Brine Disposal in the Gulf of Mexico: Projected Impacts For West Hackberry Based on Bryan Mound Experience

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Environmental Data and Information Service

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Center for Environmental Assessment Services

Marine Environmental Assessment Division

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U. S. DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary

National Oceanic and Atmospheric Administration
James P. Walsh, Acting Administrator

Environmental Data and Information Service
Thomas D. Potter, Director

PREFACE

The National Oceanic and Atmospheric Administration was created to develop, manage, and conserve environmental resources. The Center for Environmental Assessment Services, located within the Environmental Data and Information Service, is charged with conducting environmental analysis and data synthesis for decisionmakers in the public and private sectors. The Center for Environmental Assessment Services (CEAS), utilizing an in-house interdisciplinary team, provides this function by accessing archived data and tailoring it to meet the requirements of the user community.

Brine Disposal in the Gulf of Mexico: Projected Impacts for West Hackberry Based on Bryan Mound Experience is the result of several field studies managed by CEAS in support of the Department of Energy's Strategic Petroleum Reserve Program. This report reviews the actual experience at Bryan Mound and analyzes the earlier environmental predictions at West Hackberry. The question addressed by the study centered on whether brine discharge produced from solution mining of salt domes along the Louisiana coast would adversely effect the marine environment. The investigators concluded that these specific activities would not affect valuable commercial fisheries in the area.

The success of this report results from the efforts of Charles A. Burroughs, Fred G. Everdale, Jack Foreman, Fredric A. Godshall, and Kenneth W. Turgeon of CEAS, and Walter H. Delaplane, Strategic Petroleum Reserve Office, DOE. The task of typing the manuscript was completed by Carolyn Mackie.

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ACRONYMS AND ABBREVIATIONS

CEAS	Center for Environmental Assessment Services
DOE	Department of Energy
EDIS	Environmental Data and Information Service
EPA	Environmental Protection Agency
FEIS	Final Environmental Impact Statement
MEAD	Marine Environmental Assessment Division
MIT	Massachusetts Institute of Technology
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Survey
NPDES	National Pollutant Discharge Elimination System
NTIS	National Technical Information Service
SAI	Science Applications, Inc.
SEFC	Southeast Fisheries Center
SPR	Strategic Petroleum Reserve
TAMU	Texas A&M University

bbls	barrels
cm	centimeters(s)
DO	dissolved oxygen
E_h	redox potential, the energy gained in the transfer of one mole of electrons from an oxidant to H_2, expressed in volts
fm	fathom(s)
ft	feet
ft^2	square feet
gal	gallon(s)
km	kilometer(s)
kt	knot, 1 nm per hour
LC_{10}	lethal concentration for 10 percent of a population
LC_{50}	lethal concentration for 50 percent of a population
m	meter
MBD	thousand barrels per day
mg/1	milligrams per liter
MMB	million barrels
nm	nautical mile(s)
pH	hydrogen ion concentration, expressed as the negative logarithm, base 10, of the concentration in moles per liter, (measure of acidity or alkalinity)
ppm	parts per million
ppt	parts per thousand
sec	second(s)
st.mi.	statute mile(s)
TOC	Total Organic Carbon
ϕ	phi unit: sediment particle-size diameter, negative logarithm, base 2, expressed in millimeters.

EQUIVALENTS

Length

1 meter	= 3.27 ft.
1 km	= 0.62 st. mi.
1 nm	= 6080 ft.
1 st. mi.	= 0.87 nm
1 st. mi.	= 1.61 km
1 fathom	= 6 feet

Area

1 acre	= 43,560 ft^2

Volume

1 bbl	= 42 U.S. gal.

