Bay. Results for FC and pseudo FC are shown in Figure 5-7a and 5-7b. It can be seen that

FIGURE 5-5 RELATIONSHIP BETWEEN LONG-TERM MEAN TOTAL AND FECAL COLIFORM LEVELS IN GALVESTON BAY



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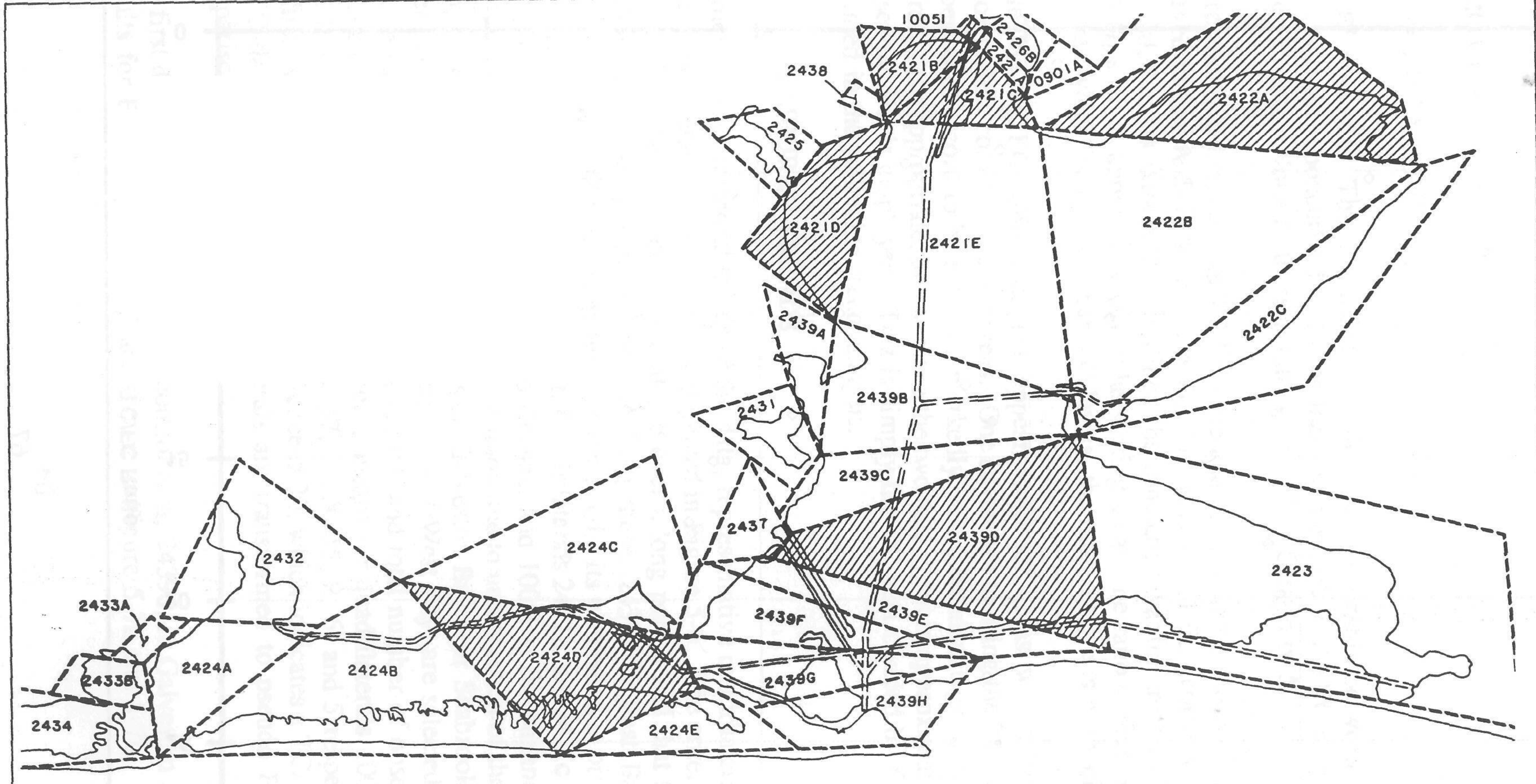

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FIGURE 5-6

QUADRILATERALS SELECTED FOR TREND ANALYSIS

FIGURE 5-7a FECAL COLIFORM DATA FOR QUADRILATERAL 2439d (Lower Galveston Bay Near East Bay)

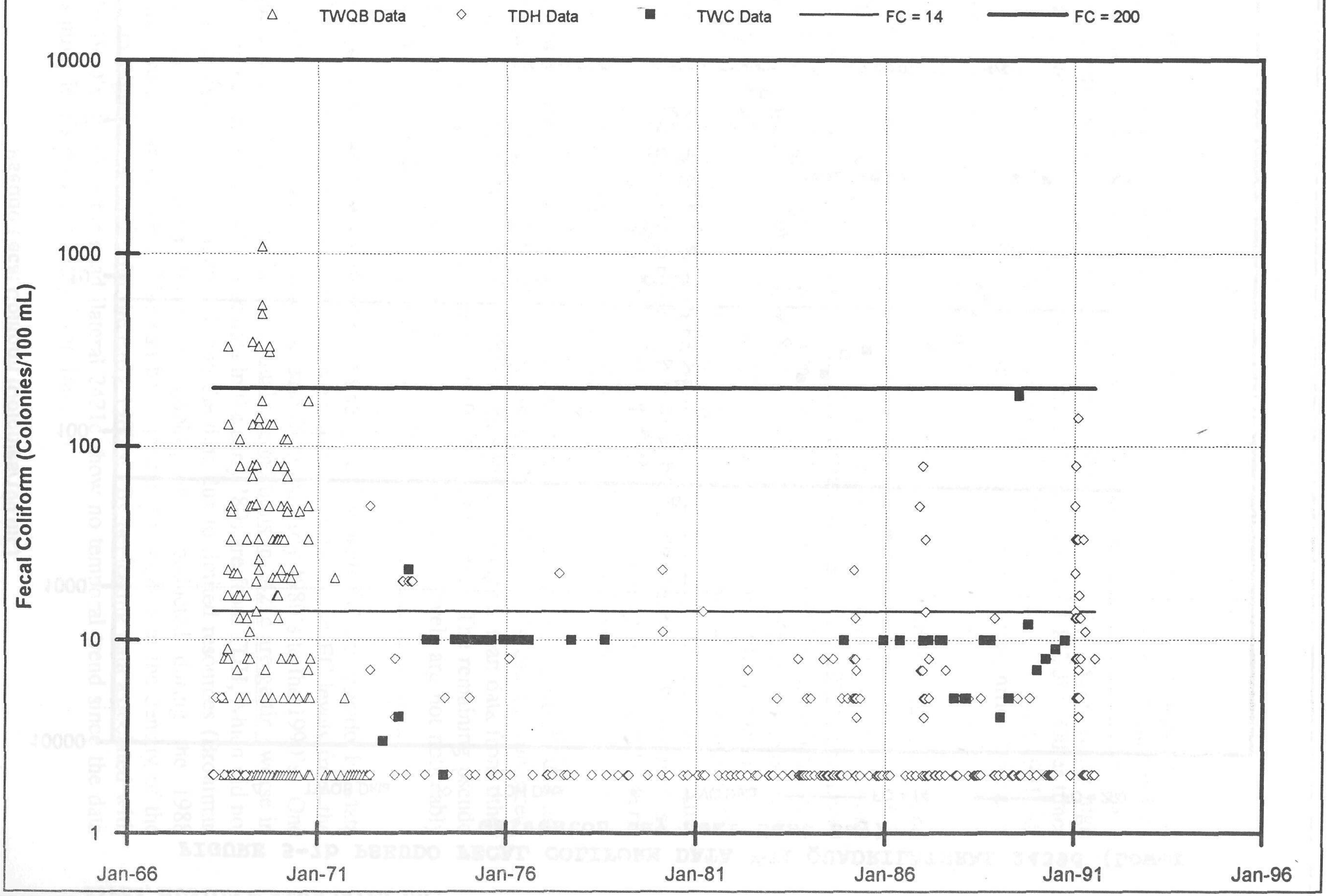
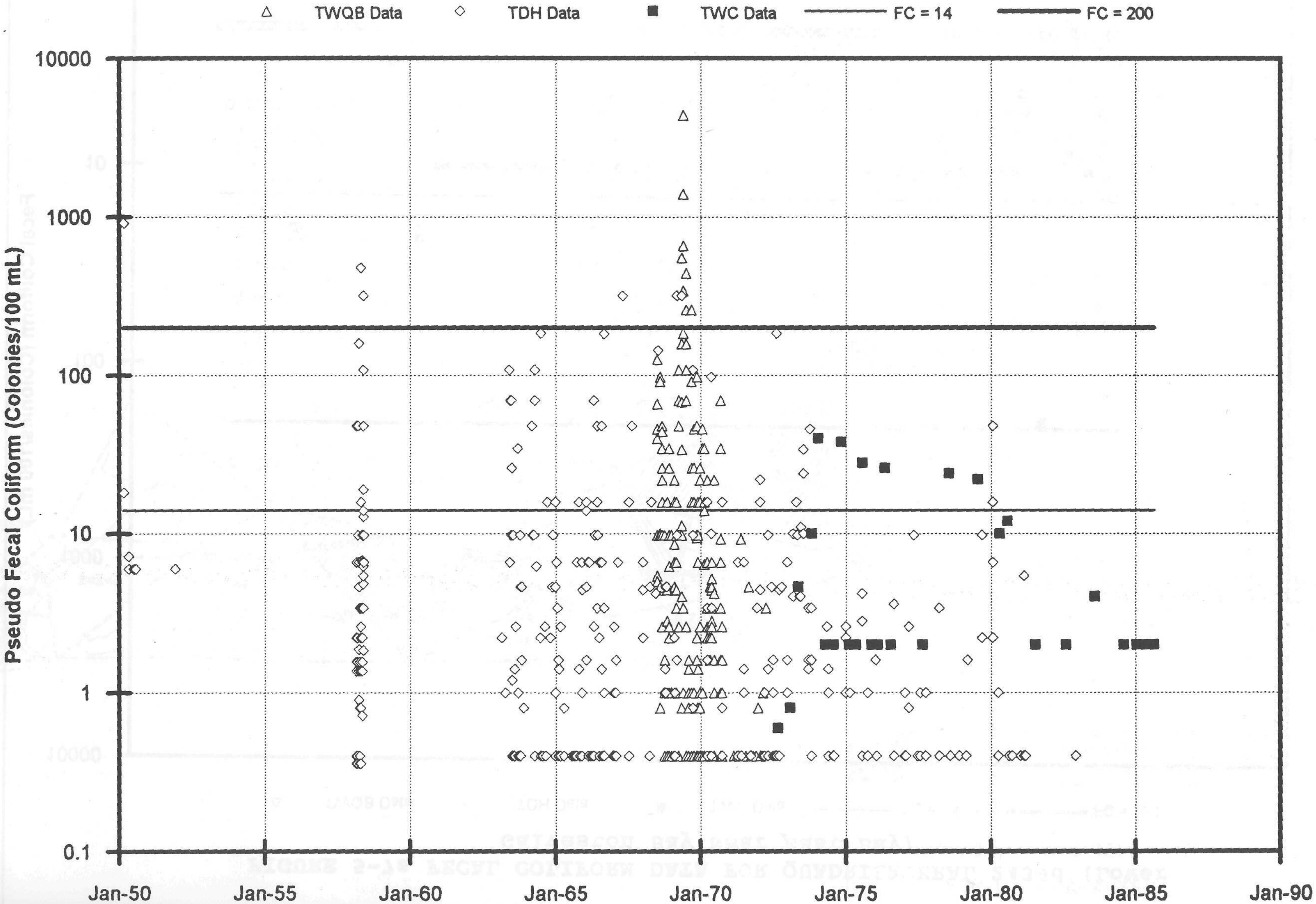


FIGURE 5-7b PSEUDO FECAL COLIFORM DATA FOR QUADRILATERAL 2439d (Lower Galveston Bay Near East Bay)



many if not most of the observations from TDH are 2 FC/dL, as would be expected in an area approved for shellfish growing with little development. A second point is that periods of higher FC levels are clustered at specific times. One such time is the intensive monitoring activity during the original Galveston Bay Project. While some fairly high values are reported, the geometric mean of the TWQB data is 7.72 FC/dL. Other times with some high coliform levels are the TDH observations in 1958, 1986, and 1991, all very wet years. It is concluded that in the control area, there is no significant trend in indicator bacteria levels.

The second trend analysis was done on quadrilateral 2421b, as shown in Figures 5-8a and 5-8b for FC and pseudo FC data respectively. For FC, there are only data from TWQB and TDH, with no TWC stations in this area. A first impression from Figure 5-8a is that the FC data seem to decline through time with higher values in the 1970's and lower values in the 1980's and 1990's. However, the high values of FC data are mostly from the TWQB source which, after checking the locations of the sampling stations, were sampled right at the mouth of the Houston Ship Channel where the coliform concentration can be expected to be high, especially in the early 1970's. If these data are excluded the declining trend is no longer obvious. Two conclusions can be drawn on the water quality condition for quadrilateral 2421b. One is that when consistent stations are considered, no significant trend can be observed. The second is that the boundary of this quadrilateral needs to be redefined to avoid including the small slice of the ship channel.

Although the long-term mean FC level for quadrilateral 2421b is high, pseudo FC data are still provided in Figure 5-8b so that coliform levels in the 1960's can be compared. Similar to the FC data, the pseudo FC data from TWQB are higher than data from other sources and are not considered representative for the entire area. The remaining pseudo FC data in Figure 5-8b show no significant trend. Also, their levels are not noticeably different from the FC levels shown in Figure 5-8a.

Figures 5-9a and 5-9b give plots for quadrilateral 2421c with FC and pseudo FC data respectively. From Figure 5-9a, the data seem to show a decline in FC levels from the 1970's to the early 1980's and then an increase from the early 1980's to the 1990's. One might jump to a conclusion that the water quality conditions in 2421c are getting worse in the '90s. However, most lower value data in the early '80s are from TDH, which did not perform intensive coliform sampling during the time due to limited resources (Broutman and Leonard, 1988). More intensive sampling was conducted during the 1988 comprehensive sanitary survey. This can be confirmed by looking at the density of the data in both Figures 5-9a and b for the early 1980's. By neglecting data associated with the early 1980's, the data for quadrilateral 2421c show no temporal trend since the data are on similar levels before and after that time.

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FIGURE 5-8a FECAL COLIFORM DATA FOR QUADRILATERAL 2421b (Upper Galveston Bay Near La Porte)

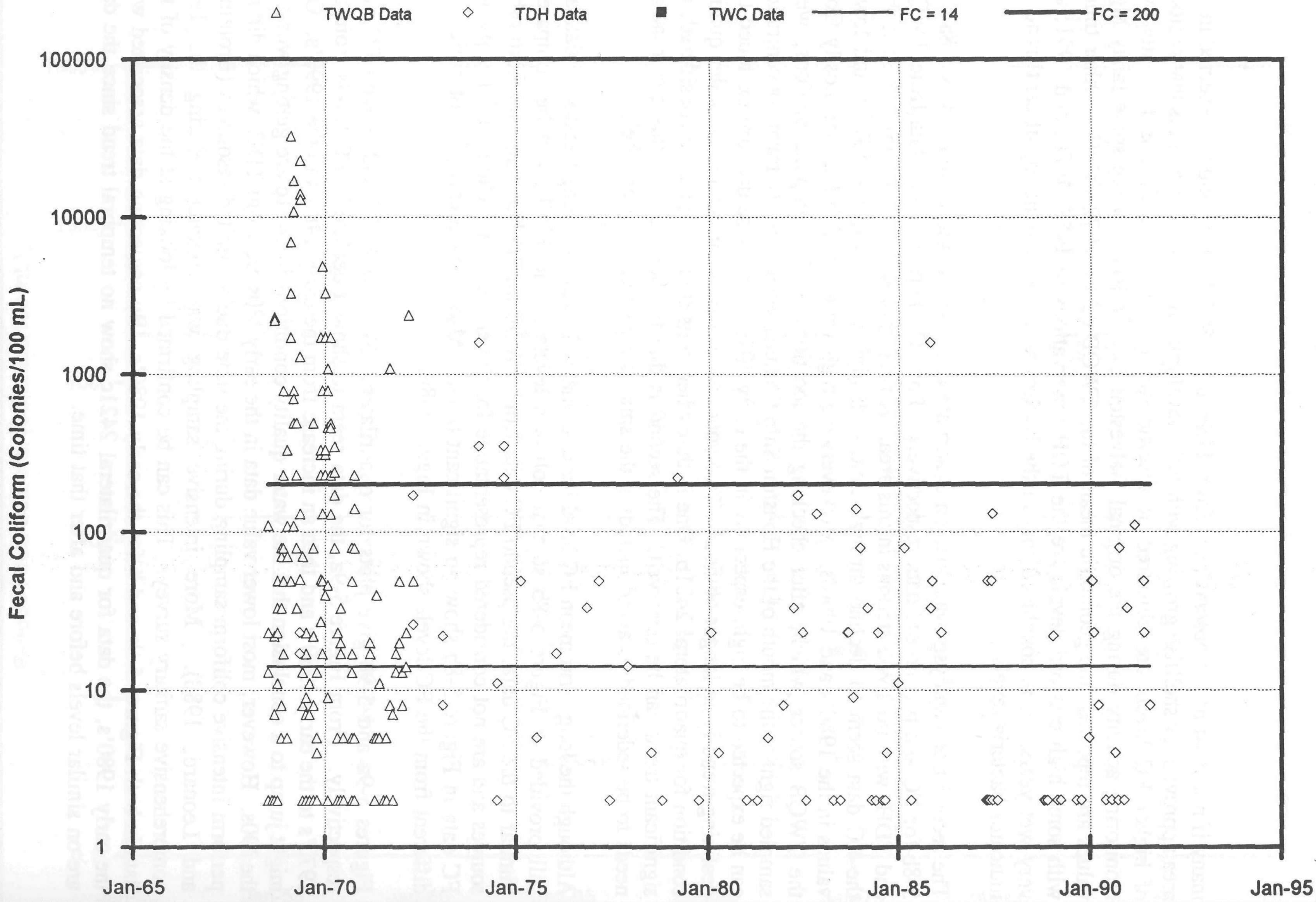


FIGURE 5-8b PSEUDO FECAL COLIFORM DATA FOR QUADRILATERAL 2421b (Upper Galveston Bay Near La Porte)

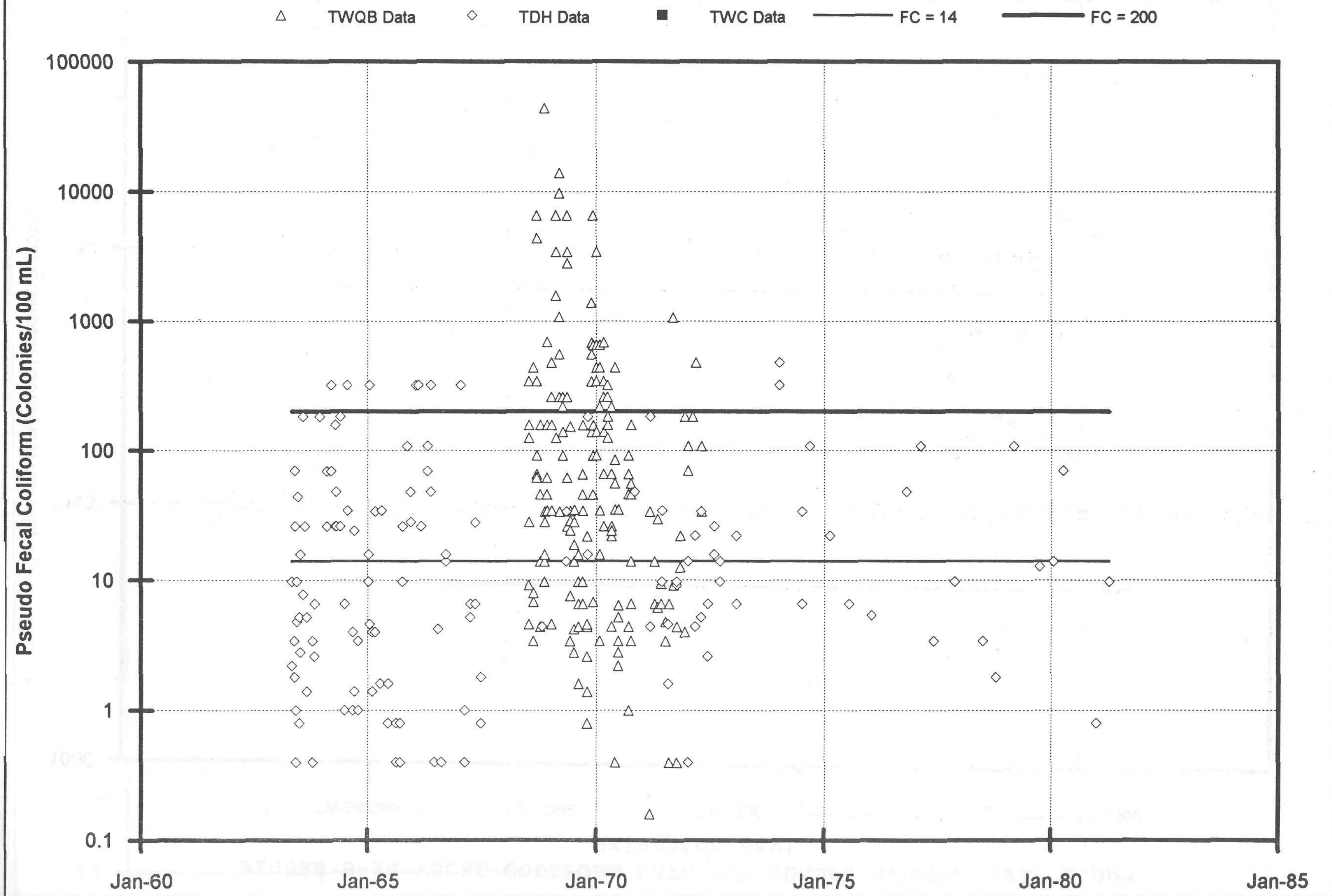


FIGURE 5-9a FECAL COLIFORM DATA FOR QUADRILATERAL 2421c (Upper Galveston Bay)

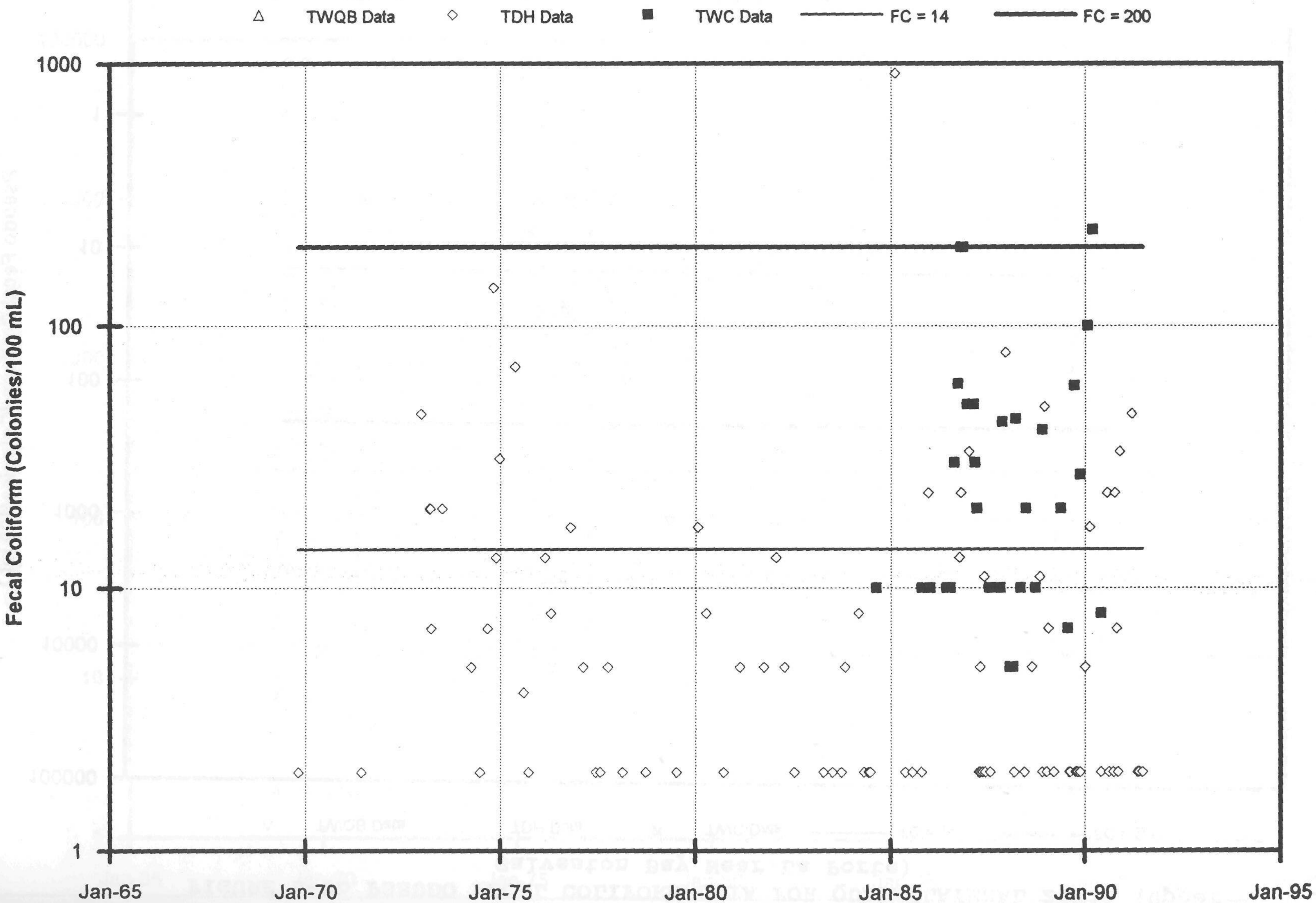
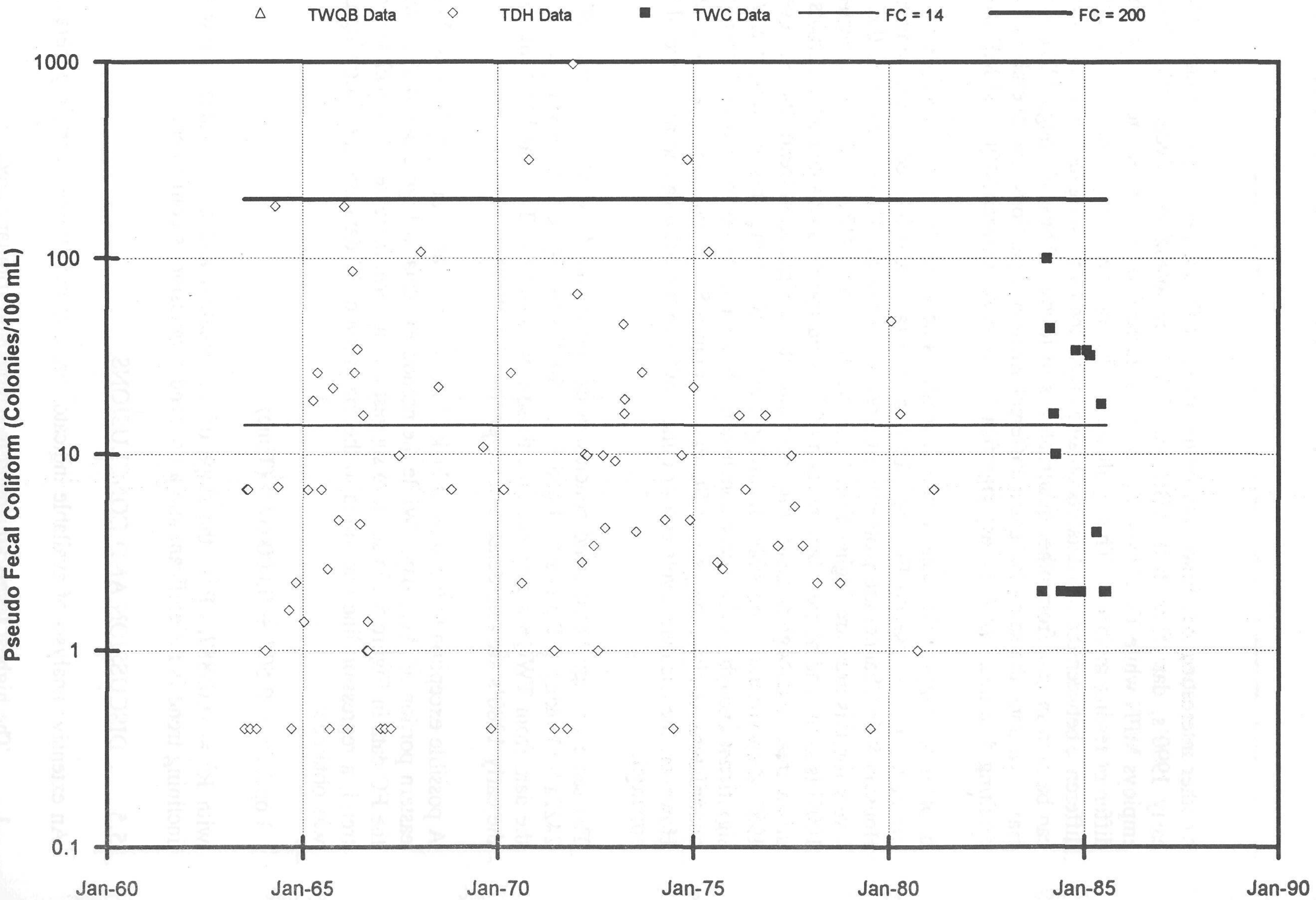


FIGURE 5-9b PSEUDO FECAL COLIFORM DATA FOR QUADRILATERAL 2421c (Upper Galveston Bay)



Another interesting conclusion can be drawn from Figure 5-9a. For the late 1980's and early 1990's, data from both TDH and TWC are available. Recall that since TDH employs MPN while TWC uses MF methods, these data can be used to compare the two different testing methods. The result shows that on the average there is no significant difference between the two datasets obtained from the two testing methods. Similar results can be seen in data from other quadrilaterals to follow. Thus, although TDH and TWC may have done the sampling under different weather conditions, the overall view of the resulting data does not show any significant difference between MPN and MF methods.