Speed

1 kt	= 51.5 cm/sec
1 cm/sec	= 0.033 ft/sec
1 ft/sec	= 30.48 cm/sec

Diffusion

1 ft^2/sec	= 0.093 m^2/sec

Flow

1 MBD	= 0.065 ft^3/sec

Concentration

1 mg/1	= 1 ppm

ABSTRACT

This report was prepared in compliance with a DOE permit issued by EPA for brine discharge into the Gulf of Mexico from the Strategic Petroleum Reserve West Hackberry facility, Cameron Parish, Louisiana. Projected impacts of brine disposal on the nearshore marine environment are presented in light of post-discharge experience and knowledge gained from the Bryan Mound, Texas brine disposal site which has been operational for one year. Discharge volume at Bryan Mound is limited by permit to about 680 thousand barrels per day; brine concentration generally is between 225 and 250 ppt. Discharge volume at West Hackberry will be limited by permit to about 1.1 million barrels per day with a similar range of brine concentrations.

A comparison of baseline environmental studies for each discharge site notes the similarities and differences between Bryan Mound and West Hackberry in physiography, circulation and other physical processes, water and sediment quality, biotic communities and fisheries. It is shown that it is valid to extrapolate observations and predictions of brine dispersion and discharge effects at Bryan Mound to West Hackberry.

An adjustment to an input to the Transient Plume Model has been made based on a comparison of hindcasts to field observations of the Bryan Mound brine plume. Subsequently, the model predicts that: the West Hackberry brine plume will not reach Calcasieu Pass; salinity excesses of 1 ppt or more will encompass 6600 acres or less; and salinity excesses of 3 ppt or more will encompass 1500 acres or less. Based on Bryan Mound discharge experience, brine disposal at West Hackberry is projected to have minimal impact on the biota and sediment and water quality.

1.0 INTRODUCTION

1.1 Authorization

This report has been prepared in compliance with Article II, Task XIV of Interagency Agreement No. DE-A101-78US07146 between NOAA and the Department of Energy (DOE), Amendment No. 15 dated December 24, 1980. It is an outgrowth of the many field studies and analyses performed by NOAA since 1977 in support of DOE's Strategic Petroleum Reserve (SPR). Specifically, this report is directed toward a requirement of the Environmental Protection Agency (EPA) to confirm or revise, in light of actual experience, previous predictions of environmental effects of ocean discharge of concentrated brine produced from solution mining of underground salt domes for the creation of crude oil storage space.

1.2 Background

In 1979, DOE submitted to EPA an application for a National Pollutant Discharge Elimination System (NPDES) permit for ocean discharge of 1.088 million barrels (MMB) per day of concentrated brine from the SPR West Hackberry storage facility, Cameron Parish, Louisiana. The brine is to be created by solution mining (leaching) new crude oil storage space in West Hackberry salt dome.

As final ocean discharge criteria did not exist in 1979, EPA decided to evaluate West Hackberry brine discharge pursuant to ocean dumping regulations under Section 102(a) of the Marine Protection, Research, and Sanctuaries Act (40 CFR, Part 227). This procedure was followed in 1978 for a similar brine discharge permit for the SPR Bryan Mound storage facility, Brazoria County, Texas. As part of this evaluation, it was necessary for DOE to demonstrate the following:

- o Compliance with marine water quality criteria for oil and grease after allowance for initial mixing.
- o Compliance with limiting permissible concentration criteria.
- o Under all environmental conditions, the proposed quantity of brine at the proposed location will not seriously reduce amenities.
- o The chosen discharge site will not present a serious obstacle or unacceptable interference with fishing.
- o There are no reasonable alternatives for brine disposal onshore, for example, underground injection.

Supporting documentation and environmental assessment provided by DOE consisted of: (1) the Final Environmental Impact Statement, SPR Texoma Group Salt Domes (DOE, 1978); (2) descriptive data incorporated in the NPDES permit application; and (3) the report, "Responses to Environmental Concerns Relating to the Discharge of Brine at the West Hackberry 30 Foot Contour Diffuser Site" (Comiskey, 1979). A public hearing on the permit was held in Cameron, Louisiana on January 30, 1980 and the permit was issued August 14, 1980.

1.3 Purpose

Conditions of the NPDES permit for West Hackberry require that prior to brine discharge, DOE shall provide to EPA the following:

- o An updated brine dispersion prediction for West Hackberry based on actual dispersion information obtained at Bryan Mound.
- o An effects assessment of the brine discharge at West Hackberry based on data obtained from the Bryan Mound Monitoring Plan.

This was in recognition of the fact that there was no prior experience in this country with a discharge of similar nature and scale, the substance of DOE predictions of brine dispersion and biological impacts in its supporting documentation was based ultimately on the Transient Plume Model, a numerical dispersion model developed by Massachusetts Institute of Technology (MIT).

The purpose of this report is to provide updated brine dispersion predictions and effects assessments based on Bryan Mound discharge experience. The fulfillment of the above requirements are necessary so that EPA may authorize commencement of brine discharge from West Hackberry.

1.4 SPR Oceanographic Support Program

Various oceanographic studies funded by DOE to evaluate brine disposal in the Gulf of Mexico have been ongoing since early 1977. In addition to providing the diffuser conceptual design, brine dispersion model and bioassays of acute toxicity of increased salinity on selected fauna and flora, the SPR oceanographic support program includes:

- o Baseline characterizations of six candidate brine discharge sites off the coasts of Texas and Louisiana.
- o Site-specific monitoring of brine discharge.
- o Regional assessments of fishery resources.
- o Development of computerized ecosystem models to assess and predict ecological effects of discharge.

The six candidate brine discharge sites that were surveyed for baseline characterizations are shown in Figure 1-1. They were named after the corresponding salt domes for which SPR storage sites were considered and include, from west to east, Bryan Mound and Big Hill off Texas and Black Bayou, West Hackberry, Weeks Island and Chacahoula off Louisiana.