In order to compare the water quality conditions between the Houston Ship Channel and the bay, FC and pseudo FC data for quadrilateral 1005i located at the mouth of the Houston Ship Channel are plotted in Figures 5-10a and b. These plots show that the FC levels for this area are higher than those on 2421b and 2421c. This is expected since 1005i is at the end of the inland portion of the Houston Ship Channel which drains a large urban area. Although in general the data indicate no significant trend, the FC levels after 1987 demonstrate a possible declining trend. However, this possible trend is not significant enough to draw any conclusion. Since the long-term mean FC level for this quadrilateral is high, the pseudo FC data in Figure 5-10b must be viewed with caution. However, the absolute levels appear quite similar to the FC data and no temporal trend is apparent.

The same no significant trend conclusion can be obtained for quadrilaterals 2421d and 2422a by looking at Figures 5-11 and 5-12. Similar to Figure 5-9, these figures show that the data from TWQB are higher than those from TDH and TWC and that the data from the early 1980's are less dense and lower than the others.

A possible exception to the general lack of trend is the data from quadrilateral 2424d, the eastern portion of West Bay. While the pseudo FC data in Figure 5-13b show no trend, the FC data in Figure 5-13a seem to suggest a long-term increase. To check this possible trend, a regression line was fitted to the logarithmic FC data and the following equation was obtained:

$$\mathrm{Log(FC)} = 0.507 + 0.000052 * (\mathrm{Time})$$

with $R^2 = 0.03887$. Both the slope of the equation and the R^2 values show that the inclining trend is insignificant and a no-trend conclusion is confirmed.

5.5 DISCUSSION AND CONCLUSIONS

An extensive analysis of available indicator bacteria data suggest certain generalizations:

1. The highest levels are found in bayous and tributary creeks,

FIGURE 5-10a FECAL COLIFORM DATA FOR QUADRILATERAL 1005i (Houston Ship Channel Near Morgan's Point)

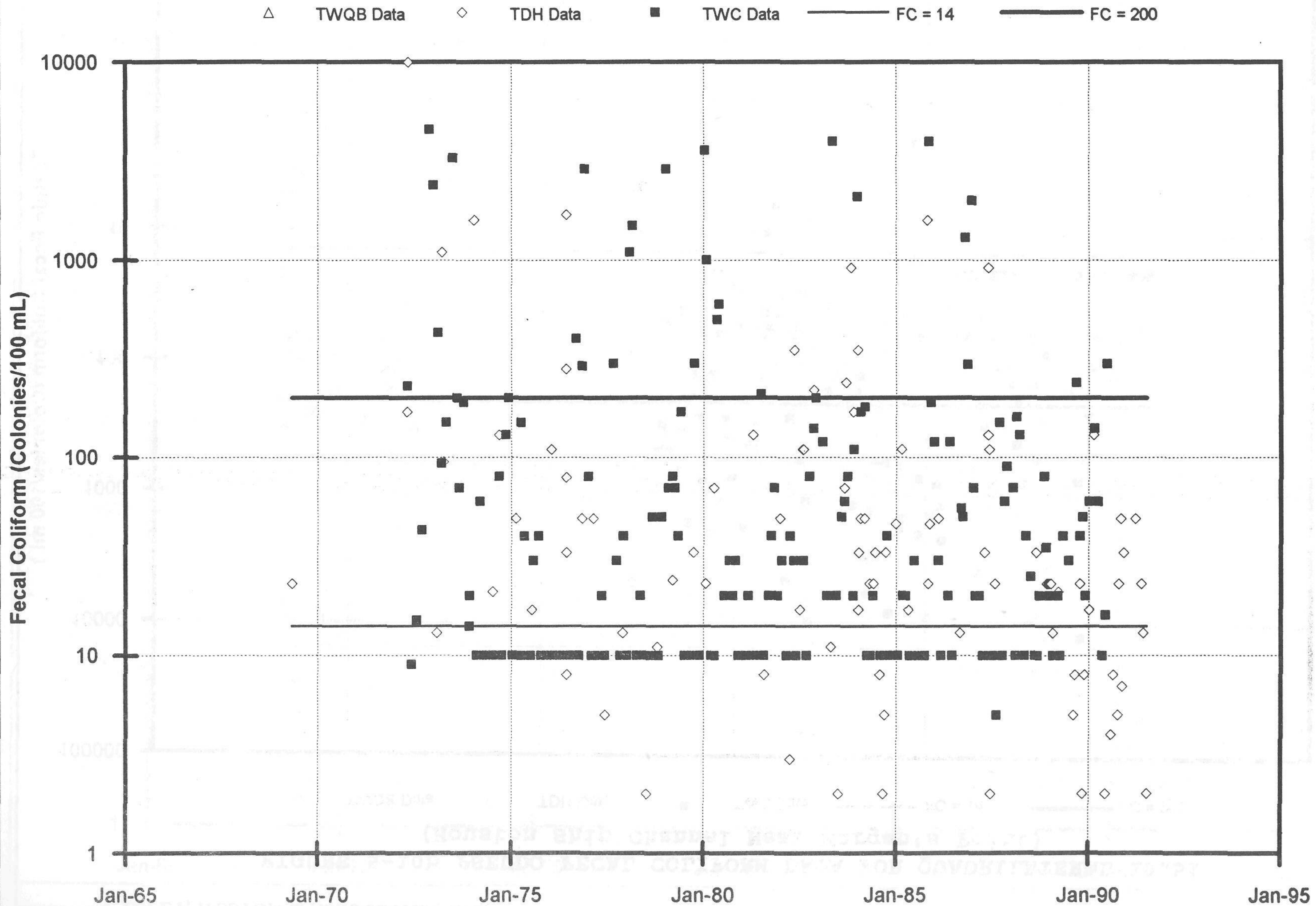


FIGURE 5-10b PSEUDO FECAL COLIFORM DATA FOR QUADRILATERAL 1005i
(Houston Ship Channel Near Morgan's Point)

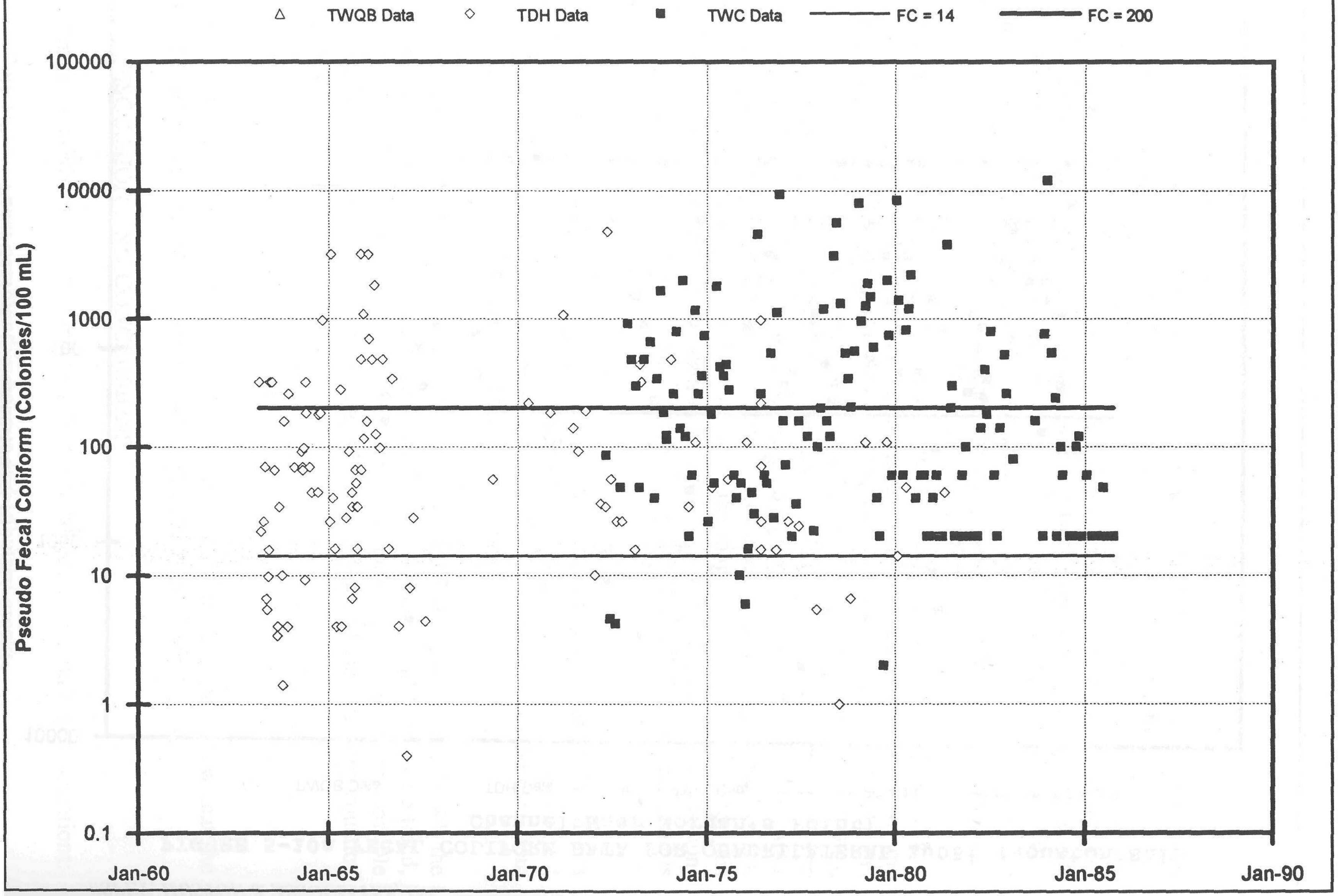


FIGURE 5-11a FECAL COLIFORM DATA FOR QUADRILATERAL 2421d (Upper Galveston Bay Near Seabrook)

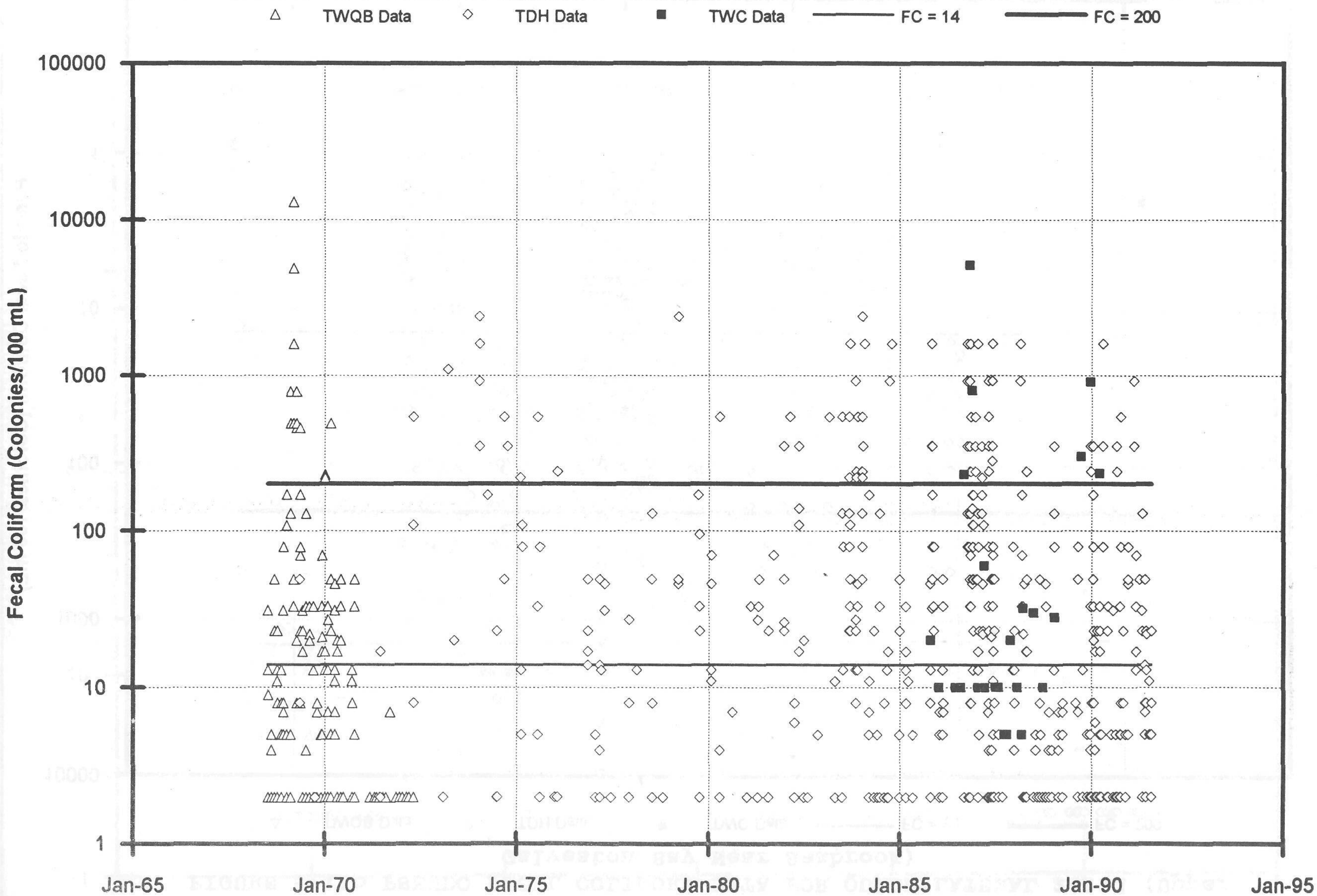


FIGURE 5-11b PSEUDO FECAL COLIFORM DATA FOR QUADRILATERAL 2421d (Upper Galveston Bay Near Seabrook)

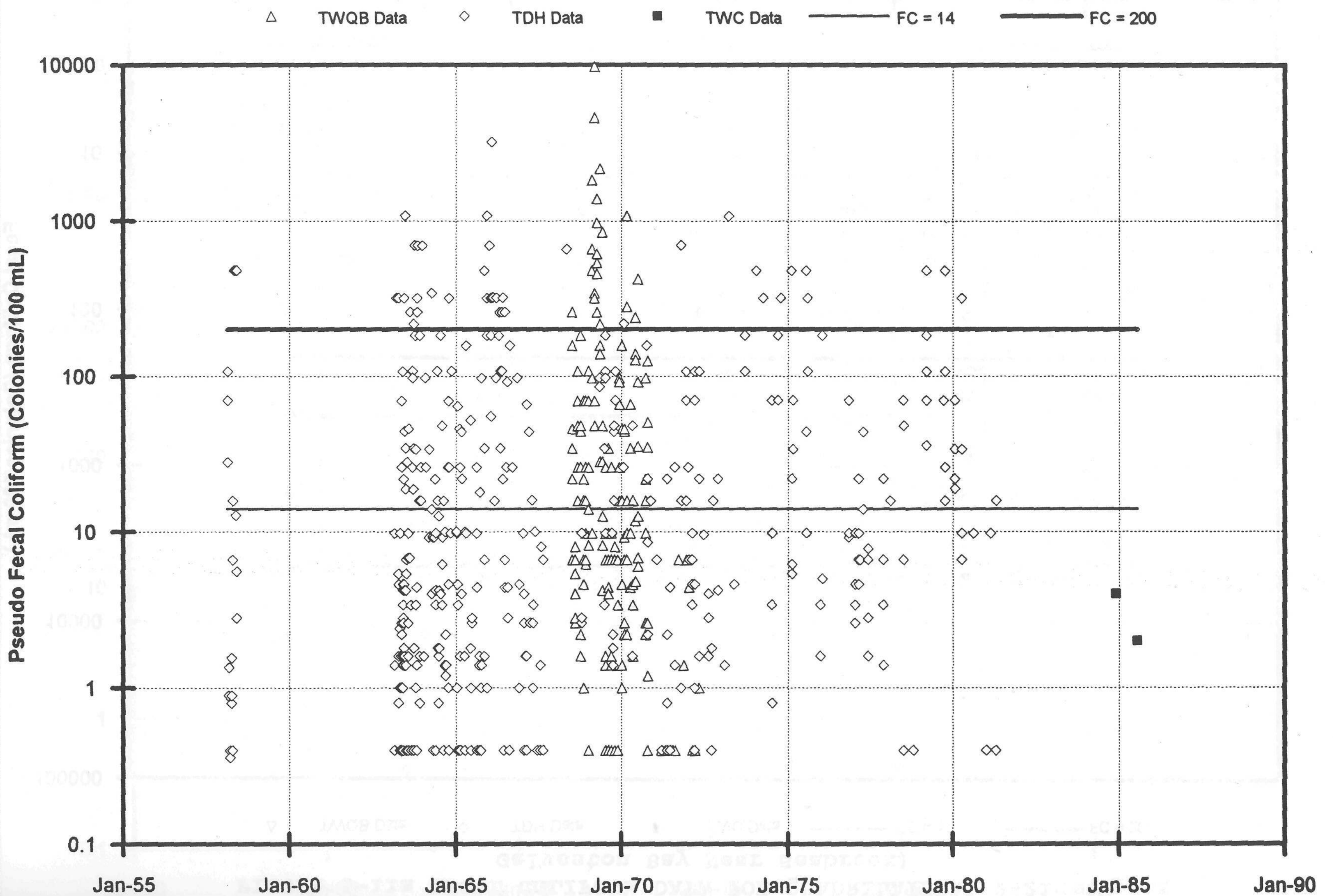
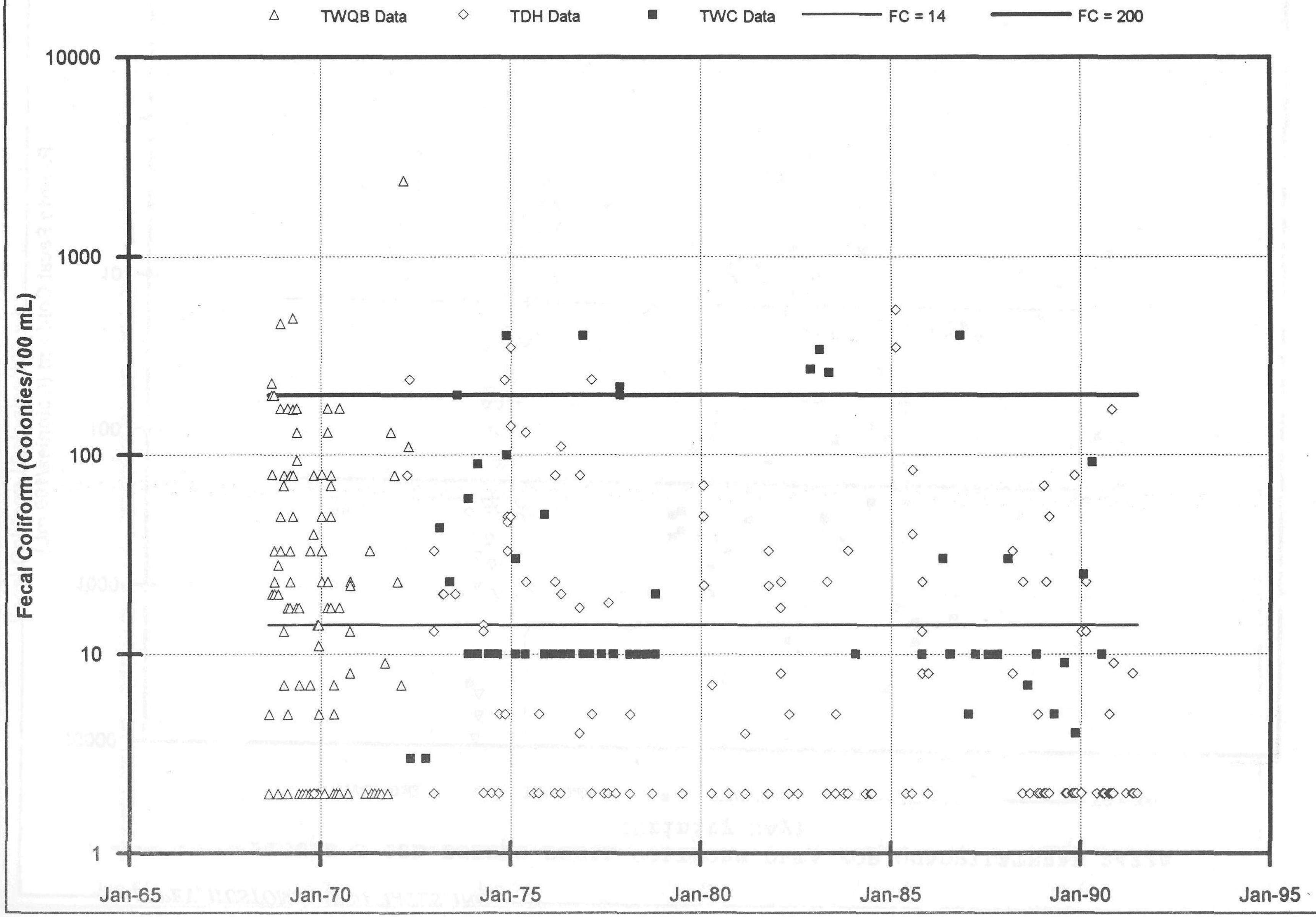


FIGURE 5-12a FECAL COLIFORM DATA FOR QUADRILATERAL 2422a (Trinity Bay)



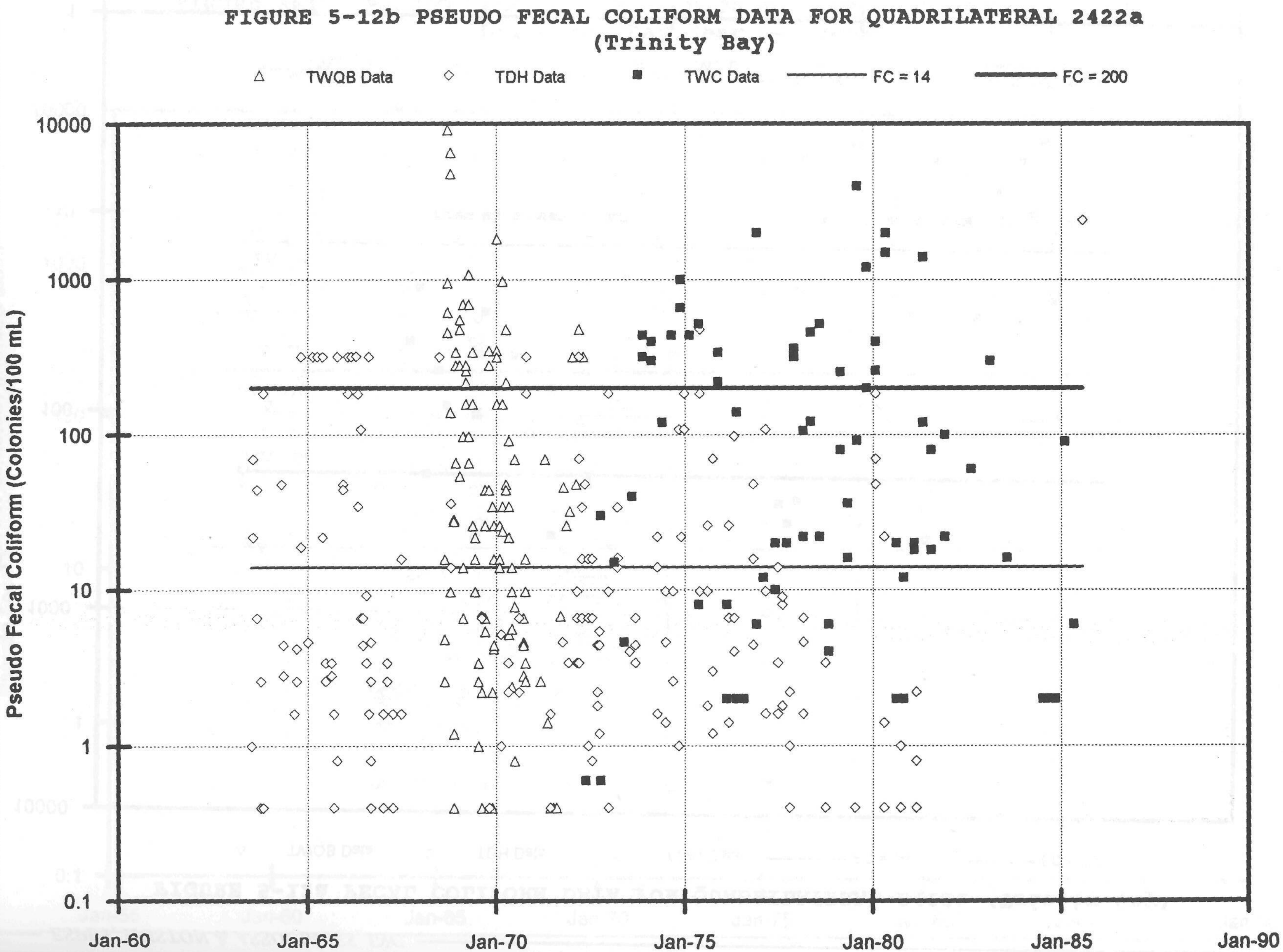


FIGURE 5-12b PSEUDO FECAL COLIFORM DATA FOR QUADRILATERAL 2422a
(Trinity Bay)
TWQB Data
TDH Data
TWC Data
FC = 14
FC = 200
Pseudo Fecal Coliform (Colonies/100 mL)
10000
1000
100
10
1
0.1
Jan-60
Jan-65
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90

FIGURE 5-13a FECAL COLIFORM DATA FOR QUADRILATERAL 2424d (East Part of West Bay)

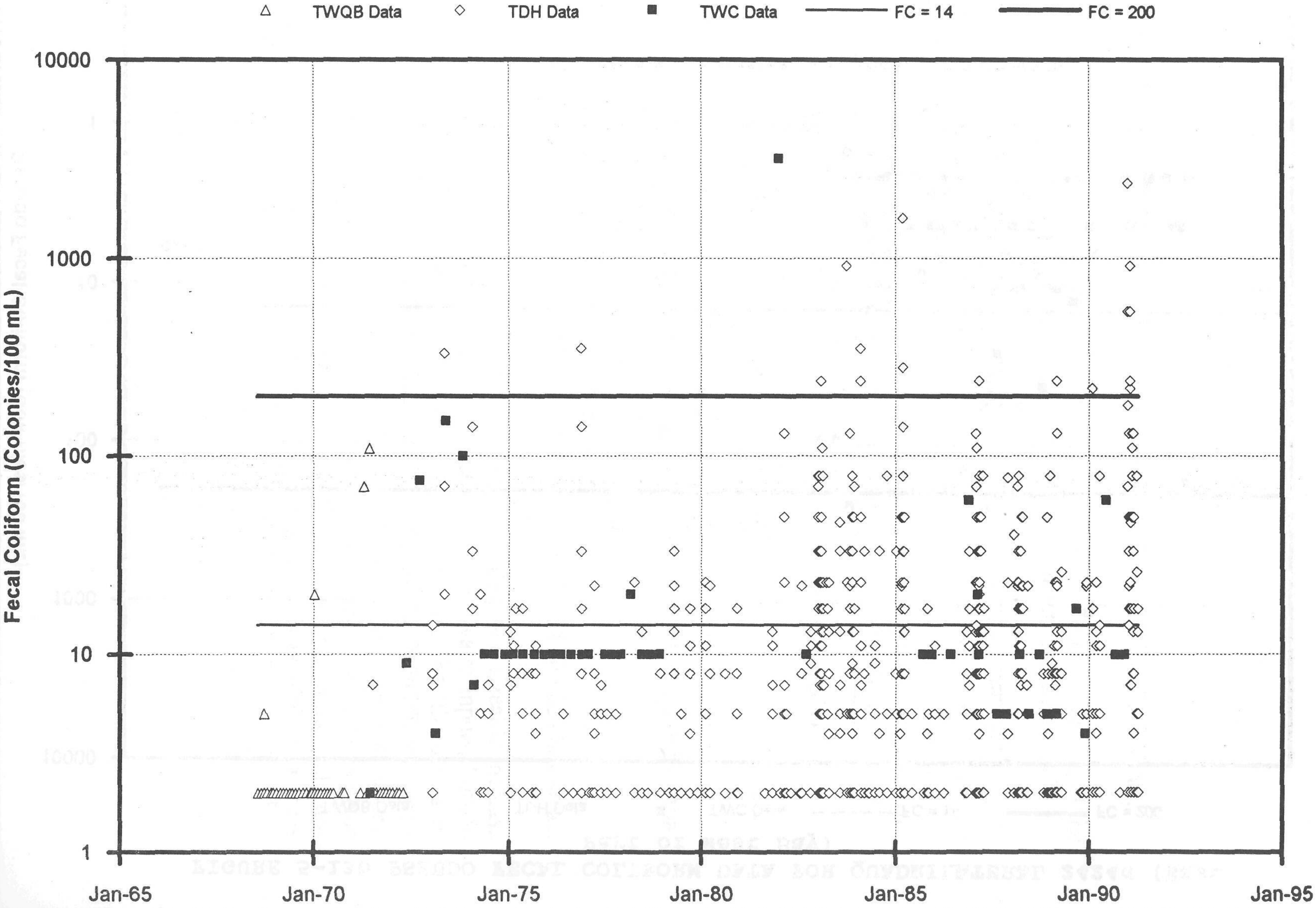
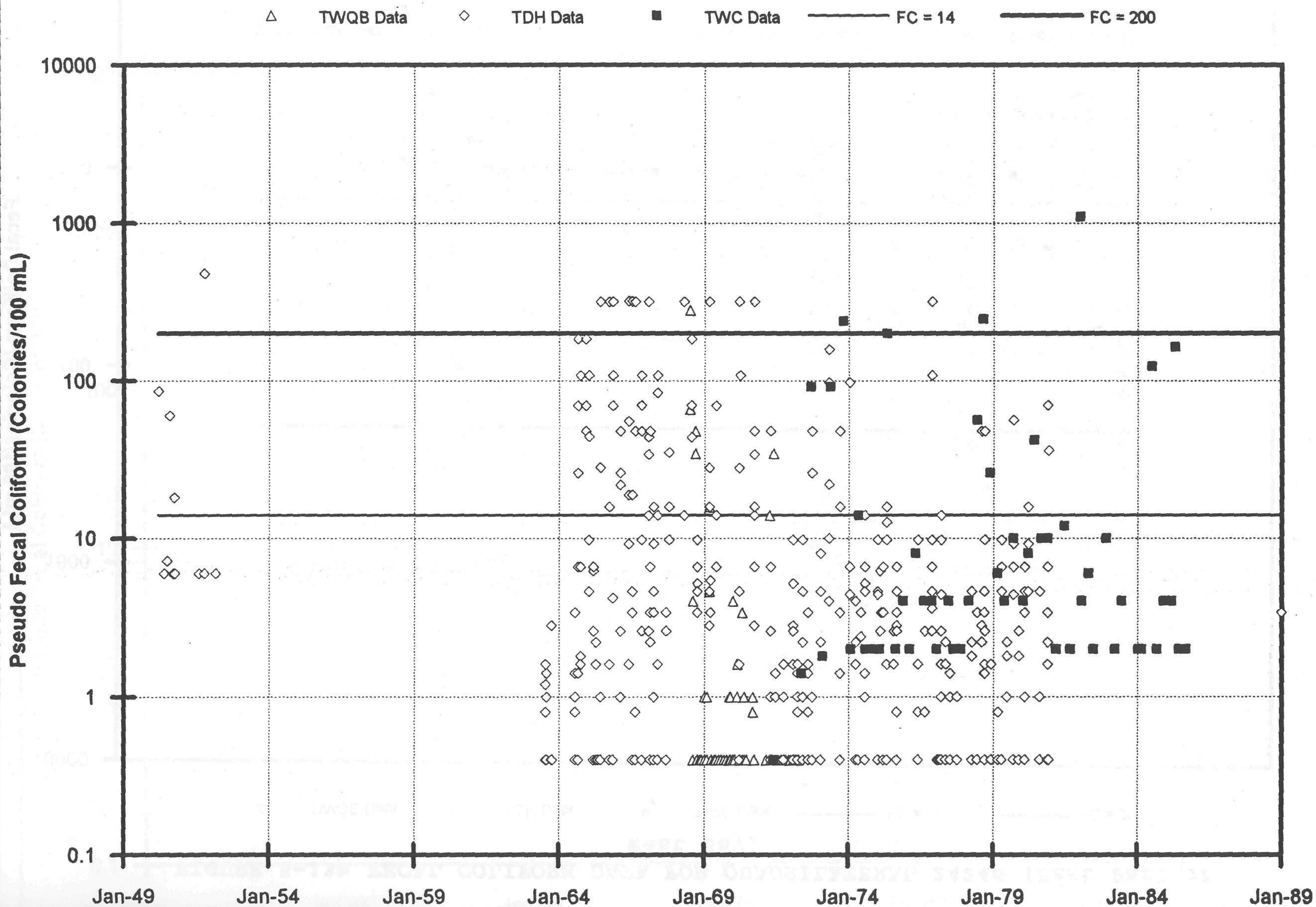


FIGURE 5-13b PSEUDO FECAL COLIFORM DATA FOR QUADRILATERAL 2424d (East Part of West Bay)



2. The urbanized tributaries have higher levels than rural,

3. The highest levels of indicator bacteria occur following heavy runoff events,

4. While 23 out of 73 quadrilaterals have long-term means >200 col/dL, all of the open bay segments currently meet state criteria for contact recreation, and

5. A total of 51 quadrilaterals out of 73 have long-term mean FC levels >14 col/dL. However, almost all of these areas are tributary bayous which do not support shellfishing. A substantial number of open bay areas which support shellfish populations are closed to harvesting either because more than 10% of the data exceed 43 col/dL or as a precaution due to proximity to human activity.

6. There is no descernable temporal trend in any of the data analyzed.

These observations are entirely consistent with the findings from the previous section on sources of indicator bacteria:

1. Runoff, carried by rivers and bayous, is the dominant source of indicator bacteria,

2. Urban runoff is larger than runoff from other land uses, and

3. Runoff dominates tributary segments but has much less effect on open bay areas.

From these observations and findings, one can conclude that, despite a sizeable increase in population surrounding the bay and substantial modifications of water inputs, both in timing and location, there has been no discernable effect on public health aspects of Galveston Bay, at least in terms of indicator bacteria. While there has been improvements in the level of wastewater treatment, the major reason for this appears to be that natural sources for indicator bacteria so dominate in bay areas that changes in anthropogenic inputs, which have undoubtedly occurred, cannot be detected. To the extent that indicator bacteria are indicating the presence of natural microorganisms, it is possible that some regulatory effort based on indicator bacteria is being misplaced.

6.0 OTHER PUBLIC HEALTH ISSUES

The purpose of this section is to investigate the possible relationship between indicator organism (FC) levels and other public health issues, particularly known pathogenic microorganisms in Galveston Bay. Among the pathogens, Vibrios are of primary concern because of their medical significance and their ability to be transmitted through various contact and noncontact recreational activities and the consumption of seafood. This transmission ability affects shellfish harvesting and shipping which are currently regulated based on FC levels. Thus, a major objective of this investigation is to assess the appropriateness of using FC for predicting possible Vibrio infections.

The first part of this section is a description of Vibrio bacteria which are of major concern. Next, data obtained from TDH concerning the incidents of Vibrio infections in Texas were analyzed and reported. The relationship between these incidents and FC data was then explored and documented. A brief investigation was also performed to determine the existence of data about other known diseases reported which are associated with shellfish and other seafood consumption. The last part of this section is a conclusion of this investigation.

6.1 THE VIBRIO ORGANISM, ITS REQUIREMENTS, RELATION TO ANTHROPOGENIC SOURCES AND CHARACTERISTICS

Vibrios are members of the genus Vibrio containing Gram-negative, rod-shaped bacteria which utilize glucose fermentatively and are widespread in many natural aquatic environments. The genus Vibrio contains eleven species which are pathogenic for humans. Those of prime medical concern are V. cholerae, V. parahaemolyticus and V. vulnificus. Other organisms implicated as opportunistic pathogens are V. alginolyticus, V. damsela, V. fluvialis, V. furnissii, V. hollisae, V. mimicus, V. metschnikovii and V. cincinnatiensis (Morris and Black, 1985; Brayton et al. 1986). A few species are economically important pathogens of fish and shellfish. For the purpose of this investigation, the focus is on the relationships between Vibrios and water temperature, salinity, shellfish, etc. and the mechanisms of infection.

6.1.1 Influence of Environmental Conditions on Survival of Pathogenic Vibrios

Human pathogenic Vibrios are naturally-occurring in aquatic environments of areas apparently free from endemic disease. The microbial ecology of these pathogens becomes important because this significantly dictates the occurrence and epidemiology of human infections (West, 1989). The significant environmental conditions which influence the survival of pathogenic Vibrios include water temperature, sediment conditions, salinity, nutrient concentration, association with higher marine and land organisms, and animal and birdlife reservoirs.

Water temperature appears to be the single most important factor governing the incidence and density of pathogenic Vibrios in natural aquatic environments. Pathogenic vibrios are found more frequently in environments whose water temperature exceeds 10°C (50°F) for at least several consecutive weeks (Bockemuhl et al. 1986; Rhode, Smith, and Ogg, 1986; Chan et al. 1989). In some regions this threshold temperature may be higher. Most pathogenic Vibrios rapidly disappear from the water column at temperatures below 10°C but can persist in sediments. Under more favorable environmental conditions Vibrios can proliferate and reemerge in the water (Williams & La Rock, 1985). At the other extreme, pathogenic Vibrios are less frequently isolated from natural aquatic environments when water temperatures exceed 30°C (86°F) (Seidler and Evans, 1984; Williams & La Rock, 1985). It would appear that from a temperature limitation standpoint Galveston Bay is ideally suited to Vibrio survival in that the water temperature in Galveston Bay is rarely less than 10°C or greater than 30°C.

Pathogenic Vibrio species have halophilic characteristics and occur most frequently in water ranging in salinity from 5 to 30 ppt, significantly limiting their presence to estuarine and inshore coastal areas (Lee and West, 1982; Seidler and Evans, 1984; Bockemuhl et al. 1986; Kelly and Dan Stroh, 1988). Pathogenic Vibrios may be isolated from some freshwaters with less than 5 ppt salinity where it is possible that the interaction of high water temperature and elevated organic nutrient concentration overcomes the deleterious effect of low salinity. Also, the prolonged survival of the organism was possible in high nutrient but low salinity environments (West, 1989).

Most pathogenic Vibrios appear to maintain high numbers and prolong their existence by association with a variety of higher organisms in the aquatic environment including plankton, shellfish and fish. In particular the chitin component in plankton appears to enhance significantly this phenomenon of prolonged survival (Huq et al. 1985, 1986). It is likely that, at some stage, all pathogenic Vibrios become associated with chitinous parts of planktonic material to both increase numbers of cells in the aquatic environment and to prolong survival in unfavorable conditions (West, 1989).

Bivalve molluscan shellfish (oysters and clams) may become rapidly contaminated when filter-feeding on planktonic material colonized by pathogenic Vibrios and so are often subsequently incriminated as vectors in food-poisoning incidents (Kelly and Dinuzzo, 1985). Association with the flesh of oysters and clams after harvesting prolongs the survival of pathogenic Vibrios outside aquatic environments. Storage of contaminated shellfish at inappropriate temperatures can then lead to rapid proliferation of pathogenic Vibrios (Karunasagar, Karunasagar, Venugopal and Nagesha, 1987). Marked seasonal variations of pathogenic Vibrios in filter-feeder flesh are often seen since the frequency of contamination is influenced by the numbers of bacteria in the surrounding water column (Kelly and Dan Stroh, 1988; Chan et al. 1989).

Crustacean shellfish can also become colonized with pathogenic Vibrios. This appears to be dependent on high counts of bacteria in the surrounding water so that it is more commonly observed in warmer climates (Davis and Sizemore, 1982; Huq et al. 1986). Fish from inshore coastal waters and estuaries can be expected to be colonized with low numbers of pathogenic Vibrios (West, 1989).

There is no clear evidence that land animals act as a significant reservoir for V. cholerae 01 in countries endemic for cholera (Miller, Feacham, and Drasae, 1985). However, non-01 serotypes of V. cholerae have been isolated from domestic animals, waterfowl and a variety of wildlife in nearshore habitats of non-endemic cholera regions (De Paola, 1981). The role of land animals in maintaining this pathogenic Vibrio in the aquatic environment, and transmitting disease remains unclear (West, 1989). Evidence has been accumulated to suggest that aquatic birds serve as carriers to disseminate V. cholerae over wide areas not endemic for cholera (Lee et al. 1982; Ogg, Ryder, and Smith, 1989). Interestingly, no other pathogenic Vibrio species appear to be harbored by aquatic birdlife (West, 1989).

6.1.2 Mechanisms of Infection by Vibrios

Since pathogenic Vibrio species occur naturally in aquatic environments, control of sewage contamination will have little or no effect in preventing the spread of infection. An exception is the cholera infection in endemic areas where secondary infections follow contamination of unprotected drinking water supplies or food. Risks of infection with pathogenic Vibrio species are most strongly associated with (i) impaired host resistance factors in susceptible hosts; (ii) occupational or recreational use of natural aquatic environments; and (iii) consumption of contaminated foods, especially seafood (West, 1989).

There is convincing epidemiological evidence that consumption of certain foods, especially raw or lightly cooked seafood and shellfish, is associated with outbreaks of diseases due to pathogenic Vibrio species. In particular, infections due to V. cholerae, V. parahaemolyticus and V. vulnificus have been associated with eating raw bivalve shellfish (Salmaso et al. 1980; Tacket, Brenner, and Blake, 1984).

Counts of free-living bacteria in water are generally less than required to induce disease. Increases in number of organisms towards an effective dose can occur as water temperatures rise seasonally followed by growth and concentration of bacteria on higher animals, such as chitinous plankton, or accumulation by shellfish and seafood.

Pathogenic Vibrio species must elaborate a series of virulence factors to elicit disease in humans. The relations among pathogenic Vibrio species and human infections can be summarized as listed in Table 6-1 (West, 1989).

TABLE 6-1
PATHOGENIC VIBRIO SPECIES ASSOCIATED WITH VARIOUS HUMAN INFECTIONS
(AFTER WEST, 1989)

SPECIES	GASTRO-INTESTINAL TRACT	WOUND	EAR	PRIMARY SEPTICAEMIA (a)
V. cholerae 01	M	R	U	U
V. cholerae non-01	M	O	O	R
V. parahaemolyticus	M	O	R	U
V. vulnificus	O	M	U	M
V. fluvialis	M	U	U	U
V. alginolyticus	U	M	O	U
V. damsela	U	M	U	U
V. furnissii	R	U	U	U
V. hollisae	M	U	U	R
V. mimicus	M	O	O	U
V. metschnikovii	R	U	U	R
V. cincinnatiensis	U	U	U	U

SPECIES	BACTEREMIA (b)	LUNG	MENINGES (c)
V. cholerae 01	U	U	U
V. cholerae non-01	R	U	R
V. parahaemolyticus	R	R	R
V. vulnificus	O	R	R
V. fluvialis	U	U	U
V. alginolyticus	R	U	U
V. damsela	U	U	U
V. furnissii	U	U	U
V. hollisae	U	U	U
V. mimicus	U	U	U
V. metschnikovii	U	U	U
V. cincinnatiensis	R	U	R

M = most common site of infection
R = rare sites of infection
O = other sites of infection
U = infection remains to be firmly established
(a) invasion of bloodstream by virulent microorganisms from a local seat of infection accompanied especially by chills, fever, and prostration
(b) the usual transient presence of bacteria or other microorganisms in the blood
(c) infections and swelling of any of the three membranes that envelop the brain and spinal cord

As can be seen in Table 6-1, Vibrio infections can be transmitted through various human activities. The most common infection type is gastrointestinal, presumably associated with consumption of seafood or some types of contact recreations which may cause the victims to ingest contaminated water. Blood or wound infections are presumably associated with noncontact recreational activities. V. vulnificus appears to be most active by this route. As reported in the following sections, the Vibrio data obtained from TDH support these findings on the mechanisms of Vibrio transmissions.

6.2 VIBRIO OCCURRENCE, INCIDENTS OF ILLNESS & FATALITIES, AND MECHANISMS OF INFECTION

After communicating with Ms. Bevely Ray of the TDH, Epidemiology Division, data on the outbreaks of Vibrio diseases were obtained (Ray, 1991). These data, include information such as the patient's age, sex, race, county of residence, Vibrio organism, onset date, outcome of infection, number of underlying medical conditions, exposure (foods, water, etc.), site (location where the patient was infected), and activity (suspected activity which caused the infection). There were a total of 176 Vibrio infection cases reported for the entire State of Texas between May of 1981 and September of 1991. Before 1986 there was no requirement for reporting so infections between 1981 and 1986 were probably under-reported (Ray, 1992).

Because the TDH site data are only approximate, analysis based upon the TWC segments cannot be performed. A first analysis of the data was performed by sorting the data into the counties surrounding the Galveston Bay. The results, listed in Tables 6-2, show that for the Brazoria, Chambers, Galveston, Harris, and Liberty Counties, there are 7, 0, 12, 46, and 3 Vibrio incidents respectively. Except for Harris County where most infections are due to consumption of (sea) foods, most infection are due to contact and noncontact recreation. The rates of infection per capita in the smaller population counties (except Chambers) probably reflect a higher participation rate in bay recreational activities.

Even though an incident of Vibrio infection may be reported in a county near Galveston Bay, the patient may not have been infected in the bay area. This is especially true for those cases in which the infections were due to the consumption of oysters in restaurants where the source is unknown.

However, as listed in Table 6-3, there are 12 cases in which the site of infection was specified to be the Galveston Bay area. Among these 12 cases, one patient died of the disease. The mechanisms of infections for these cases include various kinds of contact and non-contact recreational activities. Five cases out of 12 are due to contact recreation.

Table 6-4 lists the statistics of these 12 incidents of Vibrio infections due to activities in the bay area. Among these statistics, the onset month data indicates seasonal variations

TABLE 6–2
OUTBREAKS OF VIBRIO DISEASES IN COUNTIES AROUND GALVESTON BAY

MECHANISM OF INFECTION	COUNTY					TOTAL
	BRAZORIA	CHAMBERS	GALVESTON	HARRIS	LIBERTY	
RECREATION	4	0	7	13	2	26
% TOTAL RECREATION	15.38	0.00	26.92	50.00	7.69	100
Rate (* E5)**	2.09	0.00	3.22	0.46	6.11	0.79
FOOD CONSUMPTION	1	0	4	20	0	25
UNKNOWN	2	0	1	13	1	17
% TOTAL FOOD & UNKNOWN	7.14	0.00	11.90	78.57	2.38	100
Rate (* E5)**	1.56	0.00	2.30	1.17	3.06	1.28
TOTAL INCIDENTS	7	0	12	46	3	68
% TOTAL INCIDENTS	10.29	0.00	17.65	67.65	4.41	100
Rate (* E5)**	3.65	0.00	5.52	1.63	9.17	2.07
POPULATION*	191,707	20,088	217,399	2,818,199	32,726	3,280,119
% TOTAL POPULATION	5.84	0.61	6.63	85.92	1.00	100

* Source: Bureau of the Census (1990)

** Data represent number of Vibrio incidents per capita per 10 years of record period

TABLE 6-3
OUTBREAKS OF VIBRIO DISEASES ASSOCIATED WITH ACTIVITIES IN GALVESTON BAY

AGE	SEX	COUNTY	ORGANISM	MON-YEAR	OUTCOME*	EXPOSURE	SITE	ACTIVITY
32	F	Galveston	Vulnificus	Sep-83	R	seawater	Galveston Bay	sex
54	M	Harris	Parahaemolyticus	Jun-86	R	sustained wound	Galveston Bay	stepped on sharp object in water
57	M	Harris	Cholerae non01	Jul-87	D	sustained wound	Galveston Bay	bitten by crab
31	F	Wharton	Parahaemolyticus	Sep-87	R	sustained wound	Galveston Bay	walking
72	M	Harris	Vulnificus	Oct-87	R	water	Galveston Bay	fishing
34	M	Brazoria	Cholerae non01	Aug-89	R	sustained wound	Galveston Bay	wade fishing
28	M	Harris	Vulnificus	Apr-90	R	sustained wound	Galveston Bay	windsurfing
4	F	Henderson	Vulnificus	Jul-90	R	water	Galveston Bay	swimming
67	M	Harris	Vulnificus	Aug-90	R	sustained wound	Galveston Bay	fishing
46	M	Harris	Parahaemolyticus	Sep-90	R	sustained wound	Galveston Bay	swimming
78	M	Galveston	Parahaemolyticus	May-91	R	sustained wound	Galveston Bay	fishing
11	M	Galveston	Vulnificus	Aug-91	R	water	Texas City	playing in water

* D -died, R - recovered

TABLE 6-4
STATISTICS OF INCIDENTS OF VIBRIO DISEASES IN GALVESTON BAY

ONSET MONTH	NO. OF INCIDENTS	ONSET YEAR	NO. OF INCIDENTS	COUNTY	NO. OF INCIDENTS
JAN	0	1983	1	BRAZORIA	1
FEB	0	1984	0	GALVESTON	3
MAR	0	1985	0	HARRIS	6
APR	1	1986	1	HENDERSON	1
MAY	1	1987	3	WHARTON	1
JUN	1	1988	0		
JUL	2	1989	1		
AUG	3	1990	4		
SEP	3	1991	2		
OCT	1				
NOV	0				
DEC	0				

ORGANISMS	NO. OF INCIDENTS	ACTIVITY	NO. OF INCIDENTS
Cholerae non-01	2	Contact Recreation	5
Parahaemolyticus	4	Noncontact Recreation	7
Vulnificus	6		

in the occurrences of Vibrio infections, with summer predominating. This is consistent with the characteristics of Vibrio species described in Section 6.1 about the relationship between water temperature and Vibrios. As for the frequency of the occurrence, there is one case in 1983, 1986, and 1989, two cases in 1991 up to November, three cases in 1987, and four cases in 1990. These data for annual statistics are fairly random suggesting no obvious temporal trend. The relationship between the number of Vibrio incidents and the species indicates that the V. vulnificus may be more significant than V. cholerae. Looking at the population data (Table 6-2), Galveston County has a relatively high proportion of recreation-related incidents. Galveston County has 6.6 % of the population but had 26.9% of the recreation related incidents. The infection mechanisms of food consumption and unknown source appears to track with the population data reasonably well.

To determine the relative importance of contracting Vibrio infections through contact and noncontact recreation and through the consumption of seafood, an analysis was performed by comparing the data associated with Harris and Dallas Counties. These two counties were selected because both are highly populated areas but one is close to the coast and the other is not. The objective is to explore what effects proximity to the coast has on Vibrio outbreaks. This comparison is shown in Table 6-5.

As can be seen in Table 6-5, the rates of Vibrio infections per capita for Harris County are higher than those for Dallas County except for unknown ways of infections. For those incidents associated with contact and noncontact recreations, the rate is about nine times higher in Harris than in Dallas County. Realizing that people in Dallas have less opportunity for recreational activities in salt water, these data suggest that salinity is indeed a key factor in the survival of Vibrios. Also, if it is true that people in Harris County consume more fresh seafood than people in Dallas County, then the data listed in Table 6-5 suggest that the consumption of seafood is one of the major mechanisms for the transmission of Vibrio diseases.

6.3 RELATIONSHIP BETWEEN VIBRIO OCCURRENCE & CORRESPONDING FECAL COLIFORM RECORDS

Among the 12 cases of Vibrio infections which occurred in Galveston Bay area, 5 cases were due to contact recreational activities with the remaining 7 due to noncontact recreation. According to the Texas Surface Water Quality Standards, the FC level can not exceed 200, 2,000, and 14 colonies/dL for contact recreation, noncontact recreation, and shellfish harvesting areas respectively. The objective of this section is to determine the relationship, if any, between the occurrences of Vibrio infections and the FC levels.

Because the Vibrio data obtained from TDH are not listed by segment, there is no reasonable way to relate them with FC data in any single segment. Instead, as listed in

TABLE 6-5
INCIDENTS OF VIBRIO DISEASES IN HARRIS AND DALLAS COUNTIES

County	HARRIS	DALLAS
No of incidents	46	14
Population*	2,818,199	1,832,810
Infected by C/NC recreation	13	1
Rate (* E6)**	4.6	0.5
Infected by food consumption	20	3
Rate (* E6)**	7.1	1.6
Infected by unknown ways	13	10
Rate (* E6)**	4.6	5.5

* Source of population data: Bureau of the Census (1990)
** Data represent number of Vibrio incidents per capita per 10 years of record period

Table 6-6, FC data associated with Galveston Bay segments are averaged. The only exception is the Vibrio case which occurred at Texas City, presumably segments 2437 or 2439. For this case, the relationship between the fecal and Vibrio data is determined by FC data in Segments 2437 and 2439 only.

Table 6-6 lists the mean FC data corresponding to the months when the cases of Vibrio infections were reported. The monthly values are geometric means over all stations in the segments. For data below the detection limits, the limits themselves were used to do the averaging. One obvious result can be seen from Table 6-6 that none of the geometric mean FC values exceeds the water quality criterion for contact recreation, 200 colonies/dL. In fact, except for the case in July of 1990, none of the mean FC levels in all segments in Galveston Bay exceeds the 200 criterion although there are Vibrio incidents. This result tends to suggest that FC indicator provides little information on the possibility of Vibrio infection.

For the two cases in May and August of 1991 listed in Table 6-6, there are no FC data for comparison. This is because they were not available at the time the data were obtained from TWC. Hence, they are compared with the historical data listed in Table 6-7. These historical FC data are computed by geometrically averaging all records at a station and then all stations in a segment. Finally, an overall mean value for all segments is obtained, which is 24.5 colonies/dL, far below the 200 colonies/dL criterion. The mean FC data for segments 2437 and 2439, near Texas City where Vibrio infection was reported, are 19.2 and 34.9 respectively.

The above comparison suggests that having water with FC levels below the contact recreation criteria provides no assurance that a Vibrio disease will not be contracted. This is consistent with the investigation performed in Apalachicola Bay, Florida (Rodrick, et al., 1984). Rodrick et al. measured both the FC and the Vibrio levels and discovered that there is little relationship between the presence of Vibrio parahaemolyticus, V. cholerae, V. alginolyticus, and V. vulnificus and the standard FC MPN value for seawater and oyster meats. In addition, when seawater FC levels were acceptable ($\leq$ 14 MPN), only 58% of the oysters sampled met the acceptable tissue FC levels. In summary, Rodrick et al. concluded that both seawater and oysters can serve as a vehicle for the transmission of Vibrio infections even when considered safe by existing federal and state standards. They further pointed out that such water quality standards may be ineffective in predicting the presence of certain potentially pathogenic Vibrios which are not of human fecal origin.

Another investigation on this relationship was performed locally. In order to assess the public health significance of elevated FC levels presumably originating from non-human sources, a study was performed in the Cow Trap Lake, a shellfish growing area in Texas, by TDH, U. S. Food and Drug Administration, and U. S. Fish and Wildlife Service in 1989 (TDH et.al, 1990). The Cow Trap Lake area was selected for the study because it

TABLE 6–6
RELATIONSHIP BETWEEN VIBRIO OUTBREAKS AND LEVELS OF FECAL COLIFORM

Vibrio Infections			Fecal Coliform Level (colonies/100 mL) for Segment*																			Remark**
County	Mo/Yr	Site	2421	2422	2423	2424	2425	2426	2427	2428	2429	2430	2431	2432	2433	2434	2435	2436	2437	2438	2439	AVG	
Galveston	9 83	Galveston Bay									170	10										41	NC
Harris	6 86	Galveston Bay	13			63								10	10	10	10				26	16	NC
Harris	7 87	Galveston Bay	10			10				70										10	10	15	NC
Wharton	9 87	Galveston Bay					8															8	NC
Harris	10 87	Galveston Bay	5			10				10										5	5	7	NC
Brazoria	8 89	Galveston Bay	8	11						150			36						30		11	23	C
Harris	4 90	Galveston Bay	61		8			40	50												8	24	C
Henderson	7 90	Galveston Bay	9		9			700	1,000		13,000	4,100						1,300		9	9	190	C
Harris	8 90	Galveston Bay	16	6						10			20						10		18	12	NC
Harris	9 90	Galveston Bay				10								10	10						10	10	C
Galveston	5 91	Galveston Bay																				***	NC
Galveston	8 91	Texas City																				***	C

* Values listed are geometrically average values of all stations in corresponding segments
** NC = noncontact recreation; C = contact recreation: categorized by activities which caused Vibrio infections
*** Data not available from TWC at date this analysis was performed

TABLE 6–7
LONG–TERM MEAN FECAL COLIFORM LEVELS FOR SEGMENTS IN GALVESTON BAY

Segment	Mean Fecal Coliform Level for a Station (colonies/100 mL)							Mean*
2421	12.0	32.2	11.9	11.1	14.8	22.4		16.0
2422	17.8	11.8	15.1	21.4	11.2			15.0
2423	13.8							13.8
2424	10.8	10.8	18.3	8.8	9.5	9.2		10.9
2425	98.5	59.6	54.7	56.4				65.2
2426	34.6	16.7	200.0					48.7
2427	34.3							34.3
2428	37.2	62.2						48.1
2429	65.8							65.8
2430	200.0	55.0						104.8
2431	16.5							16.5
2432	13.0	50.0						25.5
2433	10.7							10.7
2434	9.5	12.9						11.0
2435	11.0							11.0
2436	34.2							34.2
2437	12.1	13.8	19.0					14.7
2438	19.2							19.2
2439	9.8	10.6	9.2	15.6	2,629.3	87.9	18.5	34.9
Mean Over All Segments*								24.5

* All mean values are taken geometrically and are computed based on TWC data only

was an area that had exhibited elevated FC levels that originated from non-human sources. The study was performed to determine the sources of elevated FC in the area and the densities of a selected group of microbial indicators and pathogens such as Cryptosporidium, Vibrio cholerae 01, Campylobacter, etc. During the study, water samples collected were analyzed for ten indicators and eight pathogens. Oysters were analyzed for additional indicators and seven pathogens. Sediments were analyzed for six indicators and seven pathogens. A control station was also established in a growing area impacted by human sources in Clear Lake, a portion of Galveston Bay.