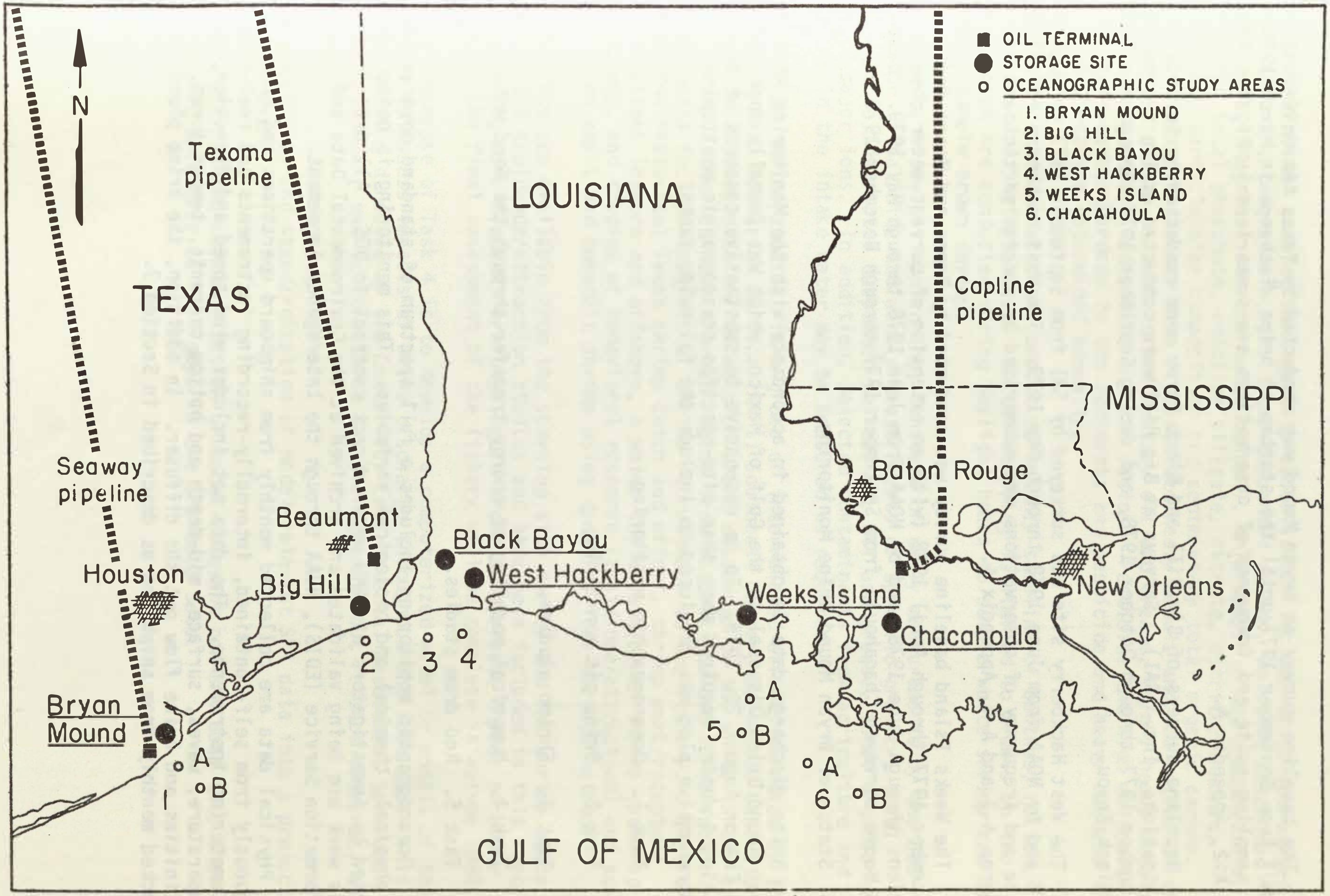


Figure 1-1. Location of baseline oceanographic studies for corresponding SPR candidate storage sites.

The baseline survey at Bryan Mound was conducted by Texas A&M University (TAMU) from September 1977 until the startup of brine discharge in March 1980. The sampling suite and frequency of observations are summarized in Figures A-1 and A-2, Appendix A.

Baseline surveys of Big Hill and Black Bayou were conducted by Science Applications, Inc. (SAI). Surveys at Big Hill were conducted during the period, September 1977 through October 1978, and during September 1977 through May 1978 at Black Bayou.

The West Hackberry site was surveyed by SAI from September 1977 through May 1978 and by NOAA from June 1978 through May 1979. The West Hackberry sampling suite and frequency of observations are summarized by program participant in Figures A-3 and A-4, Appendix A.

The Weeks Island baseline survey was conducted by Dames and Moore from September 1977 through April 1978 (with an extension of current meter observations through June 1978) and by NOAA from June 1978 through May 1979. Dames and Moore surveyed Chacahoula from September 1977 through November 1978.

1.5 Status of Bryan Mound Brine Monitoring

Brine discharge data is obtained in accordance with the Monitoring Plan for Bryan Mound Brine Disposal to the Gulf of Mexico, which was formally approved by the EPA on August 29, 1979. To be responsive to substantive concerns of the fishing industry required more than site-specific oceanographic monitoring. A comprehensive plan was developed to include the following tasks:

- Task 1. Oceanographic monitoring.
- Task 2. Brine pit monitoring.
- Task 3. Shrimp studies.
- Task 4. Numerical modeling of energy transfer through the food web.
- Task 5. Red drum studies.

Oceanographic monitoring includes a full spectrum of standard observations of physical, chemical and biological variables. This monitoring is being conducted by investigators at TAMU under direct contract to DOE. All data from this work are being validated and archived at the Environmental Data and Information Service (EDIS), NOAA through the Interagency Agreement.

Physical data are collected monthly from shipboard operations and continuously from self-contained, internally-recording instruments and real-time telemetering instruments. The data set includes wind speed and direction, air temperature, waves, surface, mid-depth and bottom currents, temperatures, salinities and brine flow out the diffuser. In addition, the brine plume is tracked monthly from shipboard as described in Section 3.

Monthly water and sediment quality observations include dissolved oxygen (DO), salinity, temperature, pH, total suspended solids, volatile suspended solids, oil and grease (in the water column), chlorophyll a and pheophytin a, ortho- and total phosphate, reactive silicate, nitrate, nitrite, ammonia, sedimentary particle size composition and sedimentary total organic carbon. Quarterly measurements are made of dissolved heavy metals and ion ratios of the major constituents, as well as sedimentary oil and grease, Eh/pH, heavy metals and pore water dissolved solids and ion ratios. Pesticide and high molecular weight hydrocarbon burdens in the sediments and pesticide and heavy burdens in selected biota are determined annually.