Seasonal variations were also investigated in this study. It was found that indicators were generally lower during spring, summer and fall sampling and were much higher during the winter study especially for FC. Cryptosporidium, Vibrio cholerae 01, and Campylobacter were found in the water during the winter study. Oyster samples exhibited elevated FC levels and relatively few pathogens. Vibrio cholerae 01 was found in water only in winter and in oysters and sediments only in the fall, although it is thought to be endemic in Gulf coast waters. Indicator levels were elevated in sediment samples, especially during the spring and winter studies. E. coli, Listeria, and Vibrio cholerae 01 were also detected in sediments.

The study indicated that the elevated FC levels probably originated from non-human sources. The low levels of pathogens encountered during the study suggest a very low likelihood of transmission of disease from consumption of oysters from the Cow Trap Lake. However, the oysters from the study area exceeded NSSP market criteria (230 FC/100 grams) in three of the four study phases. The most important conclusion from the study is that no correlation of pathogen levels with FC in sediments, oysters, or waters could be demonstrated. Therefore, FC appears to hold little public health significance in the study area.

6.4 INVESTIGATION OF OTHER PUBLIC HEALTH CONCERNS

According to Sehulster (1991) of the TDH Epidemiology Division, there is no database in TDH that contains information on other pathogenic or viral diseases associated with shellfish consumption. Ms. Sehulster also noted that the TDH is not required by law to investigate or keep record of the mechanism of infection of viral diseases. In fact, the information TDH has only includes the patient's name, sex, age, race, diagnosis, method of diagnosis, city of residence of the patient, onset date, and name of the physician. For the purpose of comparing the occurrences of diseases with shellfish consumption, there are no data available.

6.5 CONCLUSIONS

The characteristics of Vibrios were investigated and documented. It was found that Vibrios are naturally occurring with water temperature and salinity probably the key factors controlling survival in aquatic environments. The relationship between occurrences of Vibrio infections and FC data is probably non-existent. While Vibrio infections can be serious and even fatal, the infection rate is quite low.

7.0 REFERENCES

American Public Health Association, American Water Works Association, and Water Pollution Control Federation, (1989) Standard Methods for the Examination of Water and Wastewater, 17th Edition.

Bellaire, J.T., G.A. Parr-Smith, and I.G. Wallis, (1977) Significance of Diurnal Variations in Fecal Coliform Die-Off Rates in the Design of Ocean Outfalls, Journal of Water Pollution Control Federation, Vol. 49, No. 9, pp. 2022-2030.

Bockemuhl, J., K. Roch, B. Wohlers, V. Aleksic, S. Aleksic, and R. Wokatsch, (1986) Seasonal Distribution of Facultatively Enteropathogenic Vibrios (Vibrio Cholerae, Vibrio Mimicus, Vibrio Parahaemolyticus) in the freshwater of the Elbe River at Hamburg, Journal of Applied Bacteriology, Vol. 60, pp. 435-442.

Brayton, P.R., R.B. Bode, R.R. Colwell, M.T. MacDonell, H.L. Hall, D.J. Grimes, P.A. West, and T.N. Bryant, (1986) Vibrio Cincinnatinesis sp. nov. A New Human Pathogen, Journal of Clinical Microbiology, Vol. 23, pp. 104-108.

Broutman, M.A., and D.L. Leonard, (1988) The Quality of Shellfish Growing Waters in the Gulf of Mexico, National Oceanic and Atmospheric Administration's National Estuarine Inventory, U.S. Department of Commerce, 44 pp.

Bureau of the Census, (1990) 1990 Census of Population and Housing.

Cabelli, V.J., (1977) Indicators of Recreational Water Quality, Bacterial Indicators/Health Hazards Associated with Water, American Society for Testing and Materials, Ed. A.W. Hoadley and B.J. Dutka, ASTM Special Technical Publication 635, pp. 222-238.

Cabelli, V.J., A.P. Dufour, L.J. McCabe, and M.A. Levin, (1982) Swimming-Associated Gastroenteritis and Water Quality. Am. J. Epidemiol. Vol. 115, p. 606.

Chan, K.Y., M.L. Woo, L.Y. Lam, and G.L. French, (1989) Vibrio Parahaemolyticus and Other Halophilic Vibrios Assoicated with Seafood in Hong Kong, Journal of Applied Bacteriology, Vol. 66, pp. 57-64.

City of Houston, (1991) Unpublished Tabular Information on Sewer System Monitoring.

Davis, J.W., and R.K. Sizemore, (1982) Incidence of Vibrio Species Associated with Blue Crabs (Callinectes Sapidus) Collected from Galveston Bay, Texas, Applied and Environmental Microbiology, Vol. 43, pp. 1092-1097.

De La Cruz, A., (1992) Texas Water Commission District 8, Personal Communication.

De Paola, A., (1981) Vibrio Cholerae in Marine Foods and Environmental Waters: A Literature Review, Journal of Food Science, Vol. 46, pp. 66-70.

Dutka, B.J., and K.K. Kwan, (1980) Bacteria Die-off and Stream Transport Studies, Water Resources, Vol. 14, pp. 909-915.

Dufour, A.P., (1977) Escherichia Coli: The Fecal Coliform, Bacterial Indicators/Health Hazards Associated with Water, American Society for Testing and Materials, Ed. A.W. Hoadley and B.J. Dutka, ASTM Special Technical Publication 635, pp. 48-58.

Dupont, J., (1992) Texas Water Commission, Personal Communication.

Entringer, M. (1992) Galveston County Health District, Personal Communication.

Fleisher, J.M., (1991) A reanalysis of Data Supporting U.S. Federal Bacteriological Water Quality Critera Governing Marine Recreational Waters, Research J. WPCF, Vol. 63, No. 3, pp. 259-265.

Garrett, M.T., (1992) Personal Communication.

Geldreich, E.E., (1978) Bacterial Populations and Indicator Concepts in Feces, Sewage, Stormwater and Solid Wastes in Indicators of Viruses in Water and Food, G. Berg, Ed., Ann Arbor Science Pub., Inc., Ann Arbor, MI, pp. 51-97.

Glanton, T., (1992) Unpublished City of Houston Data.

Groundwater Services, Inc., and Rice University, (1991) Characterization of Non-Point Sources and Loadings to Galveston Bay, Draft Technical Report.

Hunt, D.A., (1977) Indicators of Quality for Shellfish Waters, Bacterial Indicators/Health Hazards Associated with water, American Society for Testing and Materials, Ed. A.W. Hoadley and B.J. Dutka, ASTM Special Technical Publications 635, pp. 337-345.

Huq, M.I., K.M.S. Aziz, and R.R. Colwell, (1985) Enterotoxigenic Properties of Vibrio Fluvialis (Group F Vibrio) Isolated from Clinical and Environmental Sources, Journal of Diarrhoer Disease Research, Vol. 3, pp. 96-99.

Huq, A., S.A. Huq, D.J. Crimes, M. O'Brien, K.H. Chu, J.M. Capuzzo, and R.R. Colwell, (1986) Colonization of the Gut of the Blue Crab (Callinectes Sapidus) by Vibrio Cholerae, Applied and Environmental Microbiology, Vol. 52, pp. 586-588.

Interstate Shellfish Sanitation Conference, (1990) National Shellfish Sanitation Program Manual of Operation, FDA, Washington D.C.

Jensen, P.A., W.F. Ritter, and J.M. Tyrawski, (1977) Coliform Bacteria Loadings and Dynamics, Report CMS-C-5-77 to Coastal Sussex County, Delaware 208 Program.

Jensen, P.A., A. Rola, and J.M. Tyrawski, (1980) Tidal Wetlands and Estuarine Coliform Bacteria, in Wetlands and Estuarine Processes with Emphasis on Modeling, Plenum Press.

Karunasagar, I., I. Karunasagar, M.N. Venugopal, and C.N. Nagesha, (1987) Survival of Vibrio Parahaemolyticus in Estuarine and Seawater and in Association with Clams, Systematic and Applied Microbiology, Vol. 9, pp. 316-319.

Kelly, M.T., and E.M. Dan Stroh, (1988) Occurrence of Vibrionaceae in Natural and Cultivated Oyster Populations in the Pacific Northwest, Diagnostic Microbiology and Infections Disease, Vol. 9, pp. 1-6.

Kelly, M.T., and A. Dinuzzo, (1985) Uptake and Clearance of Vibrio Vulnificus from Gulf Coast Oysters (Crassostrea Virginica), Applied and Environmental Microbiology, Vol. 50, pp. 1548-1549.

Kenner, B.A., (1978) Fecal Streptococcal Indicators, G. Berg, Ed., Indicators of Viruses in Water and Food, Ann Arbor Science Pub., Inc., Ann Arbor, MI, pp. 147-169.

Lee, J.V., D.J. Bashford, T.J. Donovan, A.L. Furniss, and P.A. West, (1982) The Incidence of Vibrio Cholerae in Waters, Animals and Birds in Kent, England, Journal of Applied Bacteriology, Vol. 52, pp. 281-291.

Metcalf & Eddy, Inc., (1991) Wastewater Engineering - Treatment Disposal, and Reuse, Third Edition, Revised by G. Tchobanoglous and F.L. Burton, McGraw-Hill, Inc., 1,334 pp.

Miller, C.J., R.G. Feacham, and B.S. Drasar, (1985) Cholera Epidemiology in Developed and Developing Countries: New Thoughts on Transmission, Seasonality, and Control, Lancet, Vol. i, pp. 261-263.

Mitchell, R., and C. Chamberlain, (1974) Factors Influencing the Survival of Enteric Micro-organisms in the Sea: An Overview, Proceedings of the International Symposium on the Discharge of Sewage from Sea Outfalls, Pergammon Press, pp. 237-251.

Morris, J.G., and R.E. Black, (1985) Cholera and Other Vibrioses in the United States, New England Journal of Medicine, Vol. 312, pp. 343-350.

Office of Technology Assessment, (1987) Wastes in the Marine Environment, U.S. Government Printing Office, Washington, D.C. 312 pp.

Ogg. J.E., R.A. Ryder, and H.L. Smith, (1989) Isolation of Vibrio Cholerae from Aquatic Birds in Colorado and Utah, Applied and Environmental Microbiology, Vol. 55, pp. 95-99.

Ray, B., (1991) Texas Department of Health, Division of Epidemiology, Personal Communication.

Ray, B., (1992) Texas Department of Health, Division of Epidemiology, comment on draft report.

Rhodes, J.B., H.L. Smith, and J.E. Ogg, (1986) Isolation of Non-01 Vibrio Cholerae Serovars from Surface Waters in Western Colorado, Applied and Environmental Microbiology, Vol. 51, pp. 1216-1219.

Rodrick, G.E., N.J. Blake, M. Tamplin, J.E. T. Cuba, and M.A. Hood, (1984) The Relationship Between Fecal Coliform Levels and The Occurrence of Vibrios in Apalachicola Bay, Florida, Vibrios in the Environment, Ed. R.R. Colwell, John, Wiley & Sons, pp. 567-575.

Salmaso, S., D. Greco, B. Bonfiglio, M. Castellani-Pastoris, G. De Felip, A. Bracciotti, G. Sitzia, A. Congiu, G. Piu, G. Angioni, L. Barra, A. Zampieri, and W.B. Baine, (1980) Recurrence of Pelecypod-Associated Cholera in Sardinia, Lancet, Vol. ii, pp. 1124-1127.

Sehulster, L., (1991) Texas Department of Health, Division of Epidemiology, Personal Communication.

Seidler, R.J., and T.M. Evans, (1984) Computer-Assisted Analysis of Vibrio Field Data: Four Coastal Areas, Vibrios in the Environment, Ed. R.R. Colwell, John, Wiley & Sons, pp. 411-426.

Slanetz, L.W., and C.H. Bartley, (1965) Health Laboratory Science, Vol. 2, 142 pp.

Soil Conservation Service, (1986) Urban Hydrology for Small Watersheds, U.S. Department of Agriculture, Technical Release 55, National Technical Information Service, Springfield, VA.

Tacket, C.O., F. Brenner, and P.A. Blake, (1984) Clinical Features and an Epidemiologic Study of Vibrio Vulnificus Infections, Journal of Infectious Diseases, Vol. 149, pp. 558-561.

Tchobanoglous, G., and E. D. Schroeder, (1985) Water Quality - Characteristics, Modeling, Modification, Addison-Wesley Publishing Company, 768 pp.

Texas Department of Health, Division of Shellfish Sanitation Control, (1988) Comprehensive Sanitary Survey of the Producing Waters of Galveston Bay, 136 pp.

Texas Department of Health, Division of Shellfish Sanitation Control, (1988) Comprehensive Sanitary Survey of the Shellfish Producing Waters of West Galveston Bay.

Texas Department of Health, U.S. Food and Drug Administration, and U.S. Fish and Wildlife Service, (1990) Cow Trap Lake - A Study of Pathogens, Indicators, and Classification of a Texas Shellfish Growing Area, 81 pp.

Texas Department of Health, (1990) Fish and Shellfish Consumption Advisory, ADV-3.

Texas Water Commission, (1991) Texas Surface Water Quality Standards, Chapter 307.

Thomann, R. V., and J.A. Mueller, (1987) Principles of Surface Water Quality Modeling and Control, Pub. Harper & Row, New York, 644 pp.

U.S. Environmental Protection Agency, (1973) Biological Field and Laboratory Methods for Measuring the Quality of Surface Waters and Effluents.

U.S. Environmental Protection Agency, (1976) Quality Criteria for Water, U.S. Gov. Printing Office, Washington, D.C.

U.S. Environmental Protection Agency, (1979) Methods for Chemical Analysis of Water and Wastes, EPA 600/4-79-020.

U.S. Environmental Protection Agency, (1986) Ambient Water Quality Criteria for Bacteria - 1986, U.S. EPA, EPA 44015-84-002, Office of Water Regulations and Standards, Washington, D.C.

Ward, G., (1991) Hydrographic Segmentation for Galveston Bay, Memorandum, Status and Trends in Water Quality Project, Galveston Bay National Estuary Program.

West, P.A., (1989) The Human Pathogenic Vibrios - A Public Health Update with Environmental Perspective, Epidemiology and Infection, Vol. 103, pp. 1-34.

Wiles, K., (1992) Texas Department of Health, Division of Shellfish Sanitation Control, Personal Communication.

Williams, L.A., and P.A. La Rock, (1985) Temporal Occurrence of Vibrio Species Aerononas Hydrophila in Estuarine Sediment, Applied and Environmental Microbiology, Vol. 50, pp. 1490-1495.

Winslow & Associates, Inc., (1986) Houston Ship Channel Urban Runoff Nonpoint Source Study Relative Significance of Waste Loads Entering the Houston Ship Channel, Texas Water Commission, Water Quality Division, Austin, Texas.

APPENDIX A

HISTORICAL CLASSIFICATION MAPS FOR SHELLFISH GROWING WATERS IN GALVESTON BAY SYSTEM

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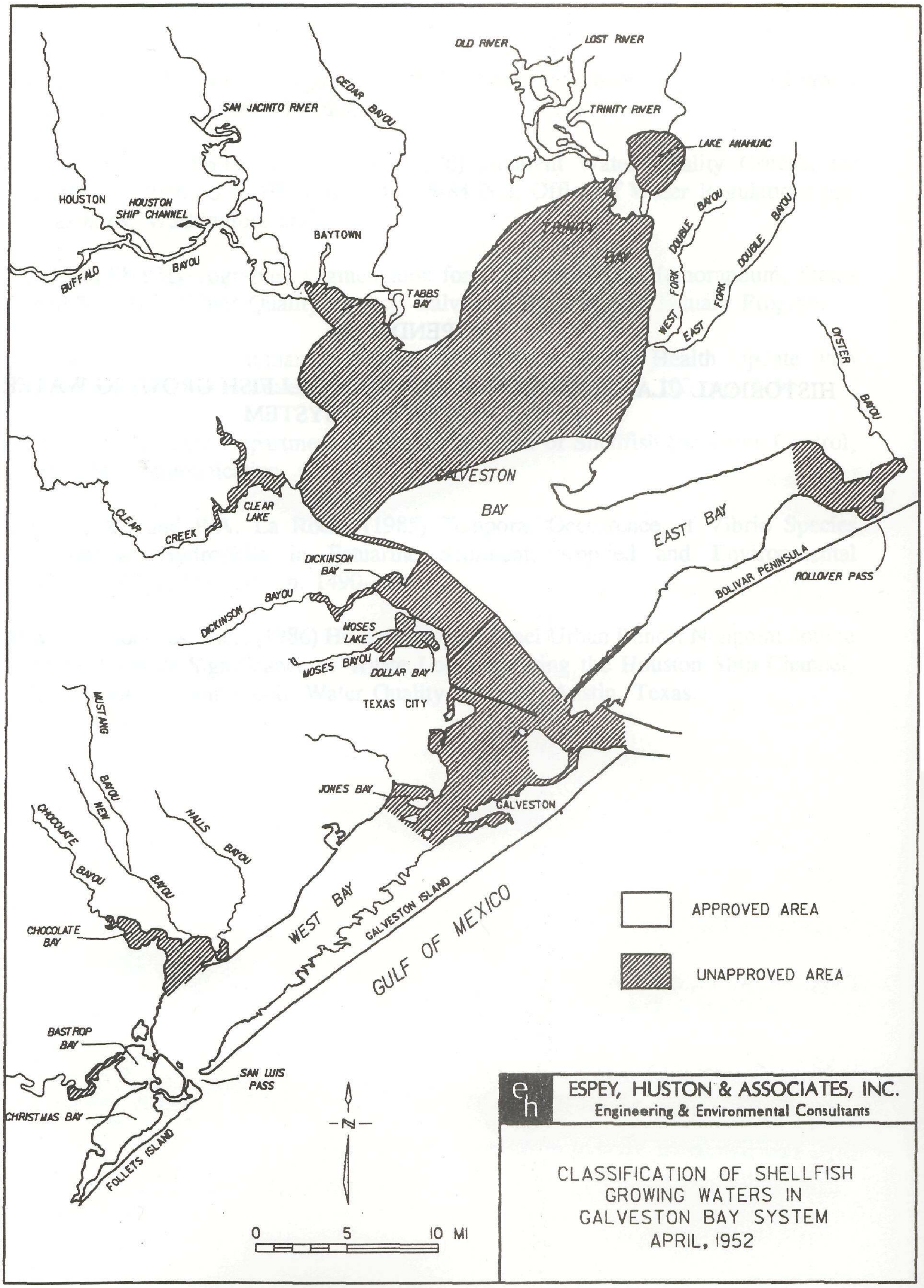
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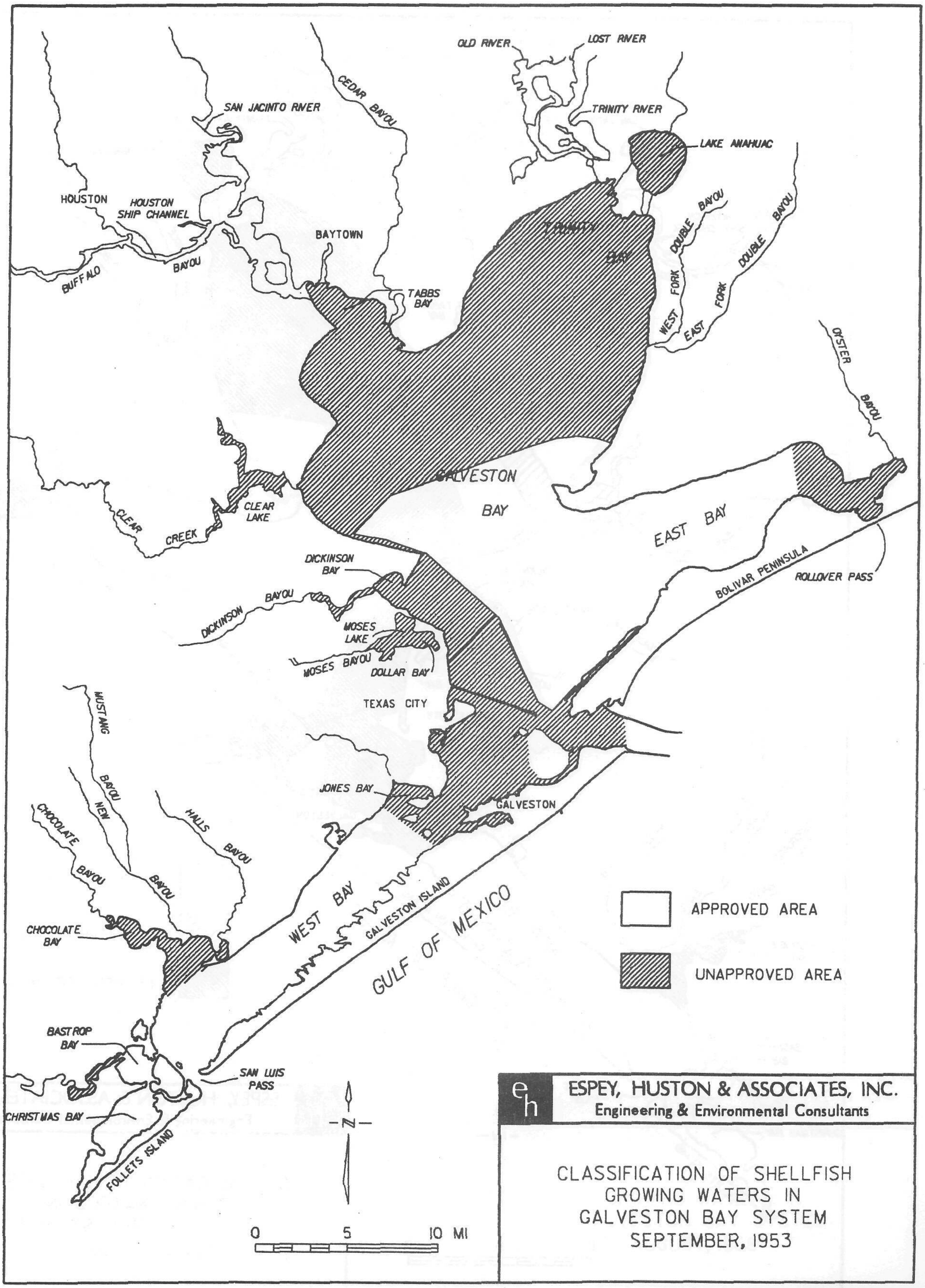
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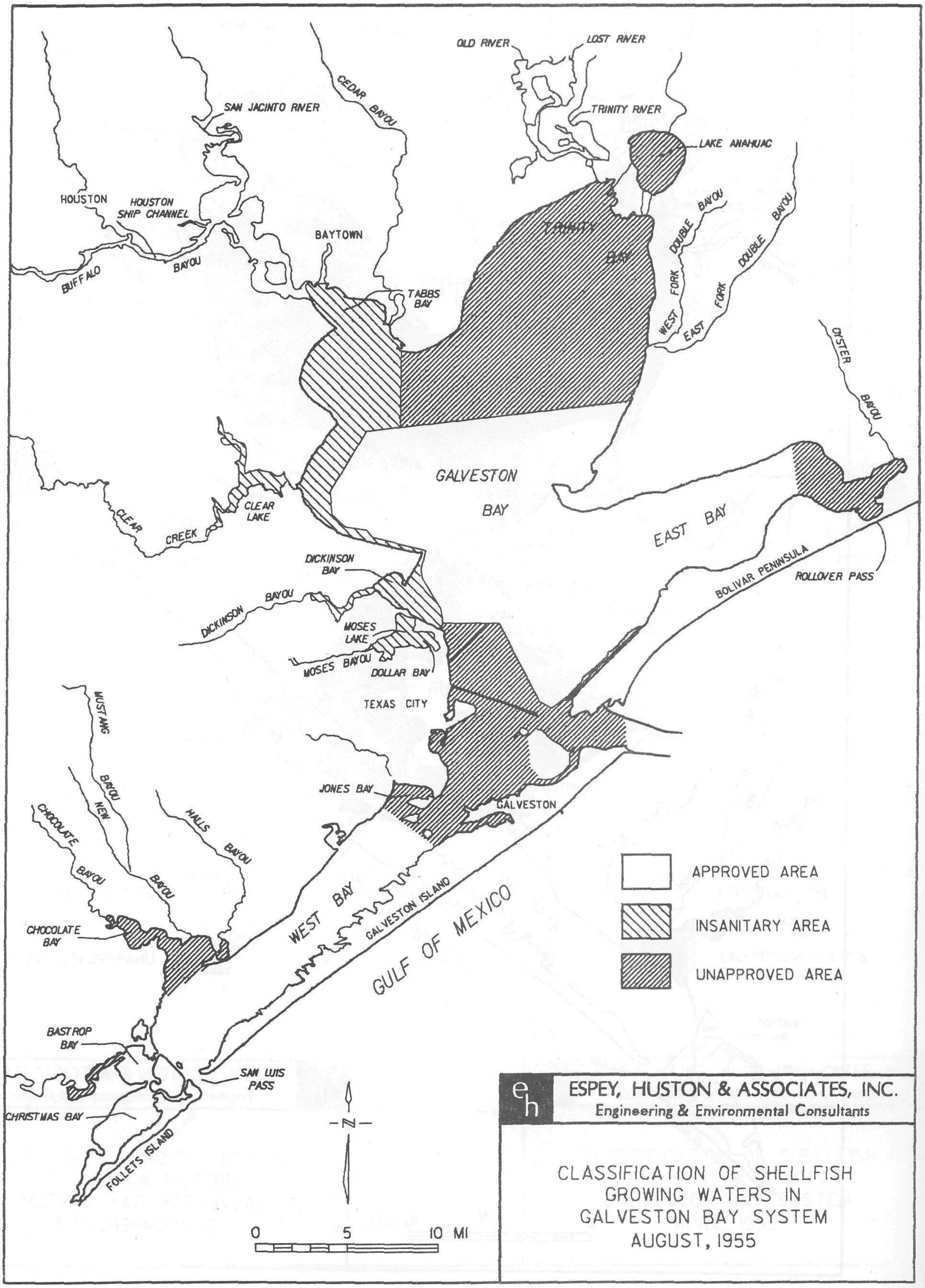
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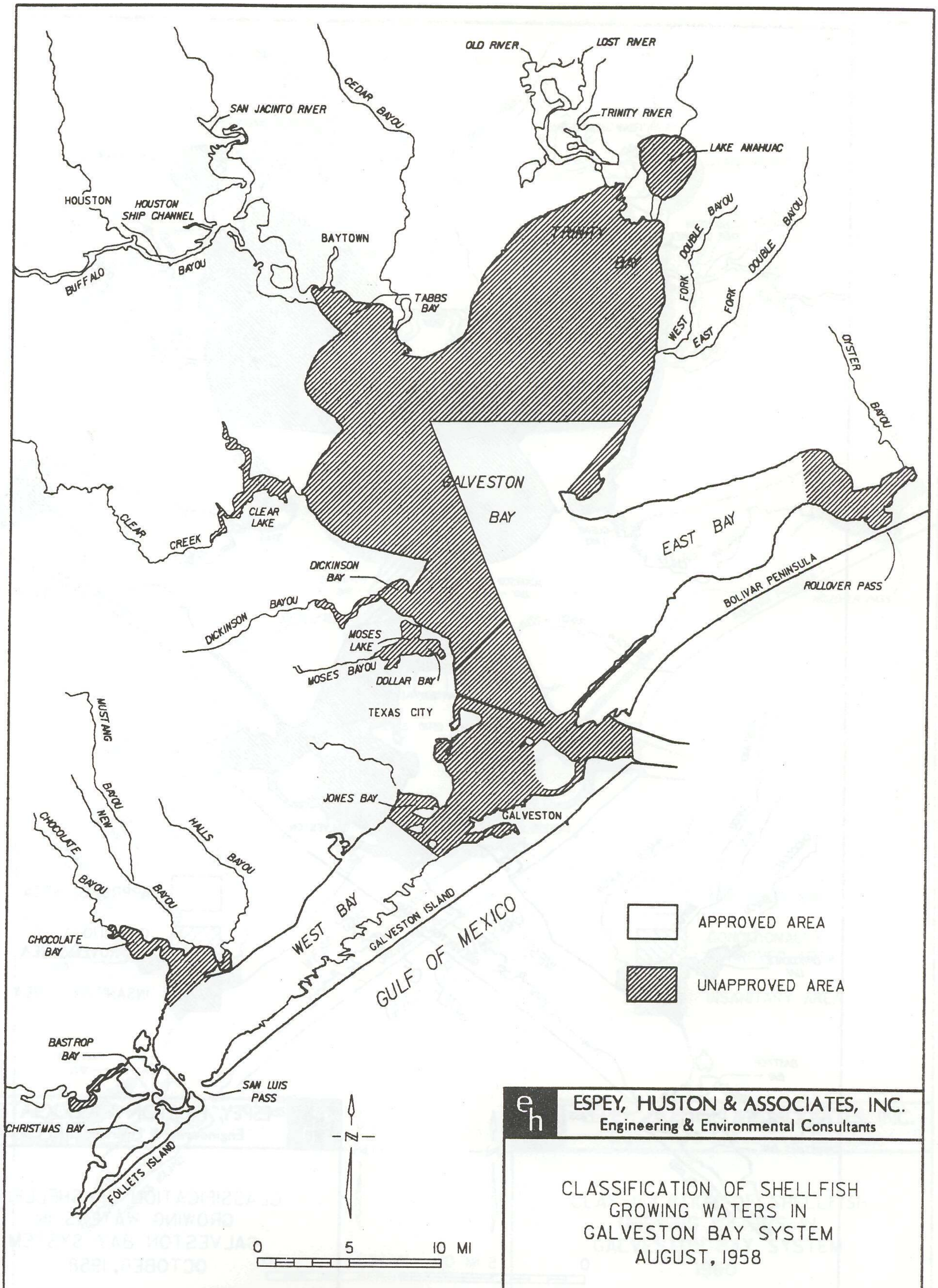
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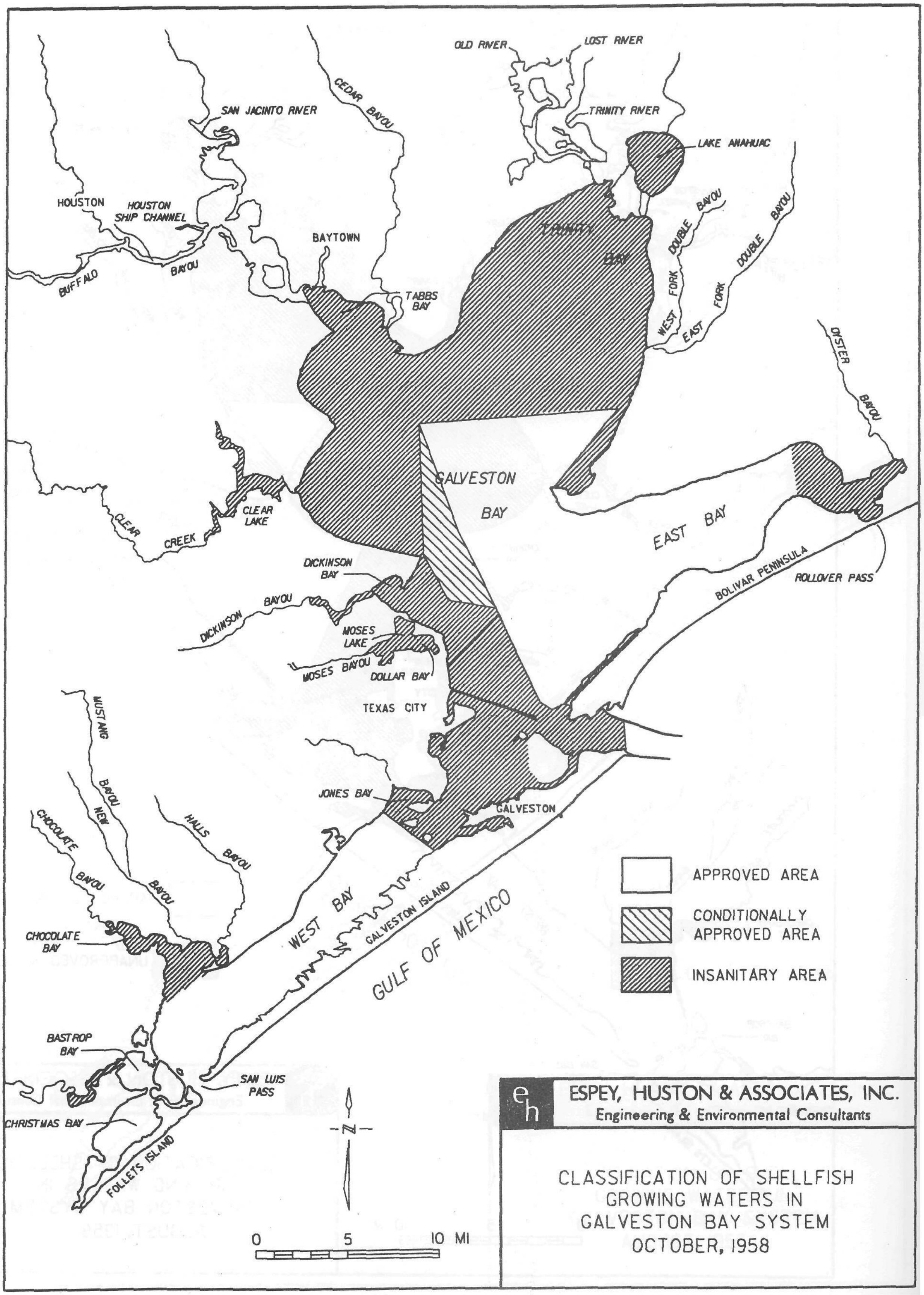
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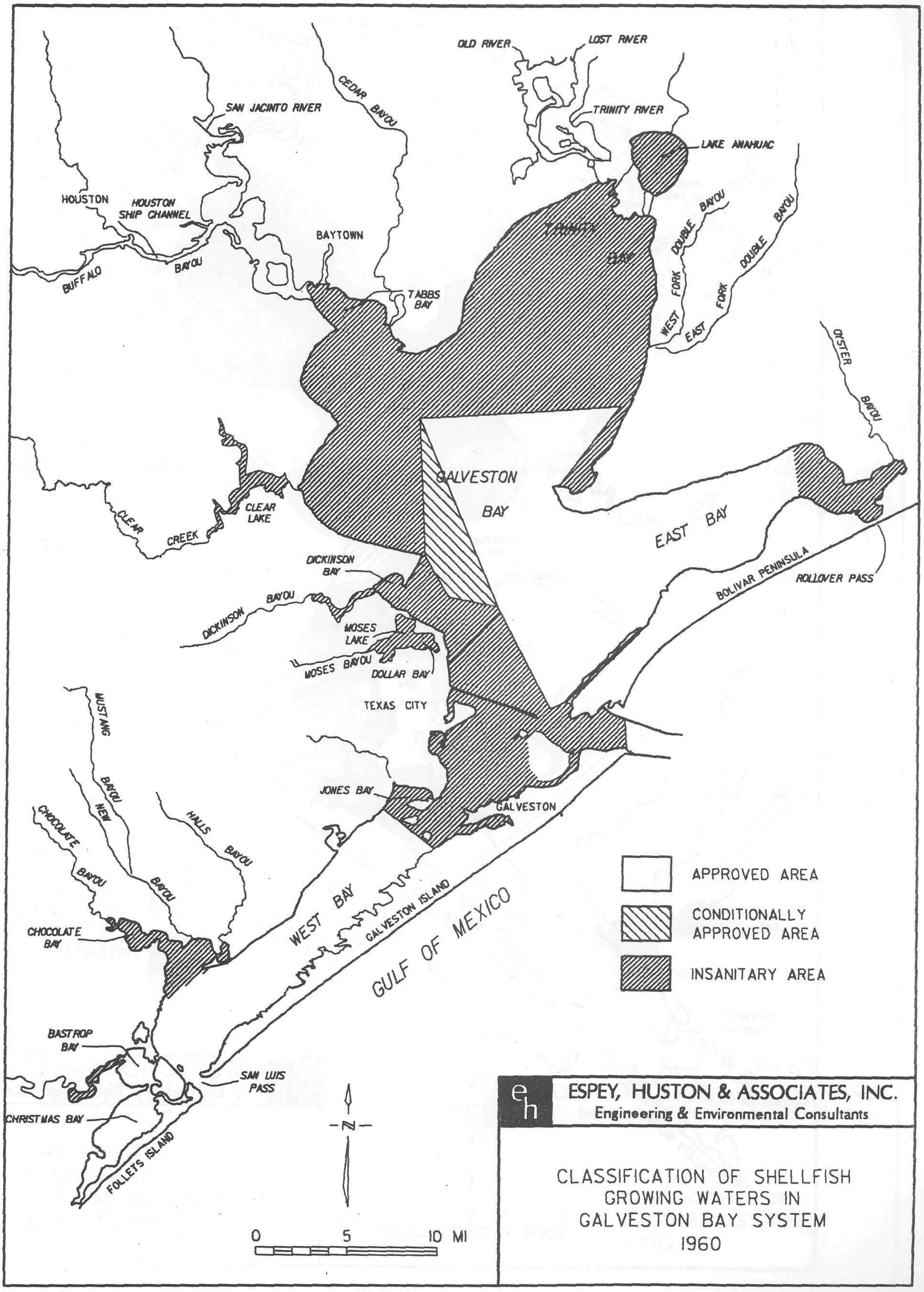
ESPEY, HUSTON & ASSOCIATES, INC.
Engineering & Environmental Consultants
CLASSIFICATION OF SHELLFISH
GROWING WATERS IN
GALVESTON BAY SYSTEM
OCTOBER, 1958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TRINITY RIVER
LAKE ANAHUAC
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HOUSTON SHIP CHANNEL
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GALVESTON BAY
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CLEAR CREEK
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ROLLOVER PASS
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MUSTANG BAYOU
NEW BAYOU
HALLS BAYOU
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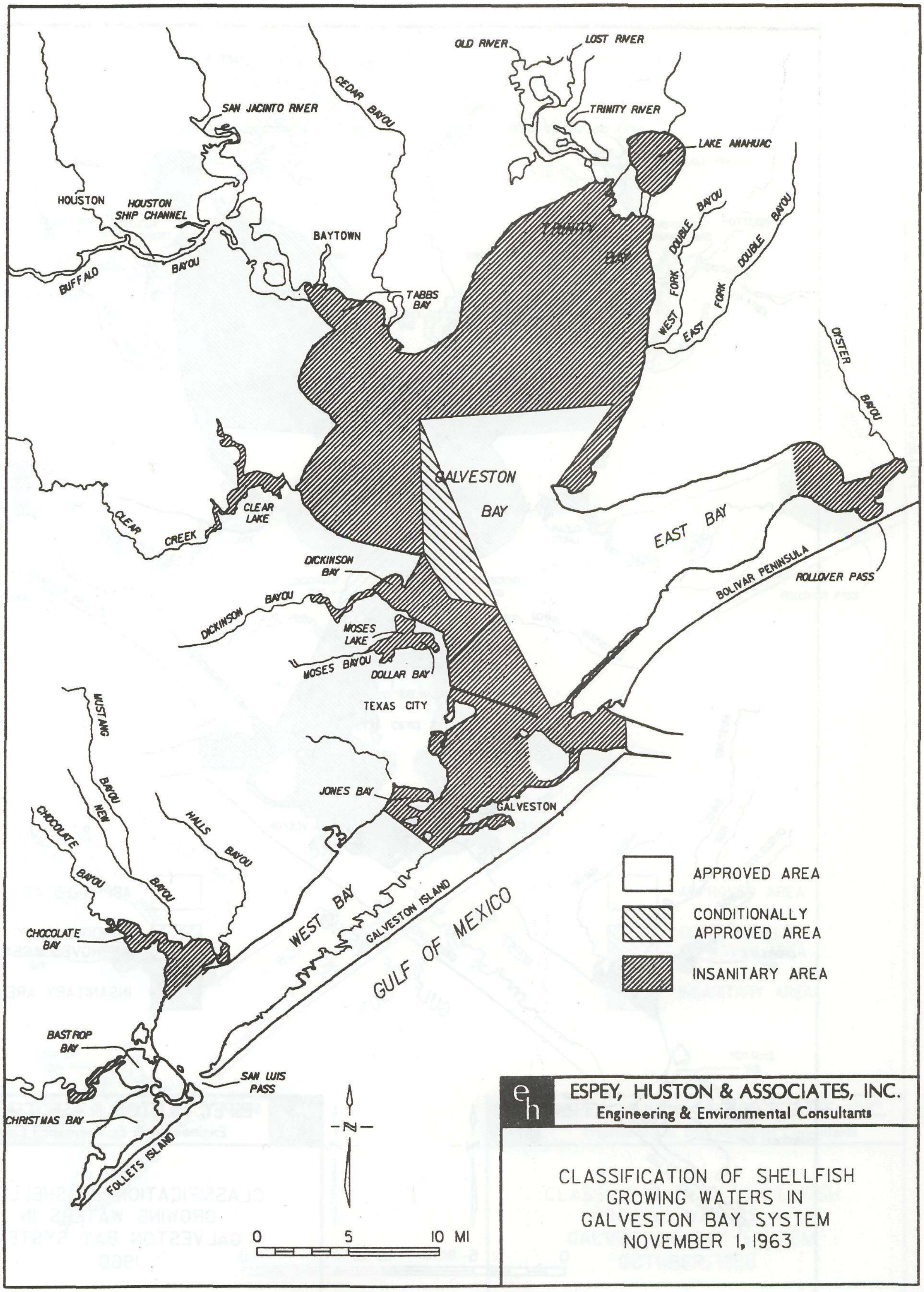
ESPEY, HUSTON & ASSOCIATES, INC.
Engineering & Environmental Consultants
CLASSIFICATION OF SHELLFISH GROWING WATERS IN GALVESTON BAY SYSTEM 1960

PROJECT NO.

PROJECT NO.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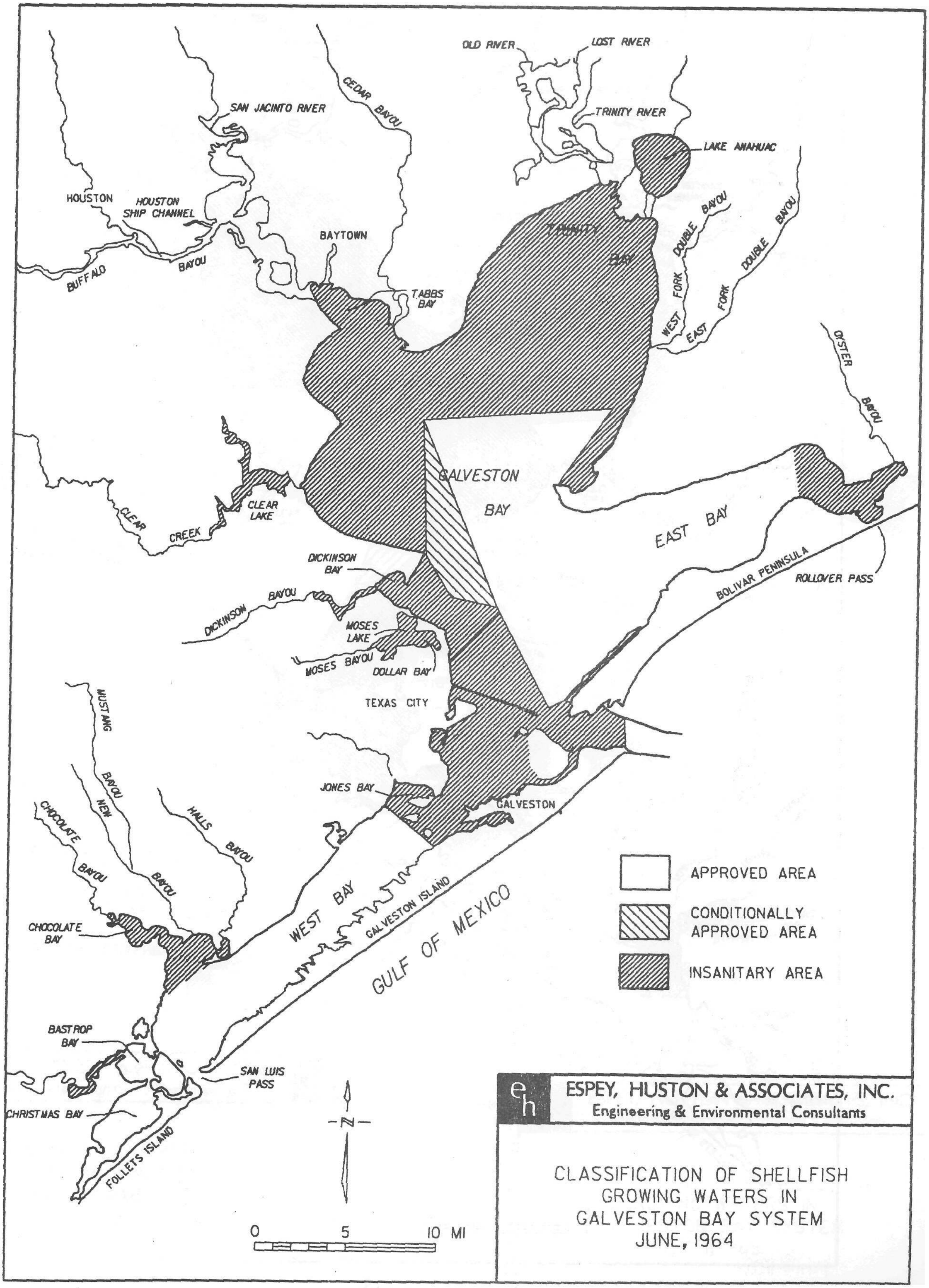
ESPEY, HUSTON & ASSOCIATES, INC.
Engineering & Environmental Consultants
CLASSIFICATION OF SHELLFISH GROWING WATERS IN GALVESTON BAY SYSTEM NOVEMBER 1, 1963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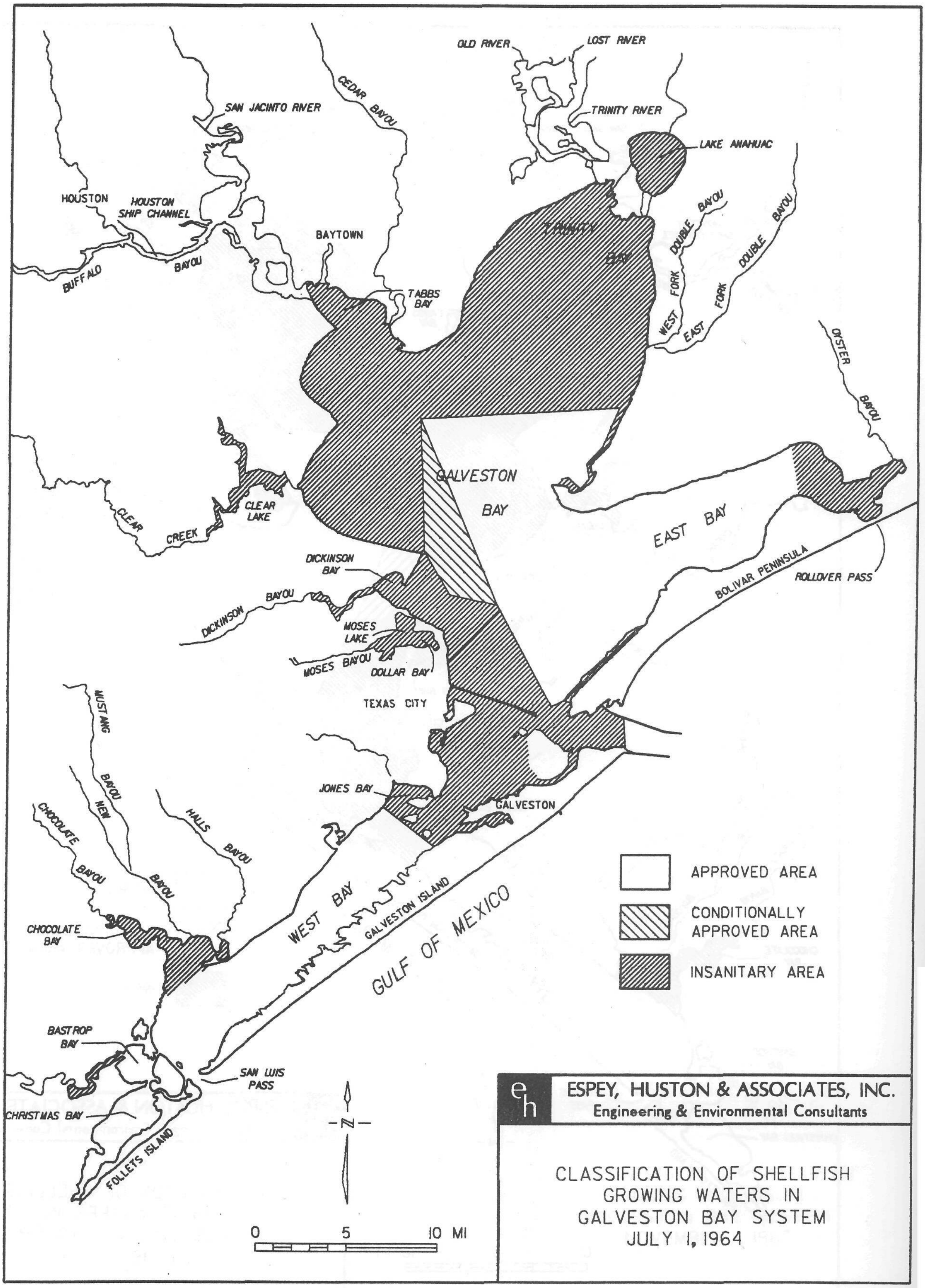
ESPEY, HUSTON & ASSOCIATES, INC.
Engineering & Environmental Consultants
CLASSIFICATION OF SHELLFISH GROWING WATERS IN GALVESTON BAY SYSTEM JUNE, 1964

PROJECT NO.



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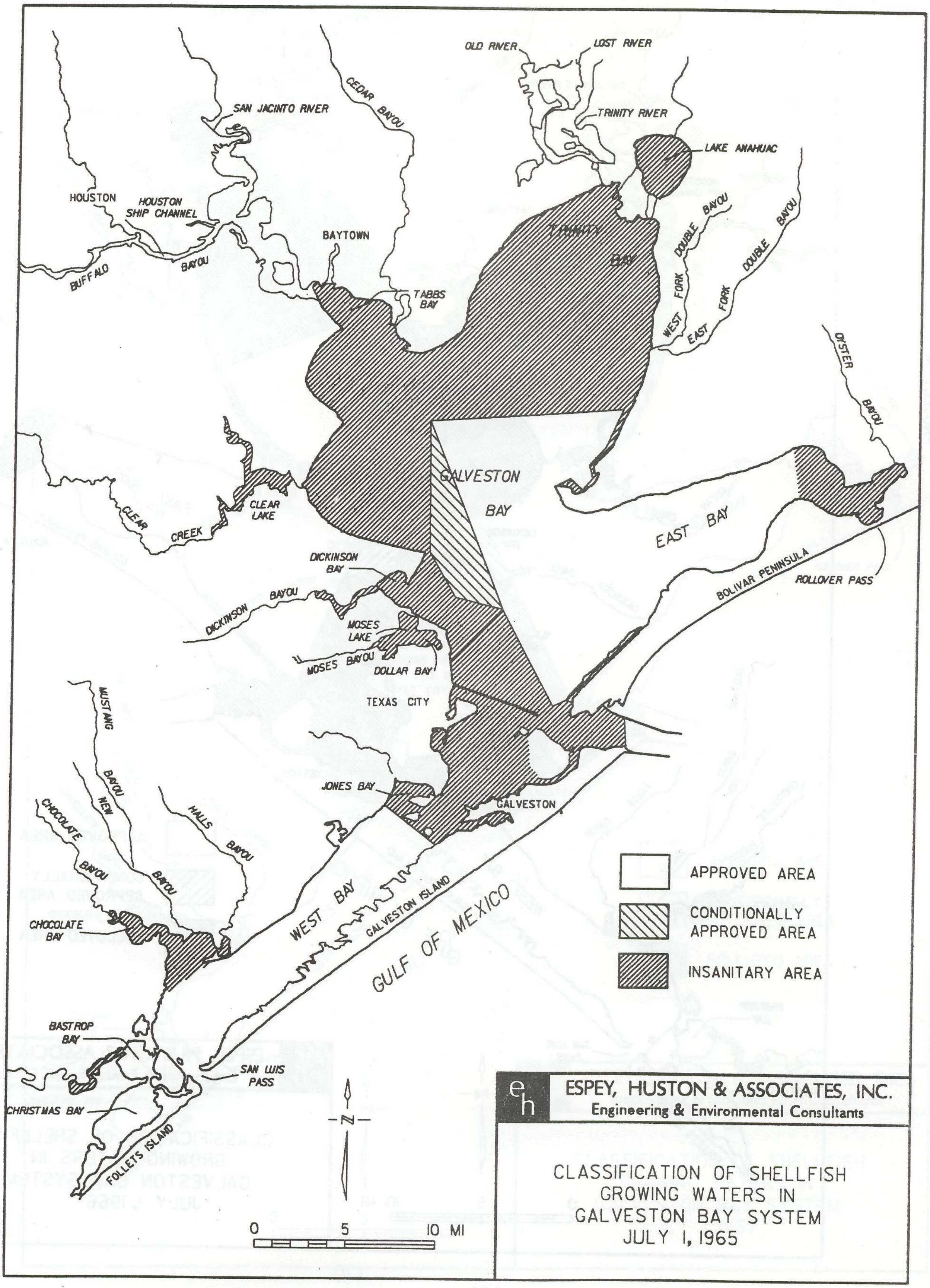
CLASSIFICATION OF SHELLFISH GROWING WATERS IN GALVESTON BAY SYSTEM JULY 1, 1964



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CLASSIFICATION OF SHELLFISH GROWING WATERS IN GALVESTON BAY SYSTEM JULY 1, 1965

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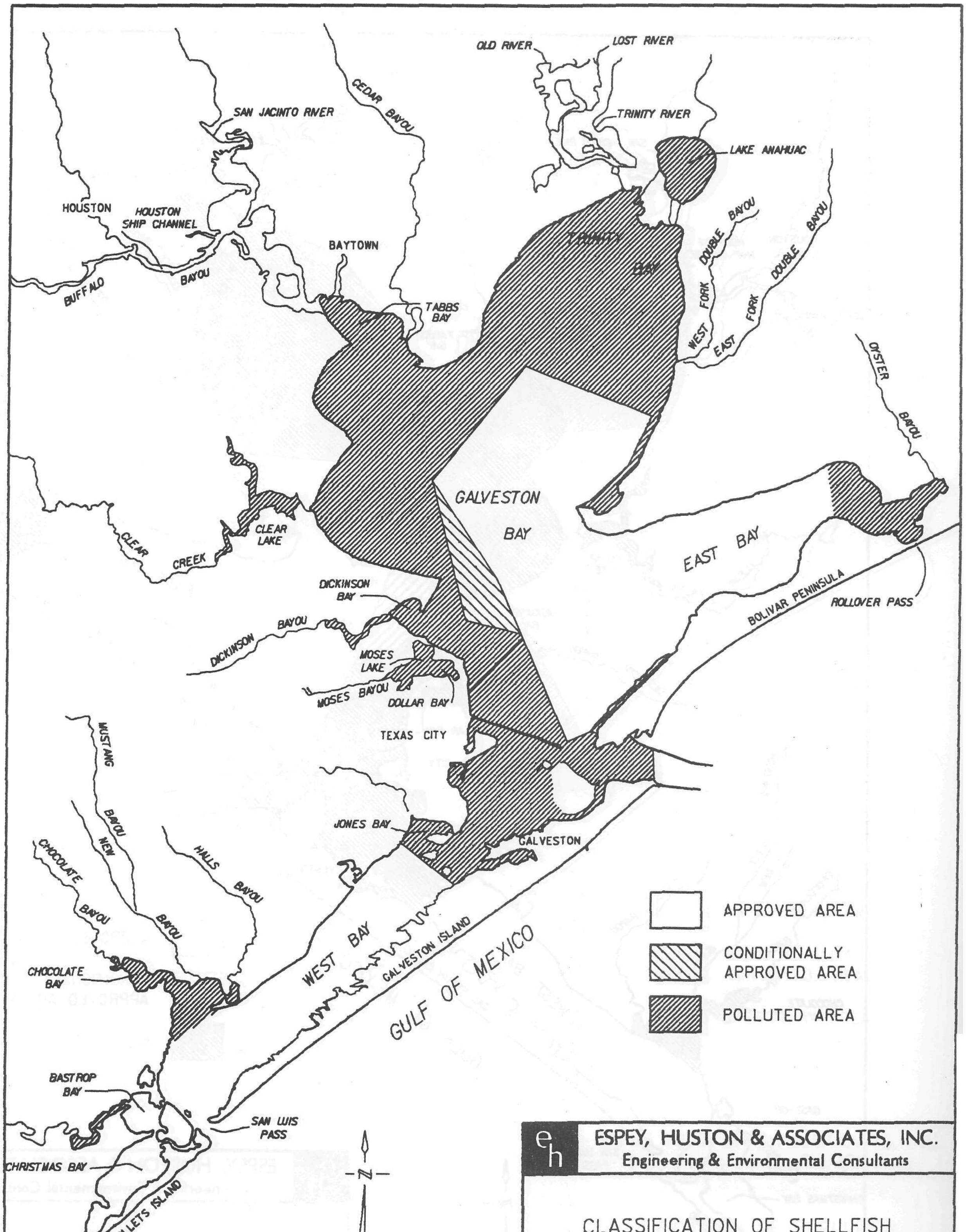