Biological observations consist of monthly sampling of benthos, nekton, zooplankton and phytoplankton. Nekton sampling is limited to trawls on the bottom which are conducted during daylight hours to sample white shrimp and at night to sample brown shrimp.

Task 2, brine pit monitoring, consists of daily measurements by the DOE contractor of salinity and weekly measurements of specific gravity, total dissolved solids, total suspended solids, pH, oil and grease, total organic carbon and major ions. In addition, selected contaminants from agriculture and industry in the intake water may be measured as required.

Task 3, shrimp studies, is a group of interrelated efforts directed by the National Marine Fisheries Service (NMFS) Southeast Center, Galveston Laboratory, designed to discriminate any effects of brine discharge on the white shrimp and brown shrimp fisheries over a broad region from natural sources of variation. Work elements include analysis of shrimp recruitment to the fishery, analysis of current and historical Texas shrimp catch and effort, shrimp mark/recapture investigations inshore and offshore, a white shrimp and brown shrimp spawning site survey, and studies of behavioral response (avoidance/attraction) and acute toxicity on adult and subadult shrimp using dynamic, flow-through methods.

Results are available from the spawning site survey and the shrimp acute toxicity and avoidance/attraction studies and have been included in this report. The remaining work elements are ongoing in order to evaluate a year of brine disposal; the final assessment of the fishery will be complete in autumn 1982.

The purpose of Task 4 is to develop a computerized model or models of the ecosystem to assess impacts of brine discharge throughout the food web. This effort is being directed by the Center for Environmental Assessment Services (CEAS), EDIS/NOAA, and is structured as five separate but related elements, as follows:

- o Compilation and standardization of model-relevant SPR data into a project data base.

- o Compilation and standardization of model-relevant non-SPR data into the project data base to fill gaps in the SPR data sets.

- Formulation of a site-specific and regional conceptual ecosystem model and its quantification into a static, steady state computer simulation model.

- Development of a statistical analysis model to test the null hypothesis, "Brine disposal has no impact on the biotic communities residing in the brine disposal region."

- Development of a computerized dynamic simulation model.

The project data base includes: all model-relevant SPR data; model-relevant non-SPR data for the northwest Gulf of Mexico, such as the Bureau of Land Management's South Texas Outer Continental Shelf survey and EPA's Buccaneer Oil Field study; and published data pertinent to biological process rates, such as primary productivity, respiration, reproduction, feeding, growth, etc.

The conceptual model expresses biological energy cycling as carbon exchange and is exhaustive in its delineation of functional biotic components. It is organized into four groupings or submodels. These are plankton, nekton, benthos and organic complex, the non-living forms of carbon which are the link between organisms of the water column and the benthos. The four submodels are further divided into 43 separate and functionally distinguishable compartments, each of which is composed of functionally similar groups.

Exercising the static and dynamic models will involve a state-of-the-art technique called ENVIRON ANALYSIS which enables calculation of energy contribution of each compartment to each and every other compartment through direct and indirect paths of carbon flow. Testing of the static model is imminent.

The statistical analysis model and dynamic model are under development. Statistical protocols have been delineated and evaluated and a test run based on predisposal data is imminent.

Completion of Task 4, ecological modeling, is behind schedule due to the fact that brine discharge was significantly below full scale operations for the first four months and the fact that the long lead times are required for processing biological data. This has resulted in insufficient verified data during full-scale discharge for testing the null hypothesis. Completion of Monitoring Plan Task 4 is anticipated during summer 1981.

Task 5 consists of dynamic, flow-through studies of red drum for acute toxicity and avoidance/attraction response to salinity change. The schedule for this task was delayed a half year due to lack of available test organisms; it is now scheduled to be completed in summer 1981.

2.0 COMPARISON OF WEST HACKBERRY AND BRYAN MOUND BASELINE CONDITIONS

2.1 Background Reports

A first attempt to describe the marine environments offshore West Hackberry and Bryan Mound was performed by NOAA utilizing available data and information early in 1977. This resulted in two publications, as follows:

Analysis of Brine Disposal in the Gulf of Mexico:
(1) Bryan Mound, NOAA, February 1977, 165 pp. (NTIS No. PB 275415)

Analysis of Brine Disposal in the Gulf of Mexico:
(2) West Hackberry. NOAA, March 1977, 84 pp. (NTIS No. PB 275416)

To predict the possible environmental impact resulting from discharging large quantities of brine into the nearshore coastal environment of the Gulf of Mexico, these early reports indicated the need for site-specific physical and biological survey information beyond what already existed at that time. Also included in these early studies was a conceptual diffuser system designed by engineers at MIT along with a mathematical model used to predict brine plume concentrations and areal extent.

TAMU and the NOAA Data Buoy Office (NDBO) measured baseline environmental conditions in the offshore Bryan Mound region, and a summary of this information for the period September 1977 to February 1979 is included in the following publication:

Handbook of the Marine Environment, Bryan Mound. NOAA, February 1980, 92 pp. (available from EDIS/NOAA).

In addition to the above compilation of data and information, subsequent environmental survey results are presented in the following document:

Evaluation of Brine Disposal from the Bryan Mound site of the Strategic Petroleum Reserve Program. Final Report of Predisposal Studies, December 1980, Volumes I, II, and III. Texas A&M University and Texas A&M Research Foundation.

This work provides an in-depth treatment of the various components of the field sampling program off Bryan Mound from September 1977 through February 1980 prior to the start of brine discharge in March 1980.

In the case of West Hackberry, field programs to characterize the marine environment also commenced in September 1977 and a report containing findings of that work through May 1978 can be found in:

Characterization of Baseline Conditions at the Texoma Group Brine Disposal Sites; (West Hackberry, Black Bayou, and Big Hill), Science Applications, Inc., report for DOE, Contract No. AC 01-77US08788.

Commencing in June 1978, NOAA continued with the baseline characterization studies at West Hackberry. The field work was divided between the NMFS for biological and chemical quarterly sampling and the National Ocean Survey (NOS) for a year of continuous physical oceanographic studies. A nine volume set, NOAA Technical Memoranda (NMFS-SEFC-25 through 33), providing study results of marine biological and chemical surveys, is listed in the references of this report. For a synopsis of this work, the reader is referred to:

Synthesis of the Texoma/Capline Chemical and Biological Survey Results: June 1978 - May 1979. NOAA/EDIS. (available from EDIS/NOAA).

Data from the NOS physical oceanographic study was provided to EDIS in January 1980 and final reports providing interpretation of results can be found in a two volume set which is presently being prepared for distribution. For a characterization of the physical oceanography of the West Hackberry site during the period June 1978 through May 1979, the reader is referred to:

NOS Strategic Petroleum Reserve Support Project: Special Report - Oceanographic Characterization of the West Hackberry Brine Disposal Site. NOS/NOAA. March 1981. (available from National Ocean Survey, NOAA)

A guide to validated archived data at EDIS and the chronologies associated with the various field programs for the West Hackberry and Bryan Mound diffuser sites are give in Appendix A.

2.2 Physiographic and Physical Oceanographic Conditions

In comparing the two diffuser sites (Fig. 2-1), the Bryan Mound diffuser is located 12.5 st. mi. offshore in a depth of 70 feet seaward of the old deltaic plain of the Brazos River (Fig. 2-2). The coastal town of Freeport, Texas lies to the north of the site. Major coastal shipping fairways are located to the east and south of the site. The West Hackberry diffuser is located approximately 125 nm to the northeast along the Gulf Coast and is 6 nm offshore in a depth of 30 feet, southwest of Calcasieu Pass and the coastal town of Cameron, Louisiana (Fig. 2-3). Major coastal shipping fairways also are located to the east and south of this site. Immediately seaward of the shipping fairway to the south of the site and approximately 10 nm from the diffuser is the major offshore feature of Sabine Bank with depths ranging from 15 to 25 feet amidst surrounding depths of 35 to 40 feet. The West Hackberry diffuser's closer proximity to the coast, together with this major offshore physiographic feature, creates a more estuarine-like environment than the more marine-like environment which exists at the Bryan Mound diffuser site; that is, a distinctive difference between the two sites is their relative variability in physical oceanographic conditions, bottom sediment and biological characteristics.