CLASSIFICATION OF SHELLFISH
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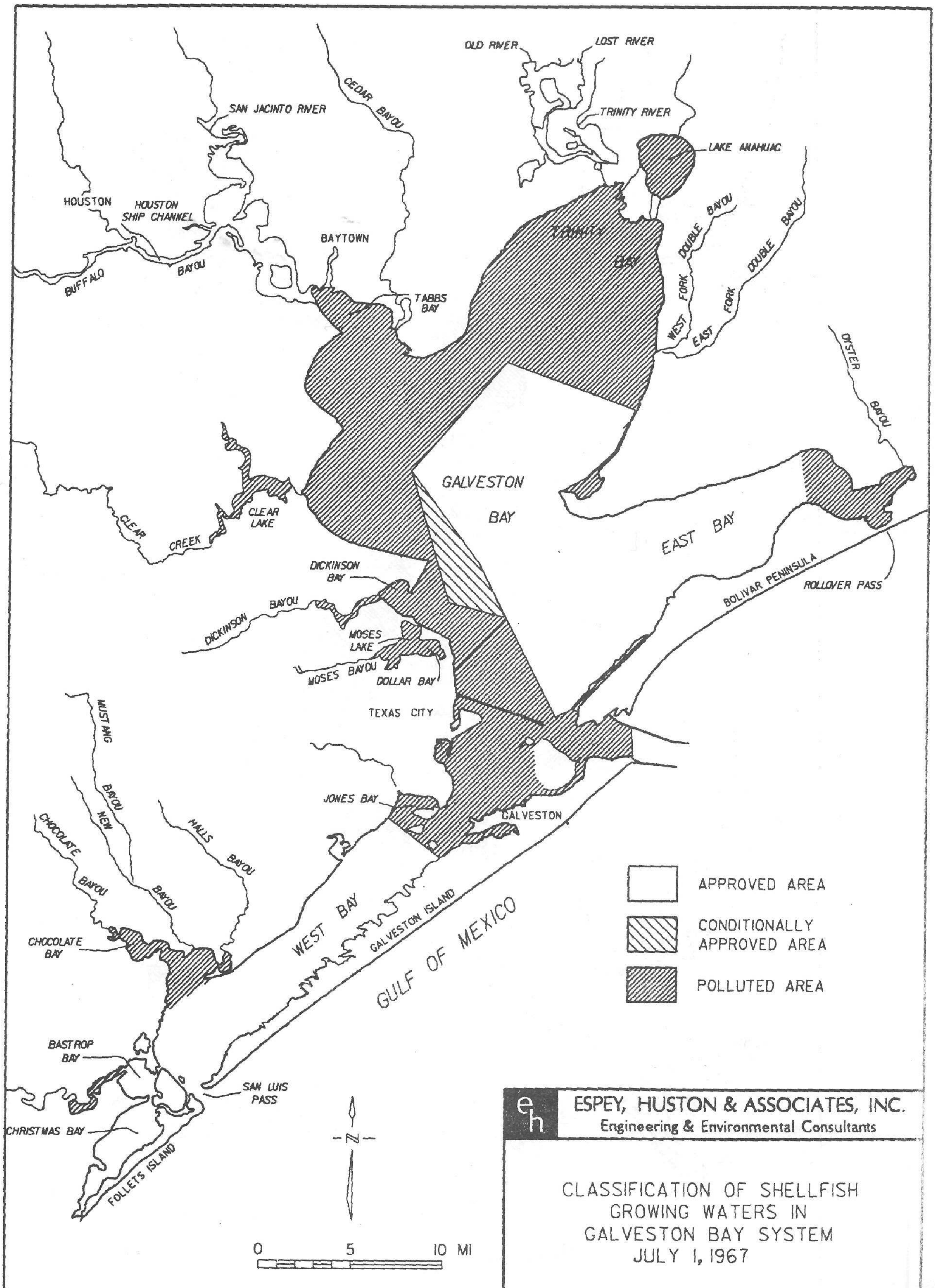
GALVESTON BAY SYSTEM
JULY 1, 1966

PROJECT NO.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ESPEY, HUSTON & ASSOCIATES, INC.
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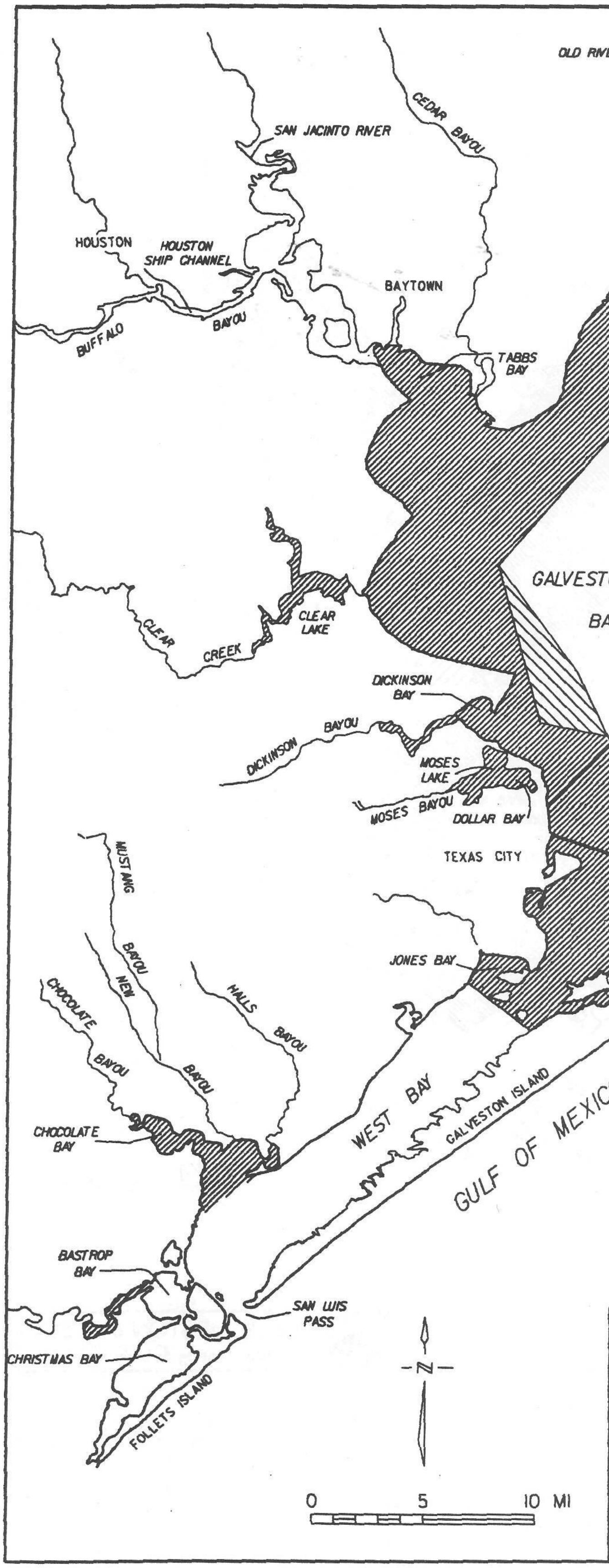
CLASSIFICATION OF SHELLFISH GROWING WATERS IN GALVESTON BAY SYSTEM JULY 1, 1967

PROJECT NO.



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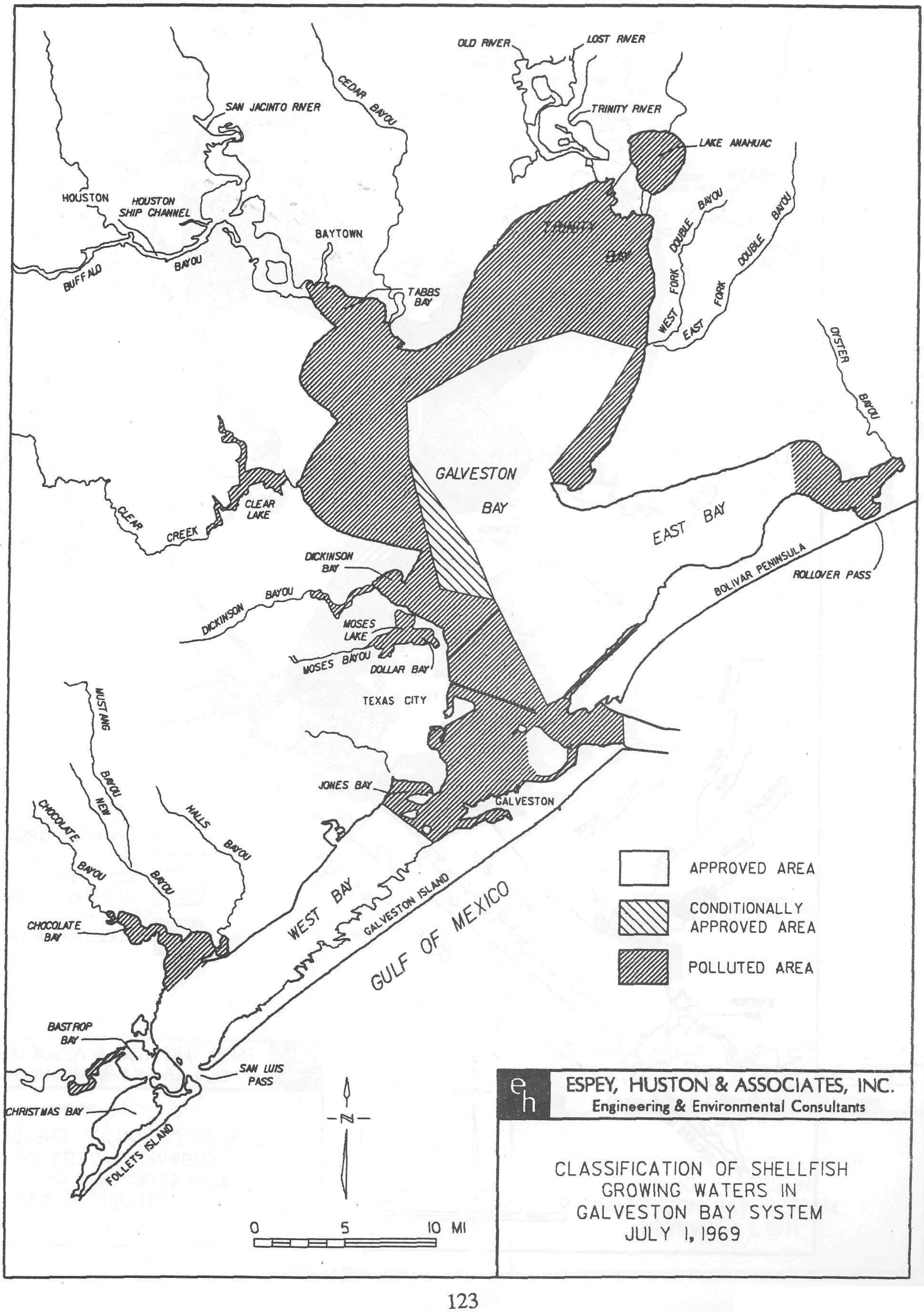
CLASSIFICATION OF SHELLFISH GROWING WATERS IN GALVESTON BAY SYSTEM JULY 1, 1968

PROJECT NO.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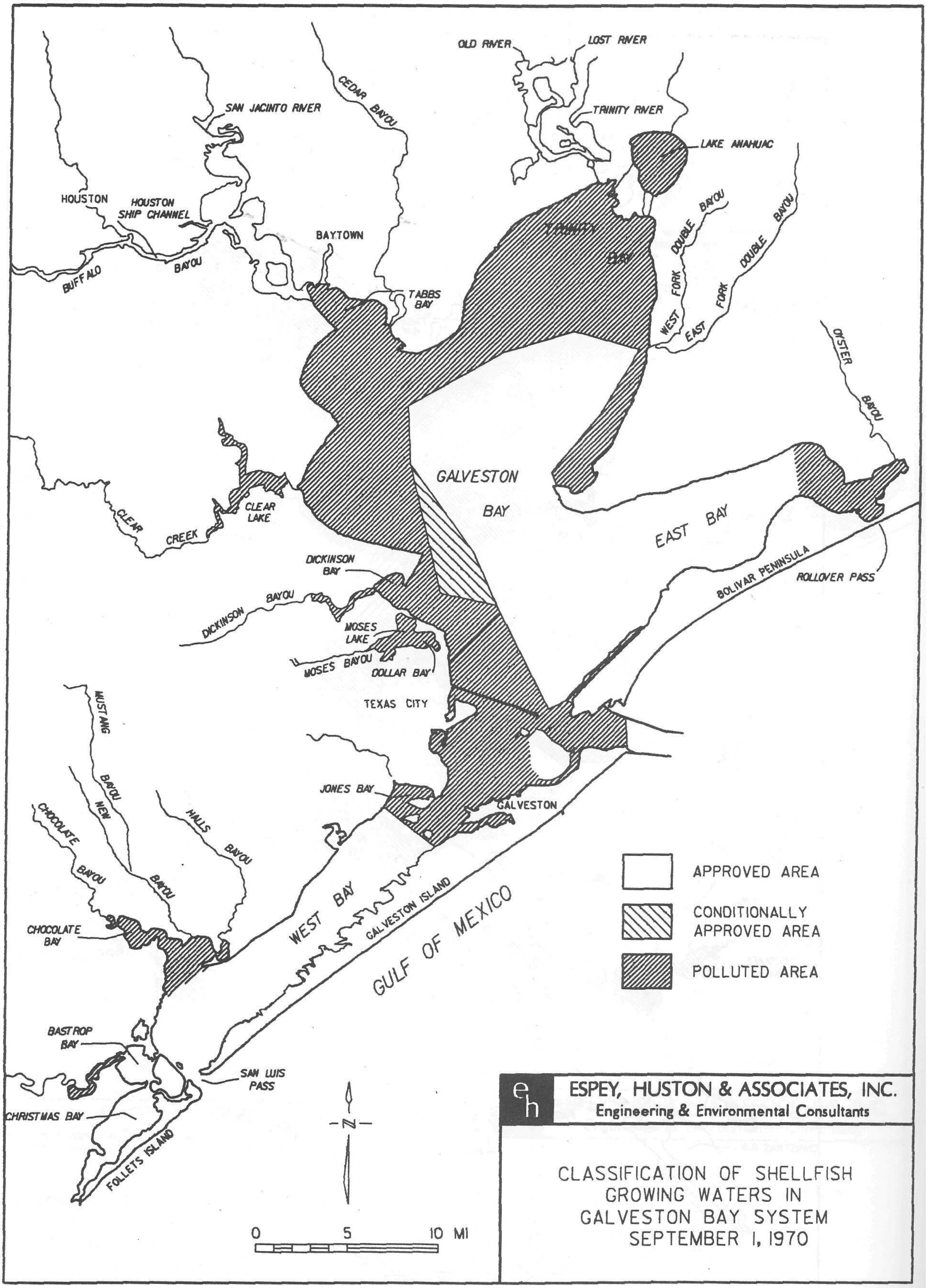
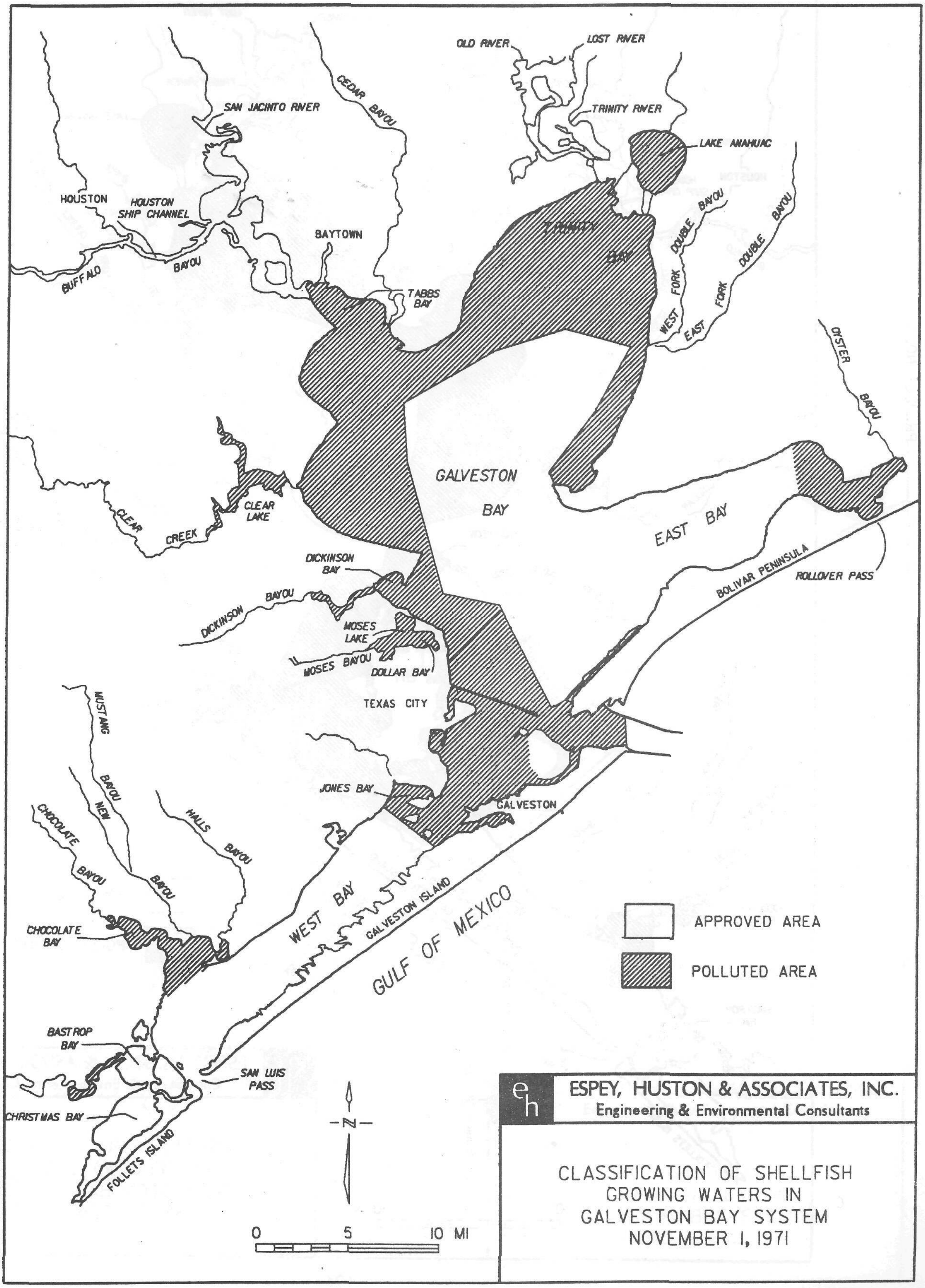
ESPEY, HUSTON & ASSOCIATES, INC.
Engineering & Environmental Consultants
CLASSIFICATION OF SHELLFISH
GROWING WATERS IN
GALVESTON BAY SYSTEM
JULY 1, 1969

PROJECT NO.



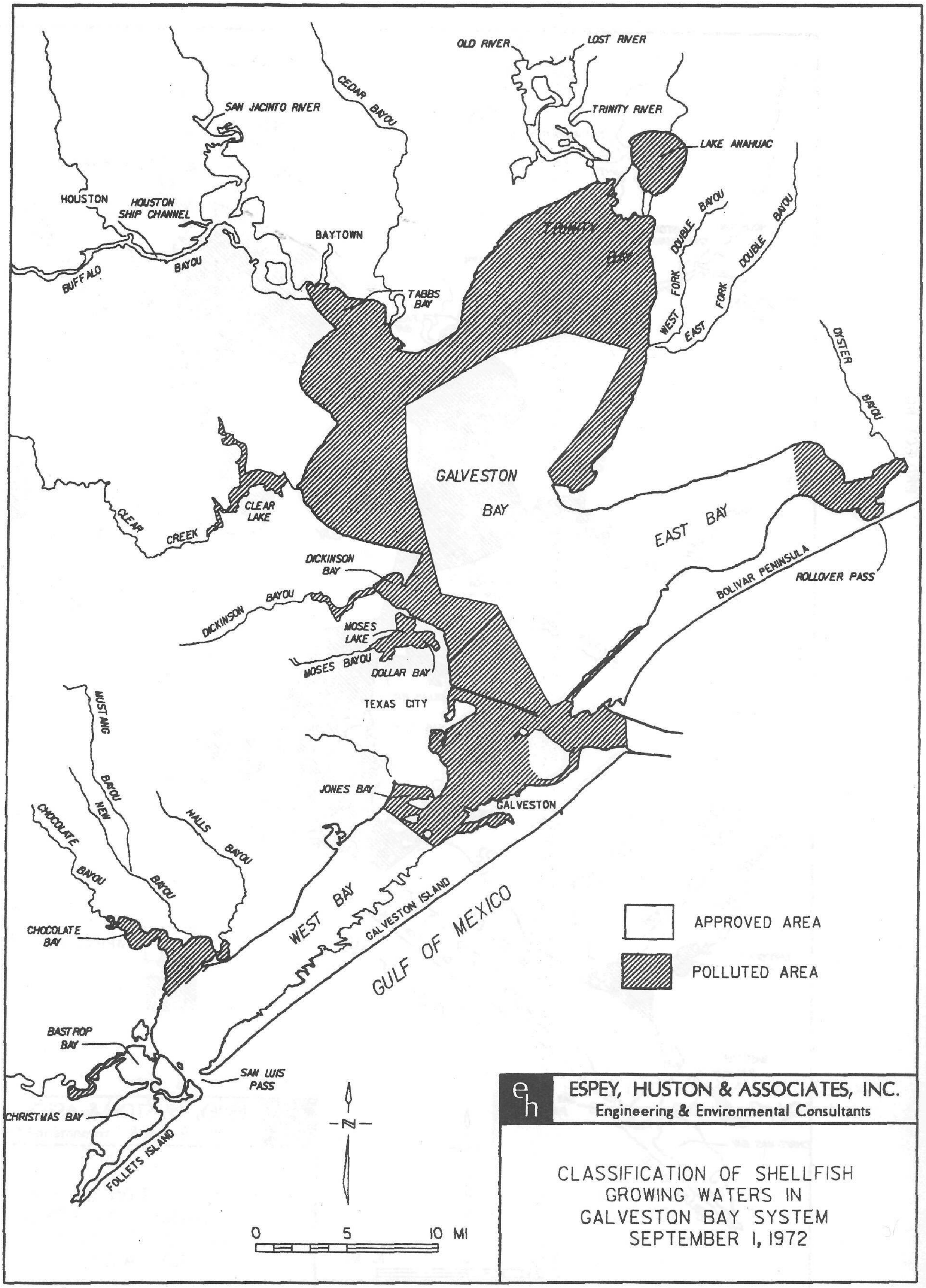
CLASSIFICATION OF SHELLFISH GROWING WATERS IN GALVESTON BAY SYSTEM SEPTEMBER 1, 1970

PROJECT NO.



ESPEY, HUSTON & ASSOCIATES, INC.
Engineering & Environmental Consultants

CLASSIFICATION OF SHELLFISH GROWING WATERS IN GALVESTON BAY SYSTEM NOVEMBER 1, 1971



ESPEY, HUSTON & ASSOCIATES, INC.
Engineering & Environmental Consultants

CLASSIFICATION OF SHELLFISH GROWING WATERS IN GALVESTON BAY SYSTEM
SEPTEMBER 1, 1972

PROJECT NO.

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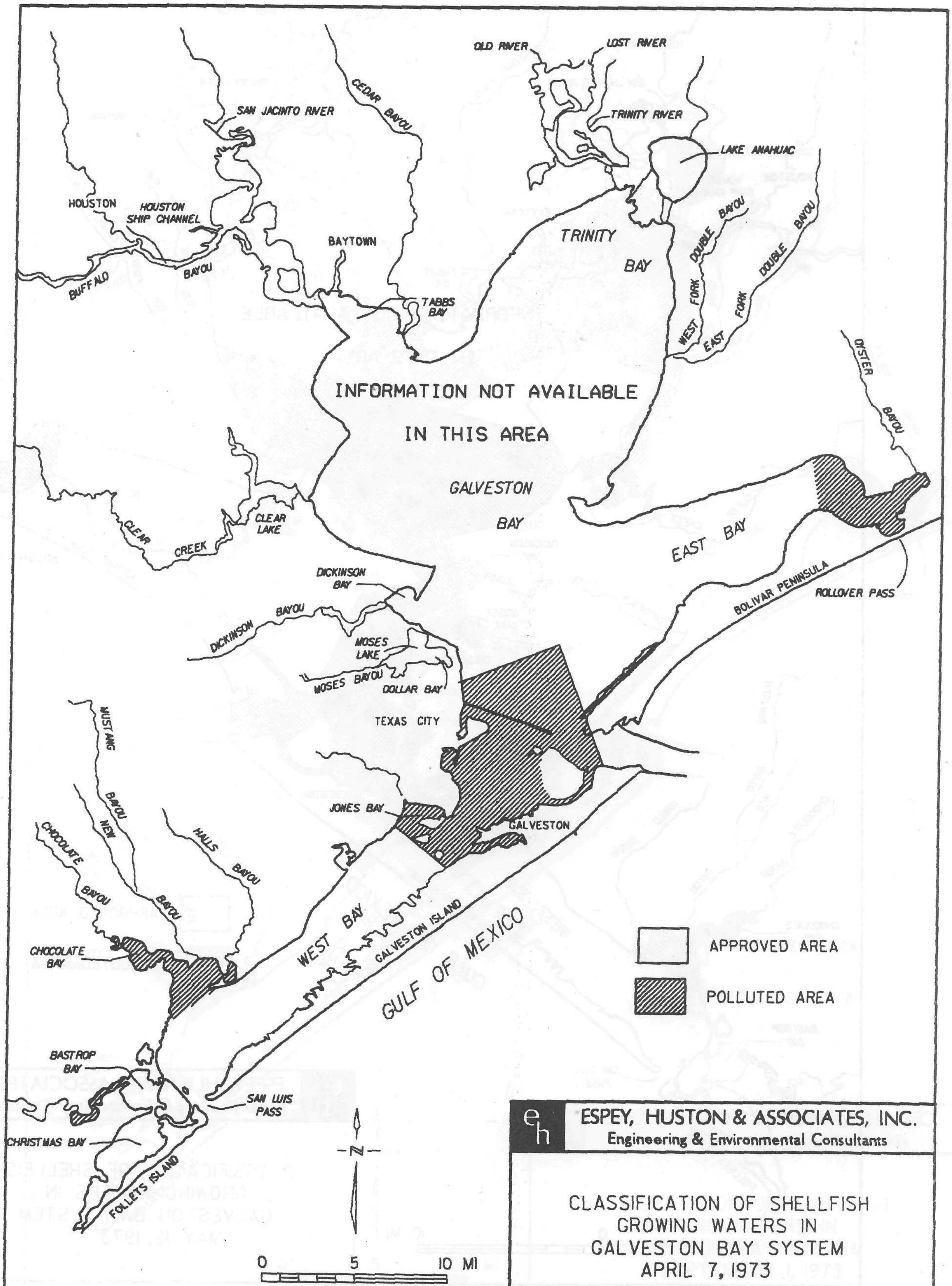
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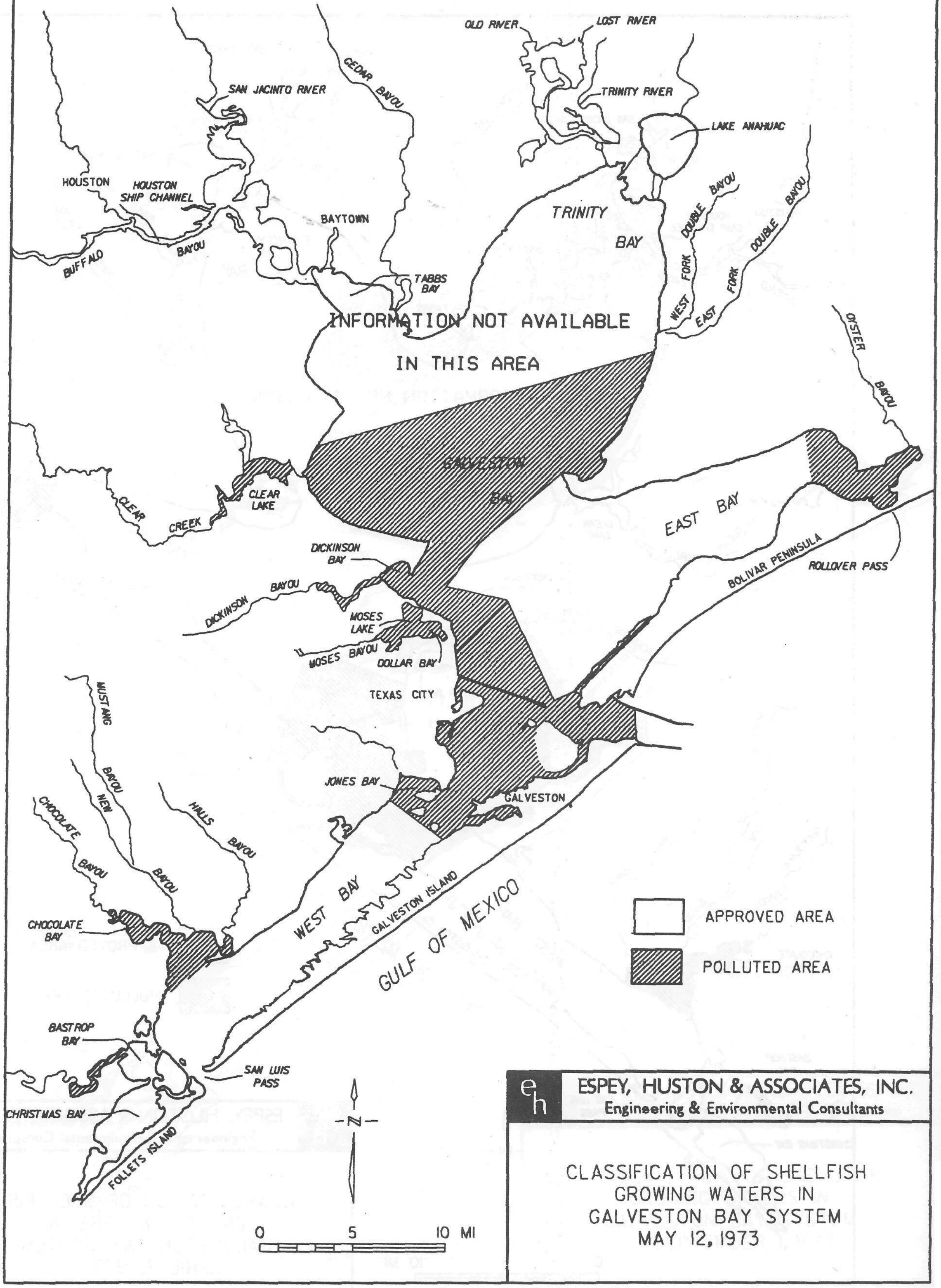
ESPEY, HUSTON & ASSOCIATES, INC.
Engineering & Environmental Consultants
CLASSIFICATION OF SHELLFISH
GROWING WATERS IN
GALVESTON BAY SYSTEM
APRIL 7, 1973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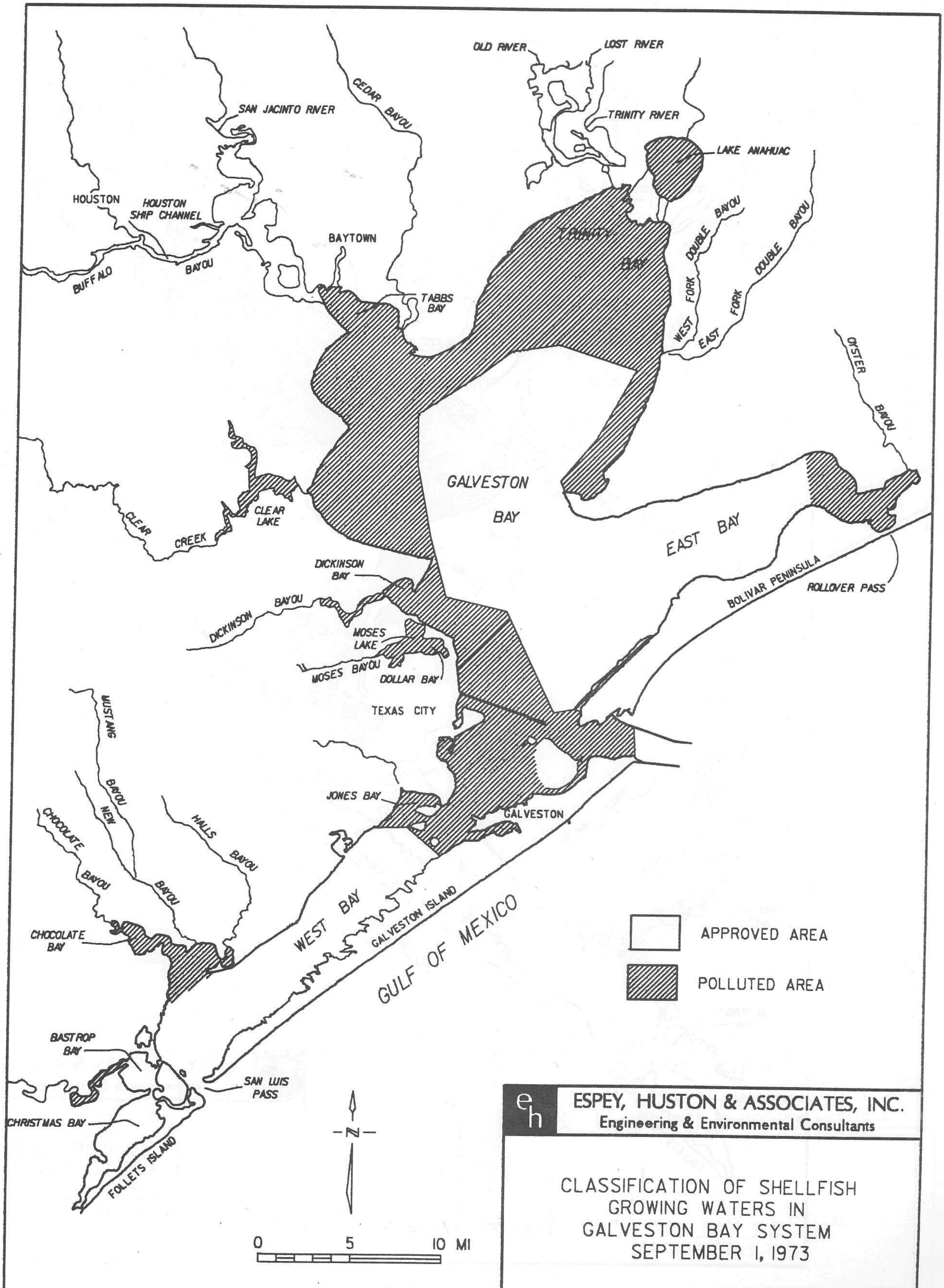
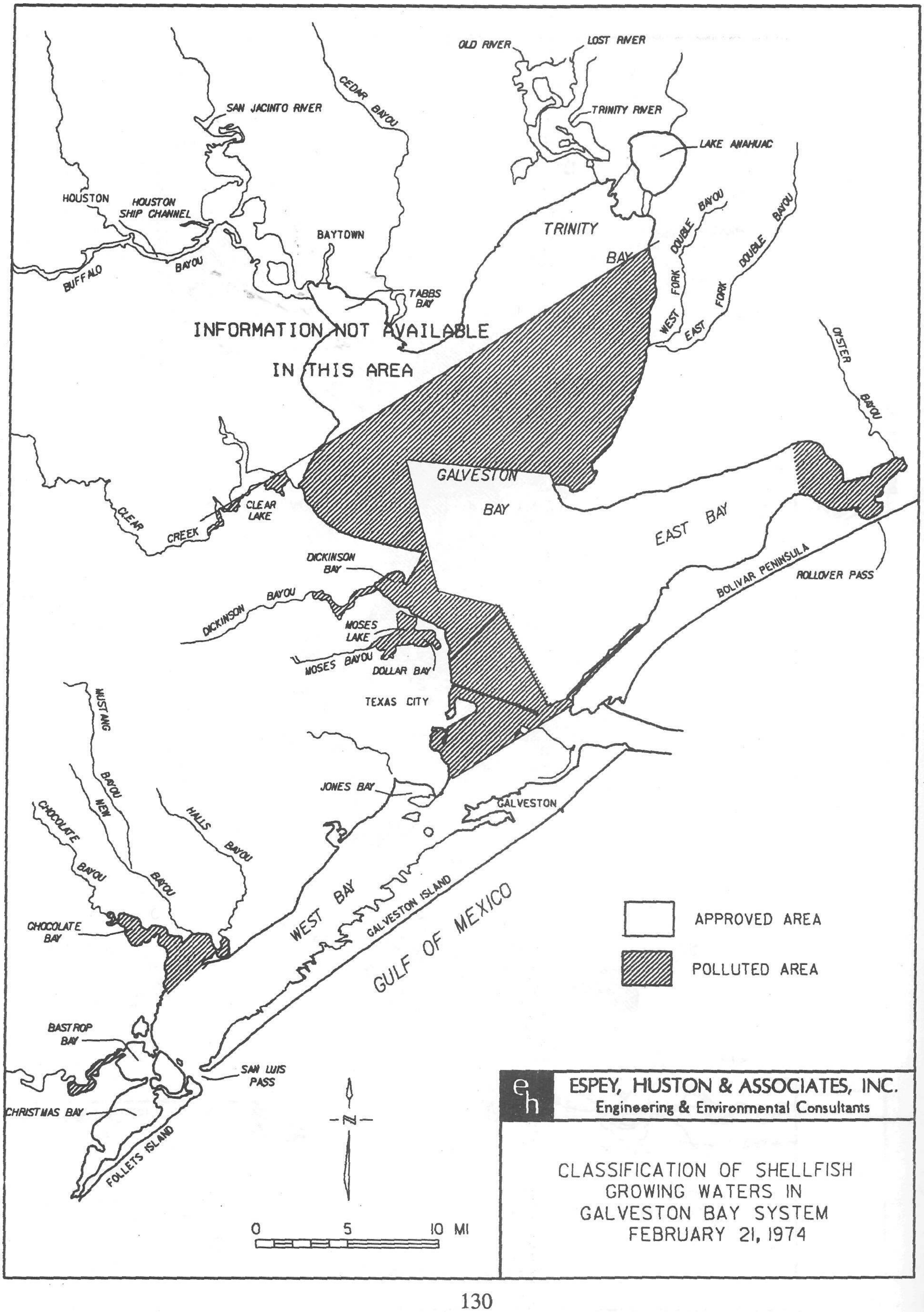
ESPEY, HUSTON & ASSOCIATES, INC.
Engineering & Environmental Consultants
CLASSIFICATION OF SHELLFISH
GROWING WATERS IN
GALVESTON BAY SYSTEM
MAY 12, 1973

PROJECT NO.



CLASSIFICATION OF SHELLFISH GROWING WATERS IN GALVESTON BAY SYSTEM SEPTEMBER 1, 1973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ESPEY, HUSTON & ASSOCIATES, INC.
Engineering & Environmental Consultants
CLASSIFICATION OF SHELLFISH GROWING WATERS IN GALVESTON BAY SYSTEM FEBRUARY 21, 1974

PROJECT NO.

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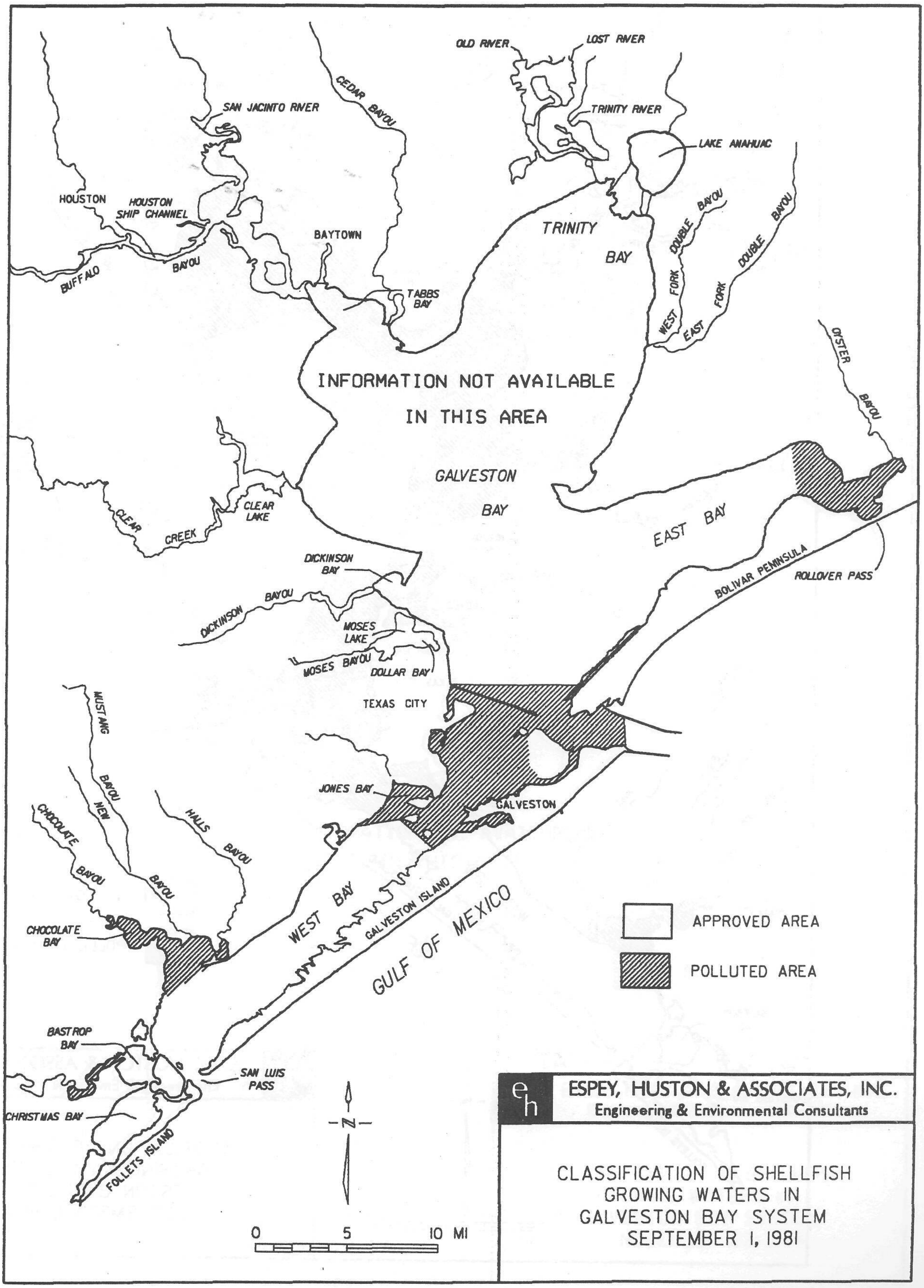
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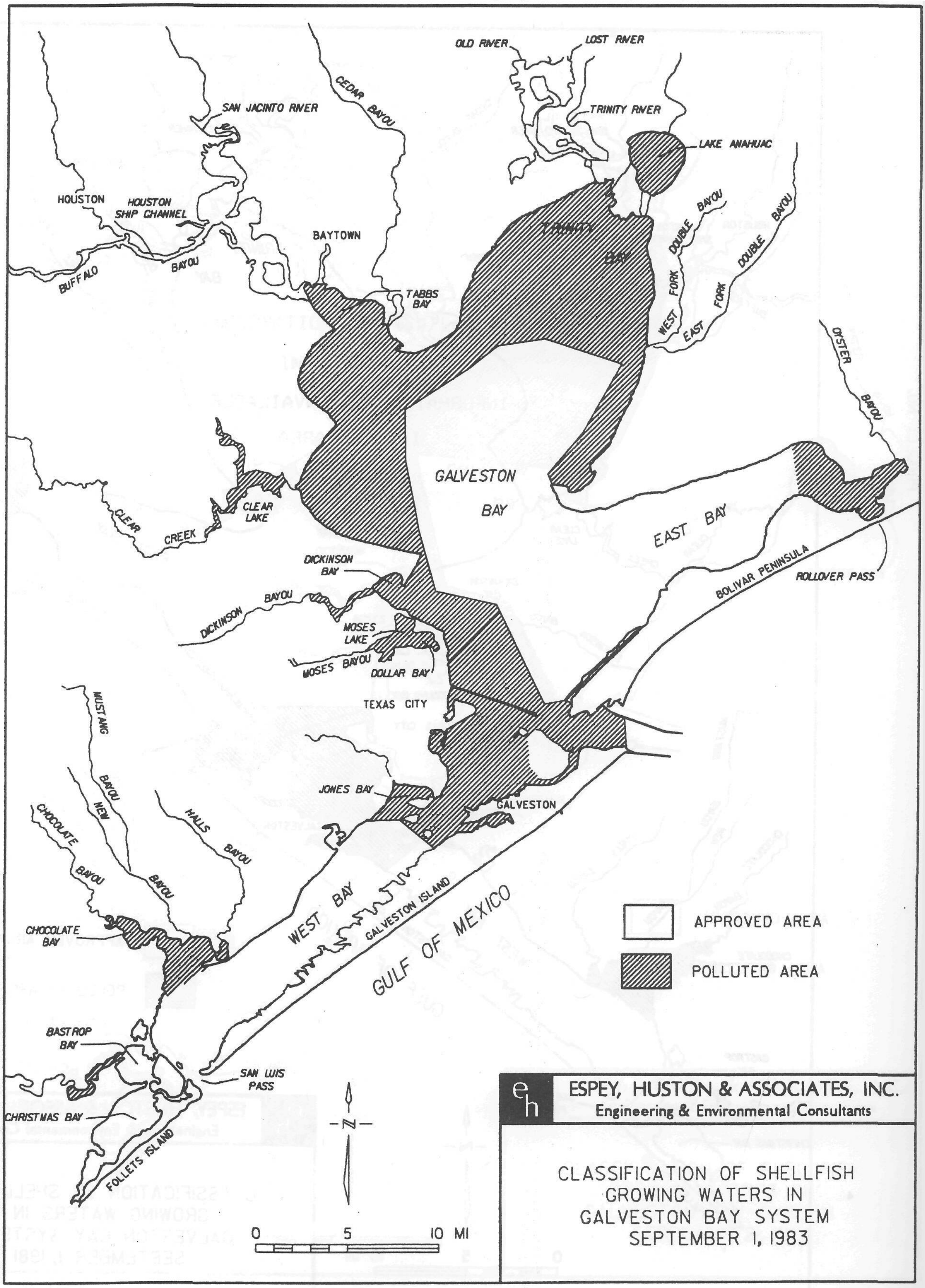
ESPEY, HUSTON & ASSOCIATES, INC.
Engineering & Environmental Consultants
CLASSIFICATION OF SHELLFISH GROWING WATERS IN GALVESTON BAY SYSTEM SEPTEMBER 1, 1981

PROJECT NO.



CLASSIFICATION OF SHELLFISH
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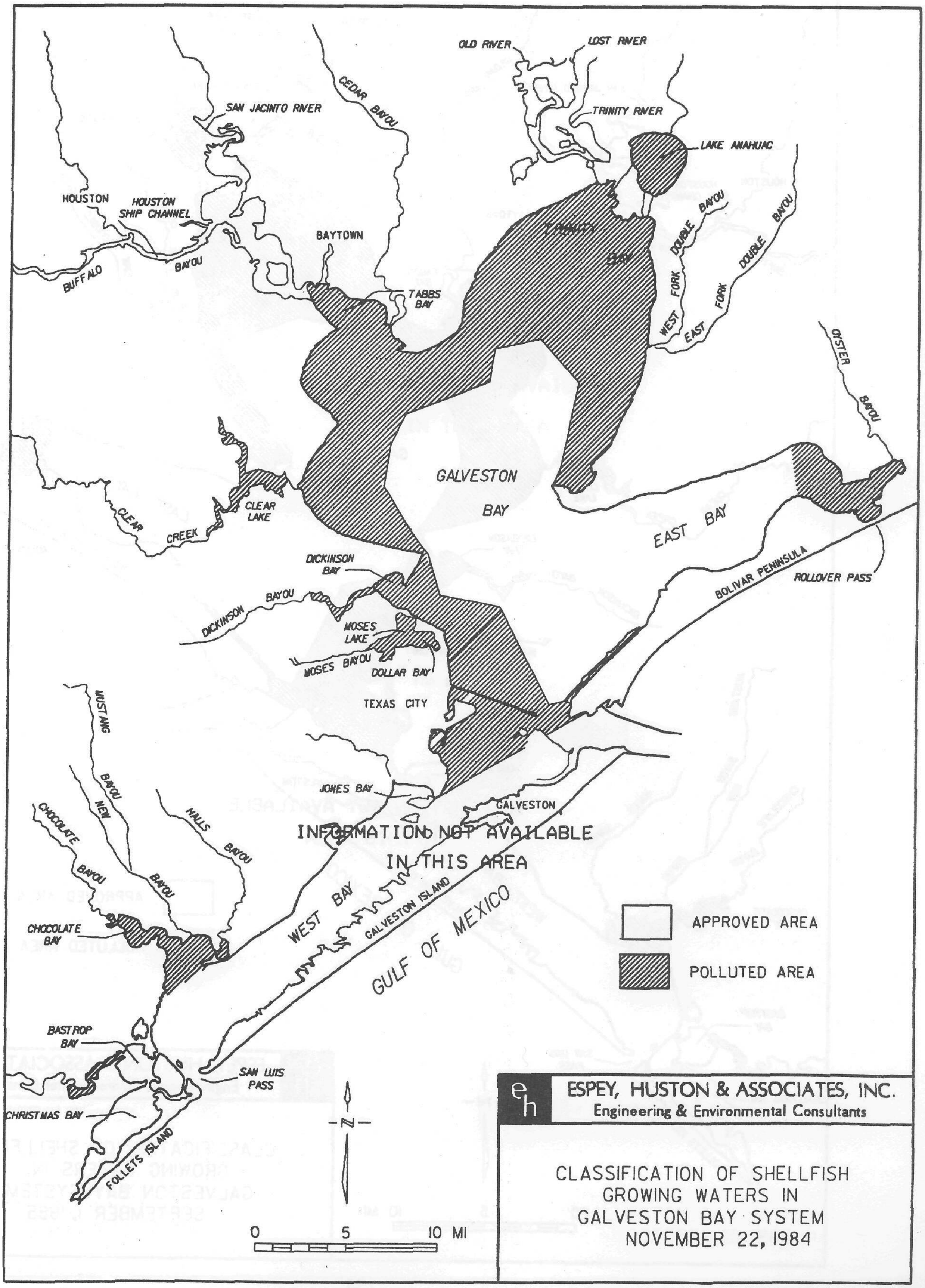
GALVESTON BAY SYSTEM
SEPTEMBER 1, 1983

PROJECT NO.



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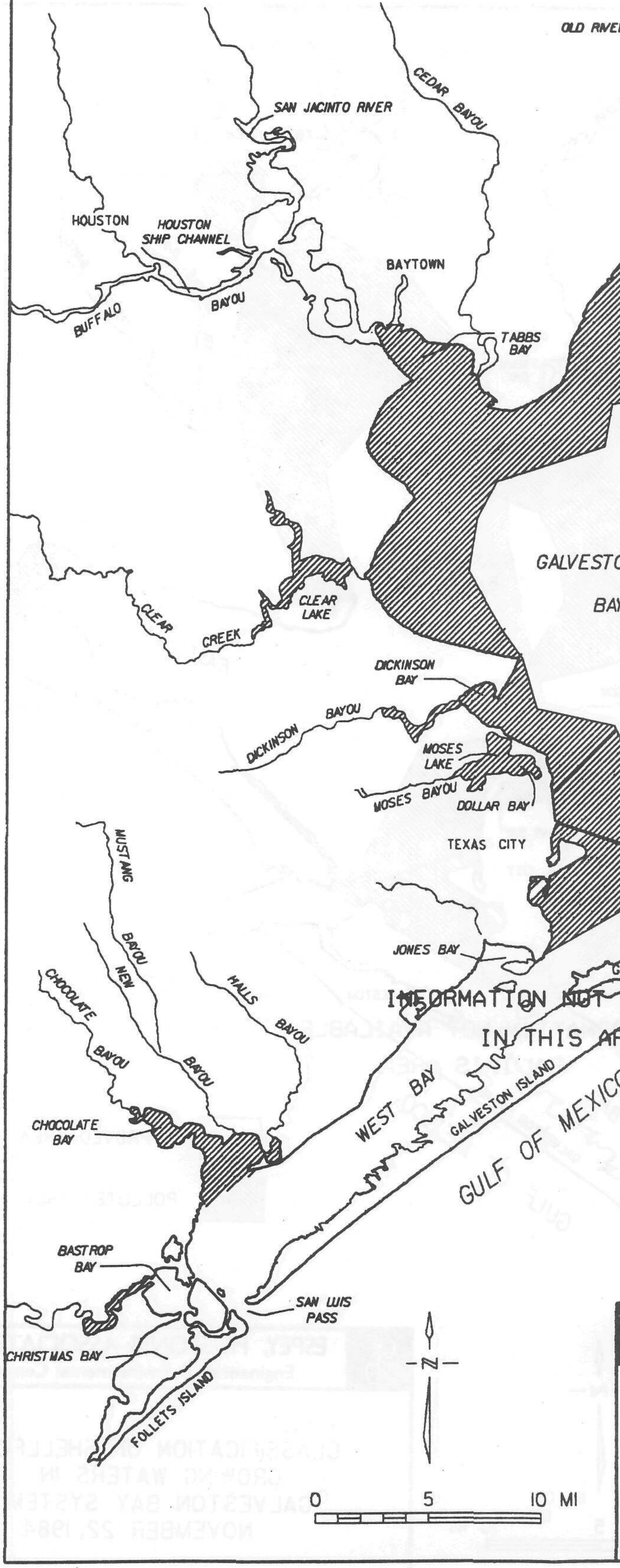
ESPEY, HUSTON & ASSOCIATES, INC.
Engineering & Environmental Consultants
CLASSIFICATION OF SHELLFISH GROWING WATERS IN GALVESTON BAY SYSTEM NOVEMBER 22, 1984



ESPEY, HUSTON & ASSOCIATES, INC.
Engineering & Environmental Consultants

CLASSIFICATION OF SHELLFISH GROWING WATERS IN GALVESTON BAY SYSTEM SEPTEMBER 1, 1985

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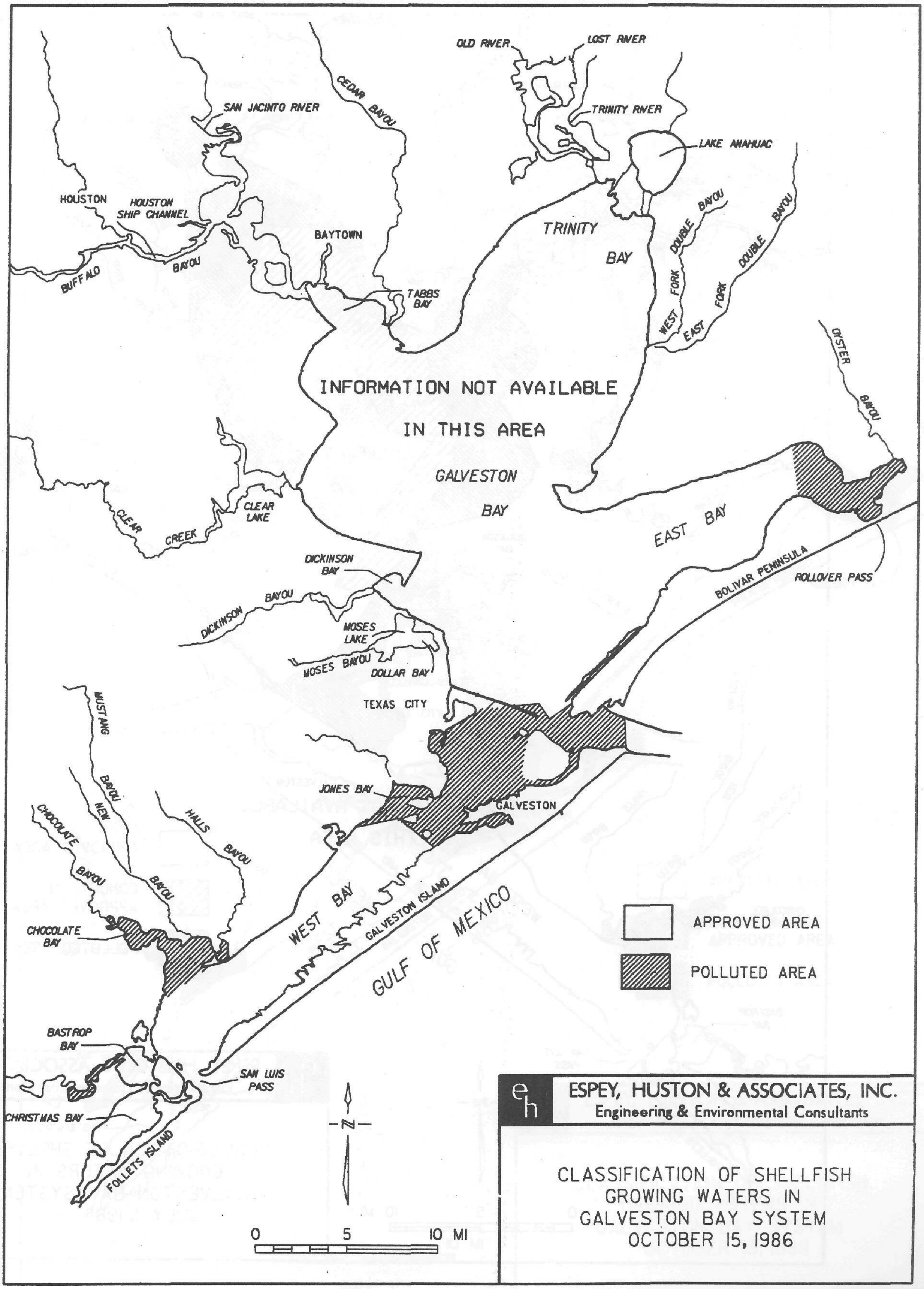
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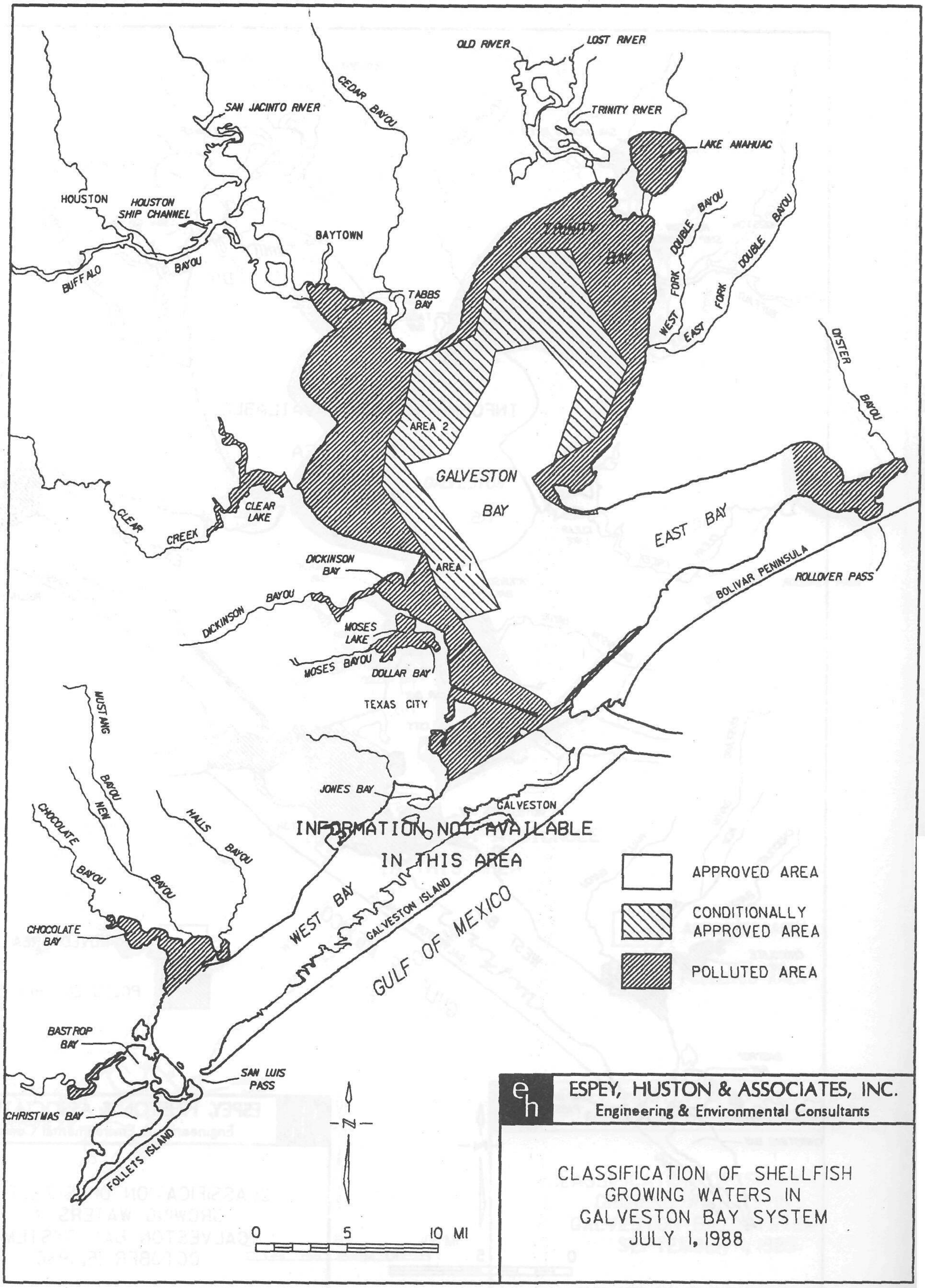
ESPEY, HUSTON & ASSOCIATES, INC.
Engineering & Environmental Consultants
CLASSIFICATION OF SHELLFISH GROWING WATERS IN GALVESTON BAY SYSTEM OCTOBER 15, 1986

PROJECT NO.