Naturally occurring bottom salinity at the Bryan Mound diffuser site over the past three years has ranged from 32 to 36 ppt with the lone exception of 28.7 ppt recorded in September 1979, following flooding from two tropical depressions (Texas A&M, 1980). Whereas, at the West Hackberry site, a much

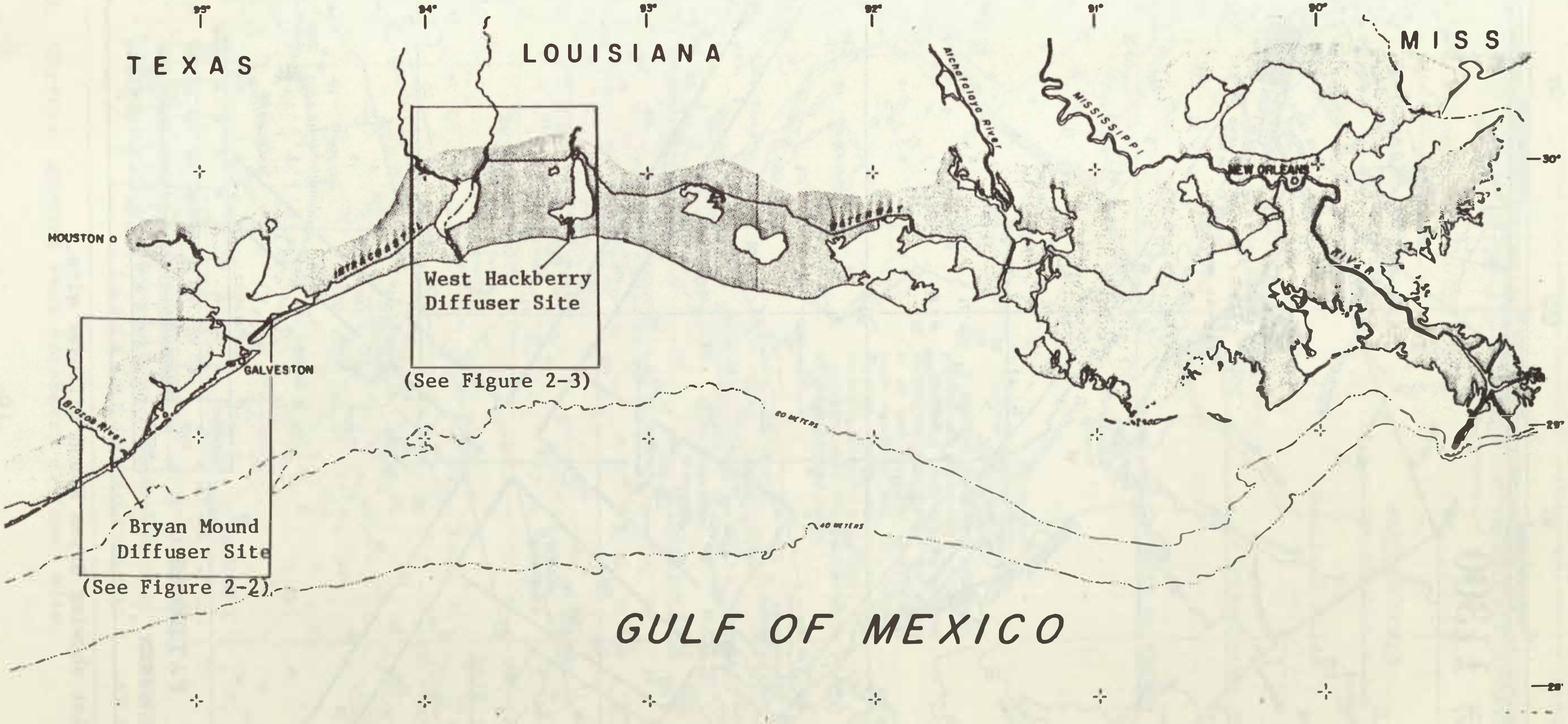


Figure 2-1. Map showing regional relationship between Bryan Mound and West Hackberry diffuser sites.