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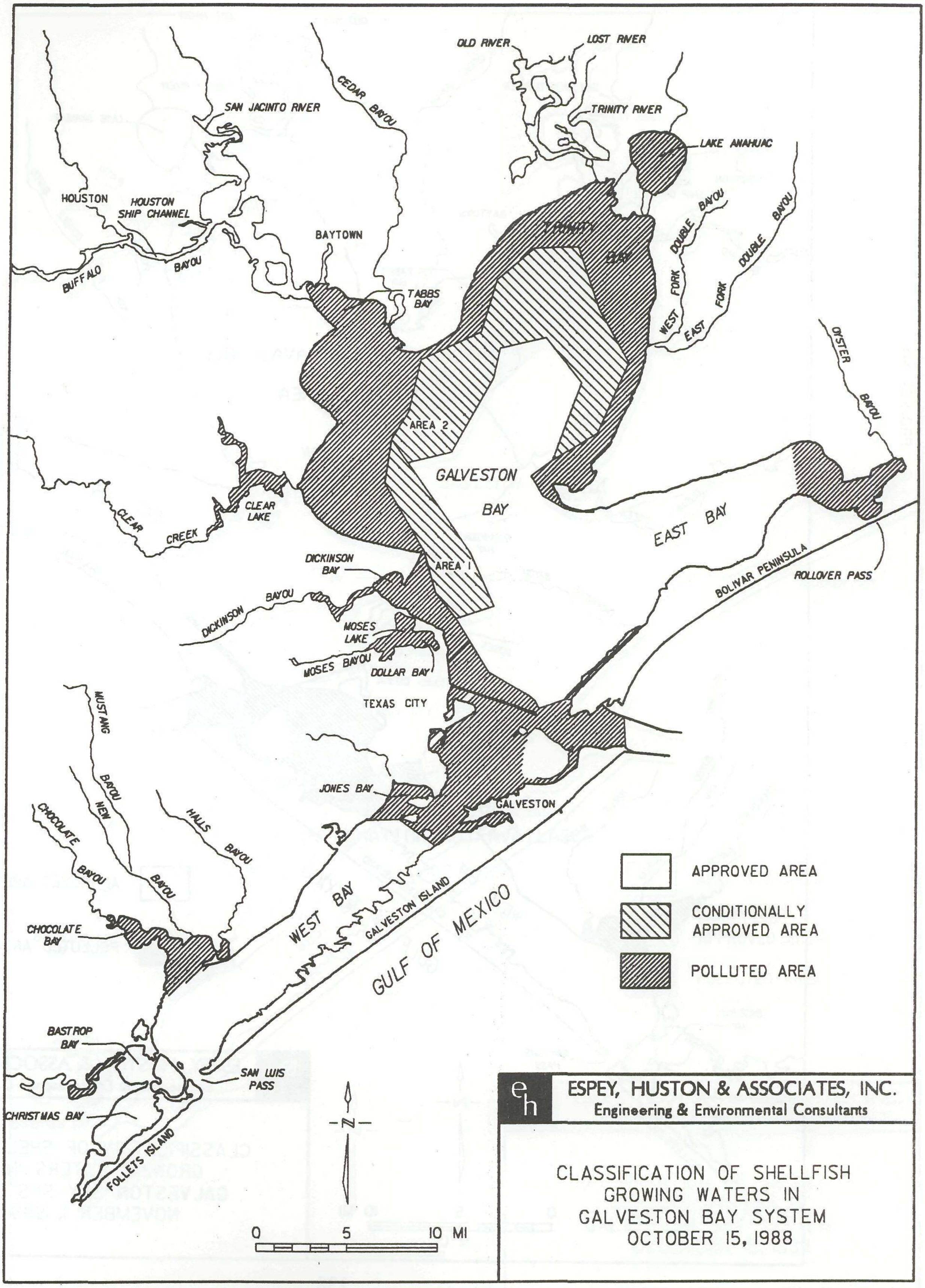
CLASSIFICATION OF SHELLFISH GROWING WATERS IN GALVESTON BAY SYSTEM JULY 1, 1988

PROJECT NO.



CLASSIFICATION OF SHELLFISH GROWING WATERS IN GALVESTON BAY SYSTEM OCTOBER 15, 1988

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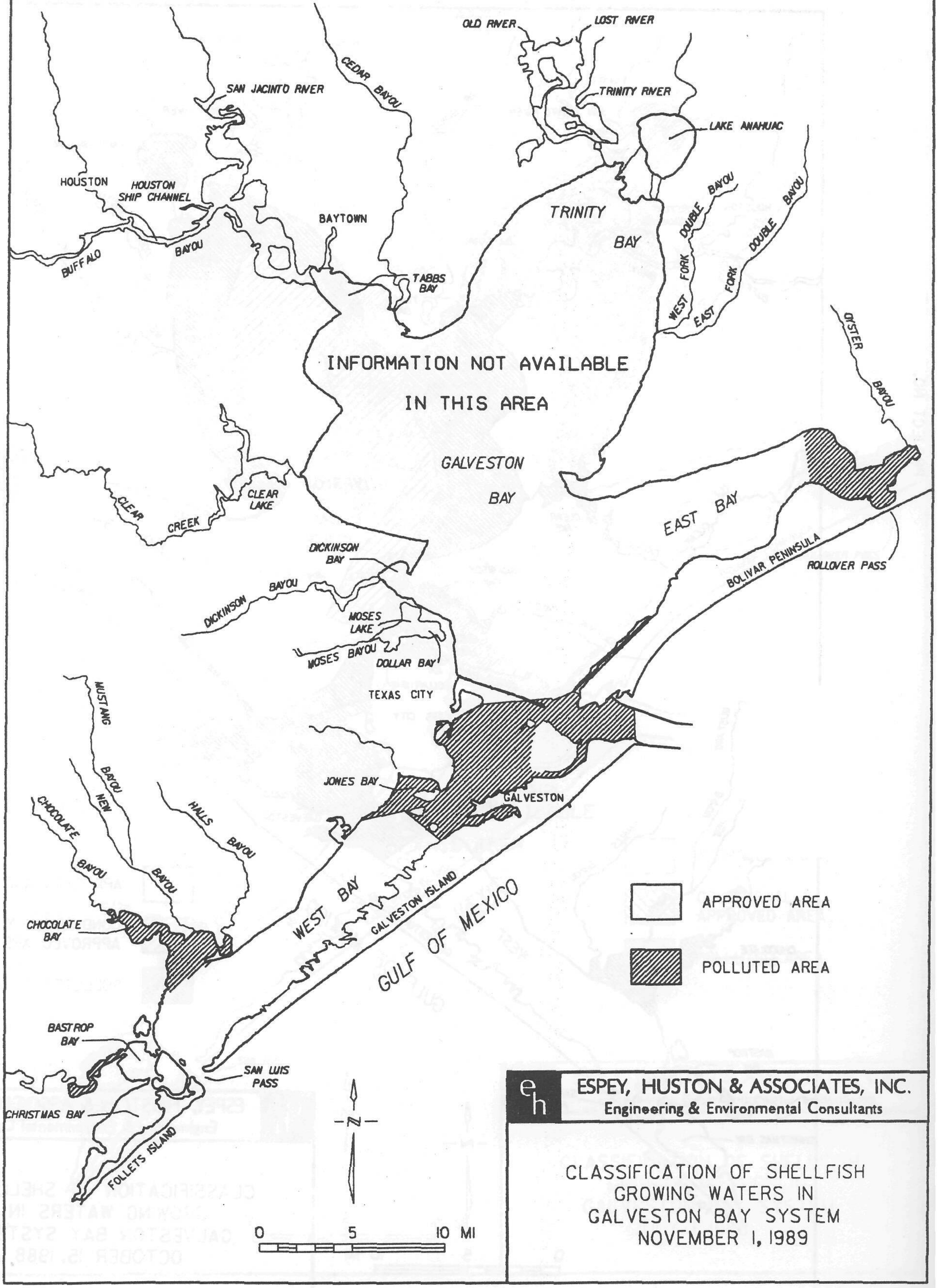
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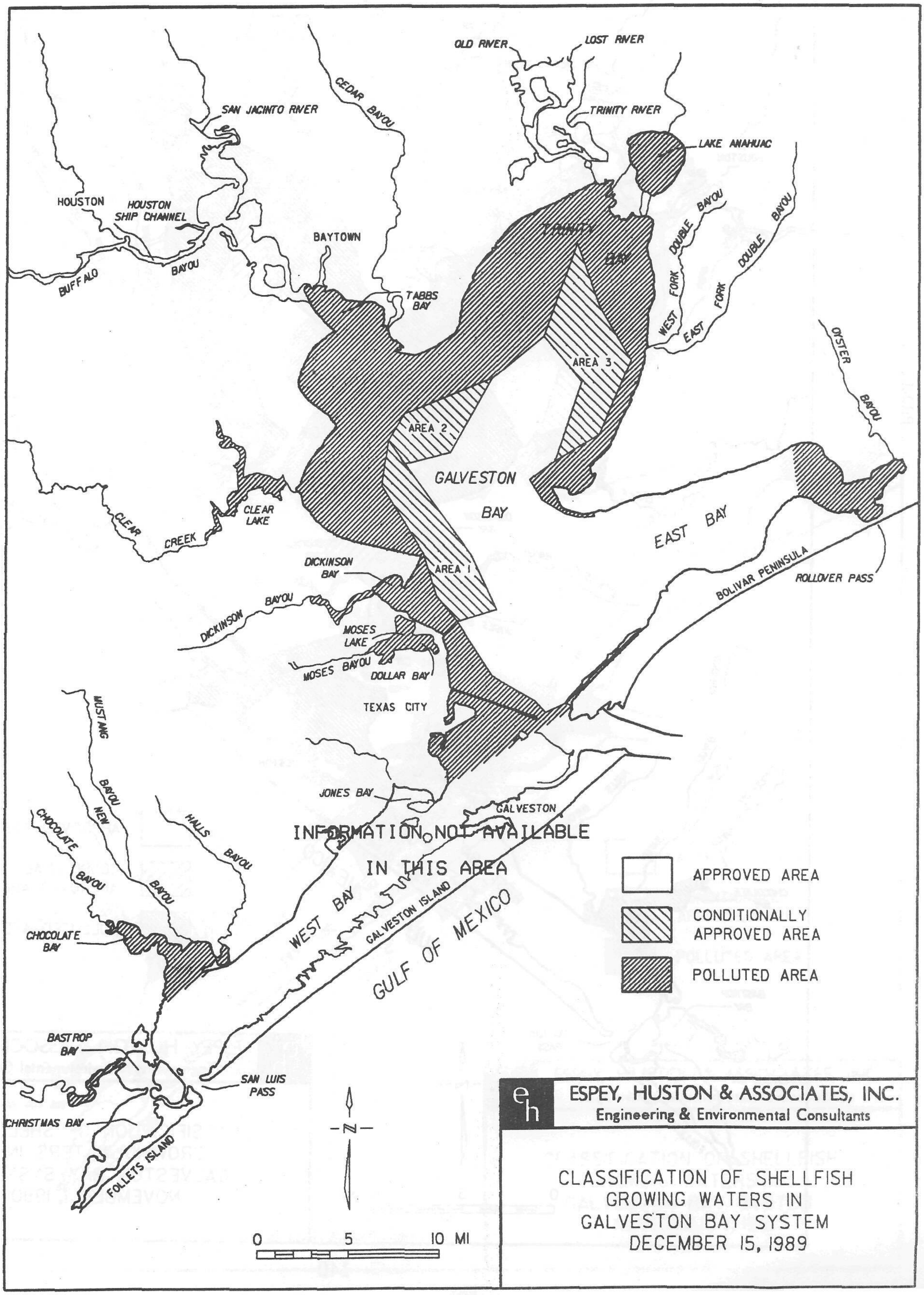
CLASSIFICATION OF SHELLFISH GROWING WATERS IN GALVESTON BAY SYSTEM NOVEMBER 1, 1989

PROJECT NO.



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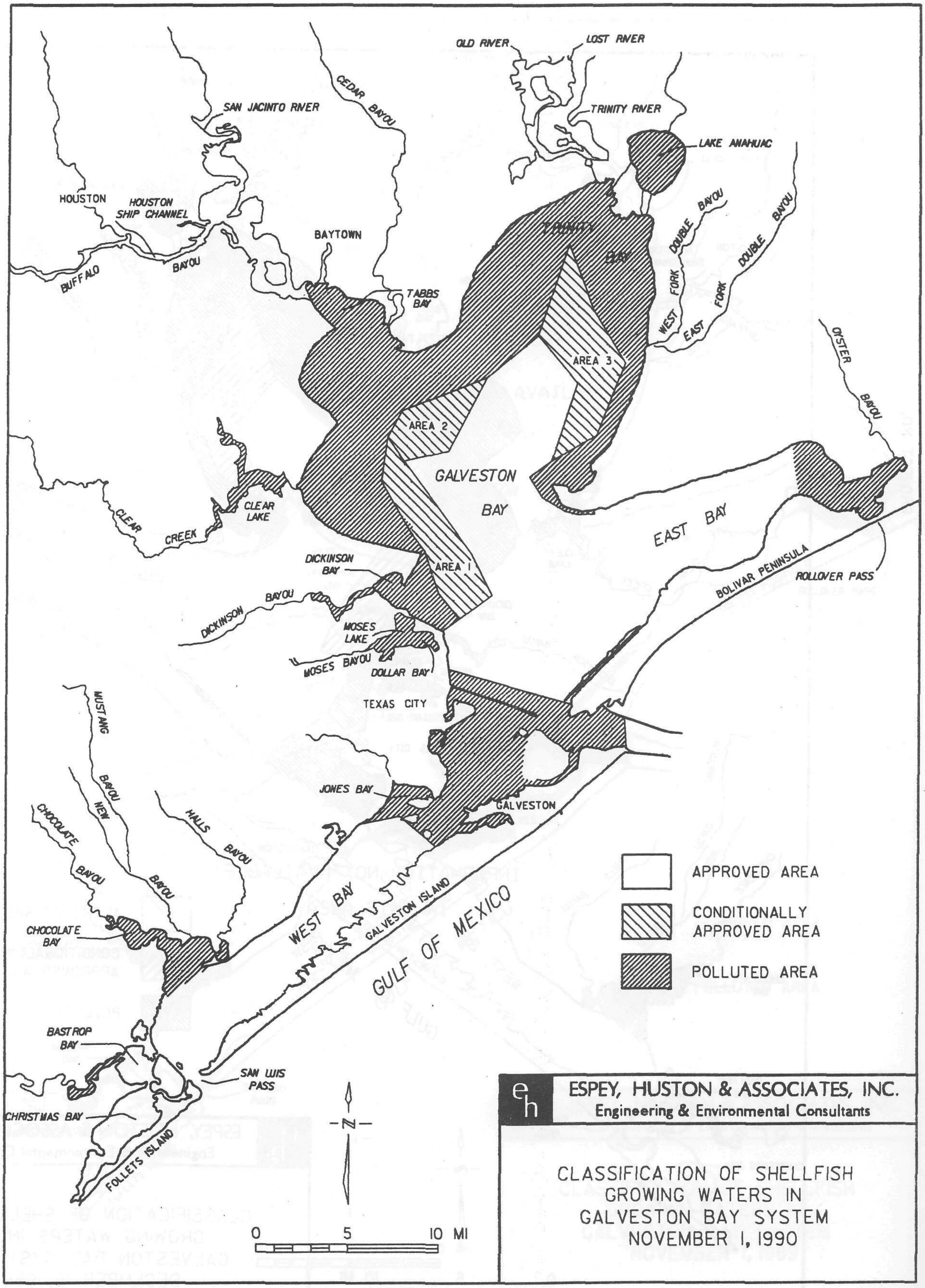
CLASSIFICATION OF SHELLFISH GROWING WATERS IN GALVESTON BAY SYSTEM DECEMBER 15, 1989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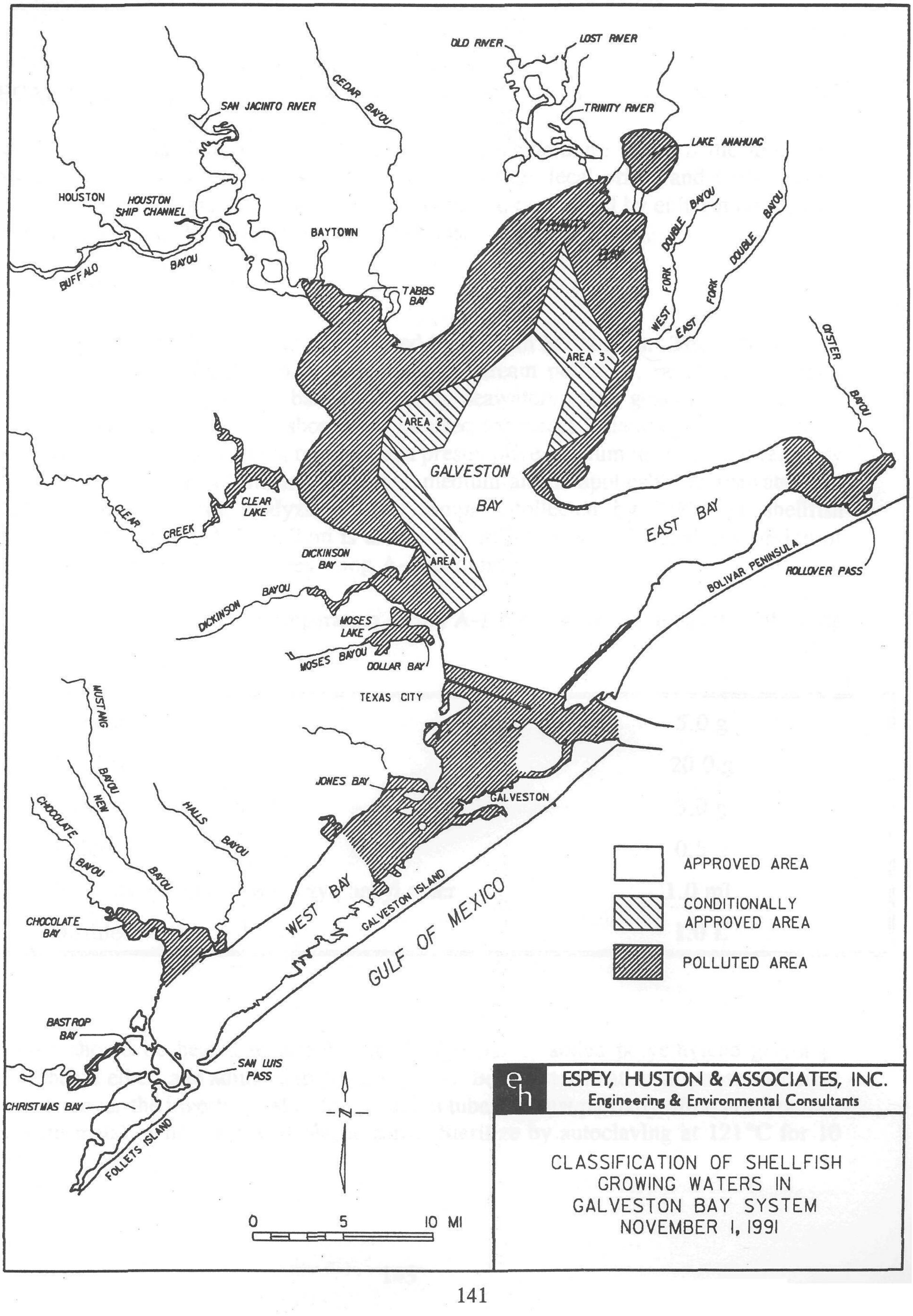
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CLASSIFICATION OF SHELLFISH GROWING WATERS IN GALVESTON BAY SYSTEM NOVEMBER 1, 1991

APPENDIX B
FECAL COLIFORM MPN AND MEMBRANE FILTER TESTING PROCEDURES

According to the Standard Methods (1989), elevated-temperature tests for the separation of organisms of the coliform group into those of possible fecal origin and those derived from nonfecal sources are available. These tests can be performed by either multiple-tube procedures (MPN) or by membrane filter methods.

B.1 MPN Tests

There are two kinds of media that can be used to perform MPN tests. The first is to use EC medium and is applicable to investigations of stream pollution, raw water sources, wastewater treatment systems, bathing waters, seawaters, and general water-quality monitoring. However, this test should not be used for direct isolation of coliform from water because prior enrichment is required in a presumptive medium for optimum recovery of fecal coliform. The second is to use A-1 medium and is applicable to seawater and treated wastewater. For analyzing water samples collected by TDH for shellfish monitoring purpose, the A-1 medium is used. The following is a detailed description of the fecal coliform MPN procedures using A-1 medium.

The procedures begin with the preparation of the A-1 broth which includes the following ingredients:

Lactose	5.0 g
Tryptose	20.0 g
Sodium chloride, NaCl	5.0 g
Salicin	0.5 g
Polyethylene glycol p-isoctylphenyl ether	1.0 mL
Distilled water	1.0 L

The broth should be heated to dissolve solid ingredients, added polyethylene glycol p-isooctylphenyl ether, and adjusted to pH 6.9 $\pm$ 0.1. Before sterilization dispense sufficient medium to cover the inverted vial in fermentation tubes at least partially after sterilization. Close with metal or heat-resistant plastic caps. Sterilize by autoclaving at 121°C for 10 minutes.

Arrange fermentation tubes in rows of five tubes each in a test tube rack. The number of five tube rows and the sample volumes selected depend upon the quality and character of the water to be examined. For potable water use five 10-mL portions or ten 10-mL portions; for nonpotable water use five tubes per dilution. Shake sample and dilutions vigorously about 25 times. Inoculate each tube of the set of five with replicate sample volumes. Mix test portions in the medium by gentle agitation. Incubate for 3 hours at 35 ± 0.5°C. Transfer tubes to a water bath at 44.5 ± 0.2°C and incubate for an additional 21 ± 2 hours.

Gas production in an A-1 broth culture within 24 hours or less is considered a positive fecal coliform reaction. Failure to produce gas (growth sometimes occurs) constitutes a negative reaction indicating a source other than the intestinal tract of warm-blooded animals. MPN value can be calculated from the number of positive A-1 broth tubes as follows (Standard Methods, 1989):

$$\text{MPN / 100 mL} = \text{MPN Index} * \frac{10}{\text{largest volume tested}}$$

where MPN Index can be obtained from the following tables:

a. When five 10-mL portions are used:

No. of Tubes Giving Positive Reaction Out of 5 of 10 mL Each	MPN Index / 100 mL	95% Confidence Limits Lower	Upper
0	<2.2	0	6.0
1	2.2	0.1	12.6
2	5.1	0.5	19.2
3	9.2	1.6	29.4
4	16.0	3.3	52.9
5	>16.0	8.0	Infinite

b. When ten 10-mL portions are used:

No. of Tubes Giving Positive Reaction Out of 10 of 10 mL Each	MPN Index / 100 mL	95% Confidence Limits Lower	Upper
0	<1.1	0	3.0
1	1.1	0.03	5.9
2	2.2	0.26	8.1
3	3.6	0.69	10.6
4	5.1	1.3	13.4
5	6.9	2.1	16.8
6	9.2	3.1	21.1
7	12.0	4.3	27.1
8	16.1	5.9	36.8
9	23.0	8.1	59.5
10	>23.0	13.5	Infinite

B.2 Fecal Coliform Membrane Filter Procedure

The membrane filter (MF) procedure uses an enriched lactose medium and incubation temperature of 44.5 ± 0.2°C for selectivity and is said to give 93% accuracy in differentiating between coliform found in the feces of warm-blooded animals and those from other environmental sources (Standard Methods, 1989). The test is used by TWC and can be described as follows.

The ingredients of M-FC medium for membrane filter test are:

Tryptose or biosate	10.0 g
Proteose peptone No. 3 or polypeptone	5.0 g
Yeast extract	3.0 g
Sodium chloride, NaCl	5.0 g
Lactose	12.5 g
Bile salts mixture or bile salts No. 3	1.5 g
Aniline blue	0.1 g
Distilled water	1.0 L

Rehydrate in distilled water containing 10 mL 1% rosolic acid in 0.2N NaOH. Heat to near boiling, promptly remove from heat, and cool to below 50°C. Do not sterilize by autoclaving. Dispense 5-to 7- mL quantities to 50- * 12-mm petri plates and let solidify if agar is used. Final pH should be 7.4. Store finished medium at 2 to 10°C.

Volume of water sample to be examined is selected in accordance with the following table. Only sample volumes that will yield counts between 20 and 60 fecal coliform colonies per membrane should be used.

Water Source	Volume to be Filtered (mL)						
	100	50	10	1	0.1	0.01	0.001
Lakes, reservoirs	X	X					
Wells, spring	X	X					
Water supply intake		X	X	X			
Natural bathing waters		X	X	X			
Sewage treatment plant, secondary effluent			X	X	X		
Farm ponds, rivers				X	X	X	
Stormwater runoff				X	X	X	
Raw municipal sewage					X	X	X
Feedlot runoff					X	X	X

Using sterile forceps, place a sterile membrane filter over porous plate of receptacle. Carefully place matched funnel unit over receptacle and lock it in place. Filter sample under partial vacuum. With filter still in place, rinse funnel by filtering three 20- to 30-mL portions of sterile dilution water. Upon completion of final rinse and the filtration process disengage vacuum, unlock and remove funnel, immediately remove membrane filter with sterile forceps, and place it on M-FC medium with a rolling motion to avoid entrapment of air.

Place a sterile absorbent pad in each culture dish and pipet approximately 2 mL M-FC medium to saturate pad. Place prepared filter on medium-impregnated pad. Place prepared cultures in waterproof plastic bags or seal petri dishes, submerge in water bath, and incubate for 24 ± 2 hours at 44.5 ± 0.2°C. Anchor dishes below water surface to maintain critical temperature requirements. All prepared cultures should be placed in the water bath within 30 minutes after filtration.

Colonies produced by fecal coliform bacteria on M-FC medium are various shades of blue. Nonfecal coliform colonies are gray to cream-colored. Count colonies with a low-power (10 to 15 magnifications) binocular wide-field dissecting microscope or other optical device. Compute the fecal coliform density from the sample quantities that produced membrane filter counts within the desired range of 20 to 60 fecal coliform colonies. The density of fecal coliform can be computed by

$$\text{coliform colonies/100 mL} = \frac{\text{coliform colonies counted}}{\text{mL sample filtered}} * 100$$