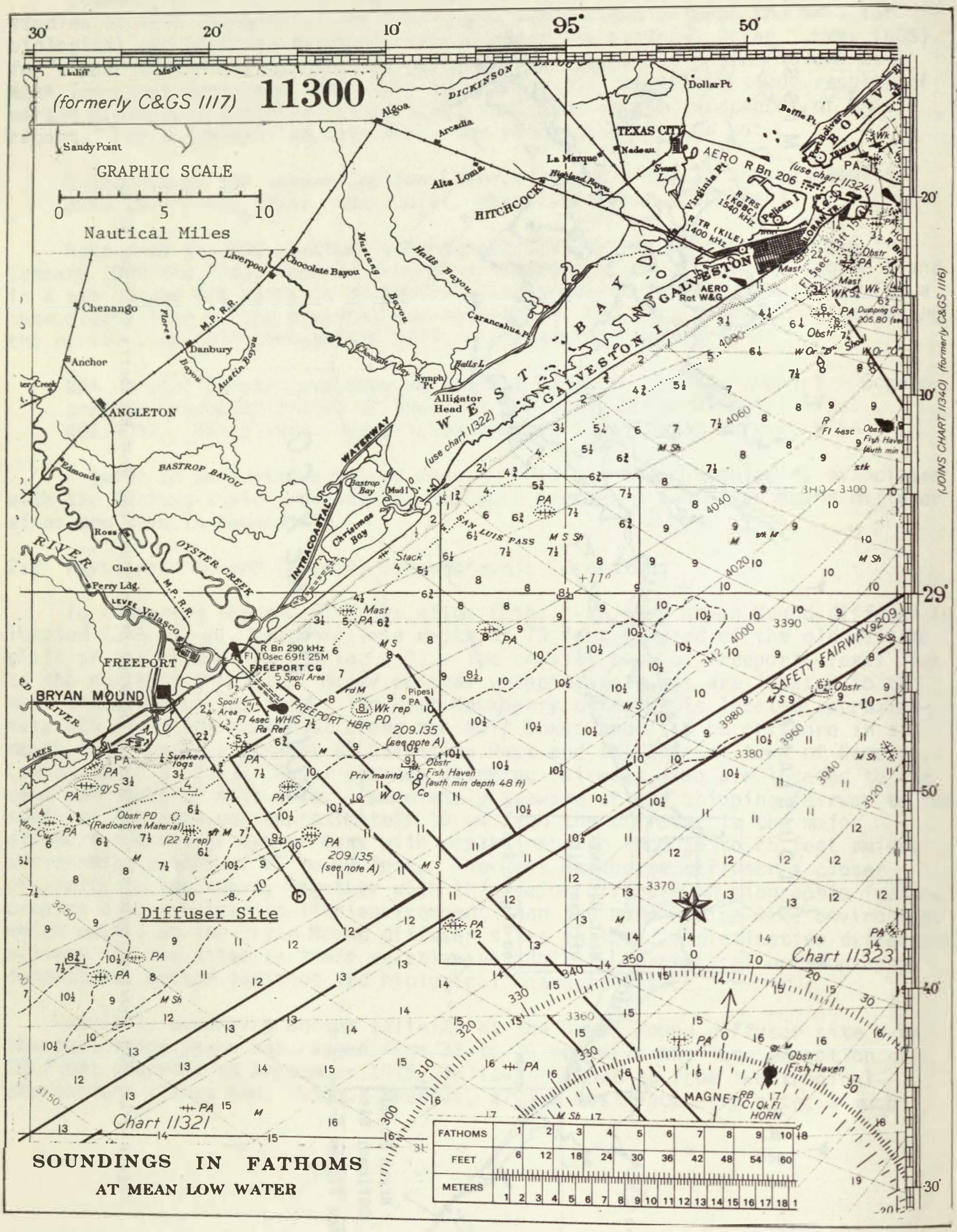


Figure 2-2. Chartlet showing Bryan Mound diffuser site.

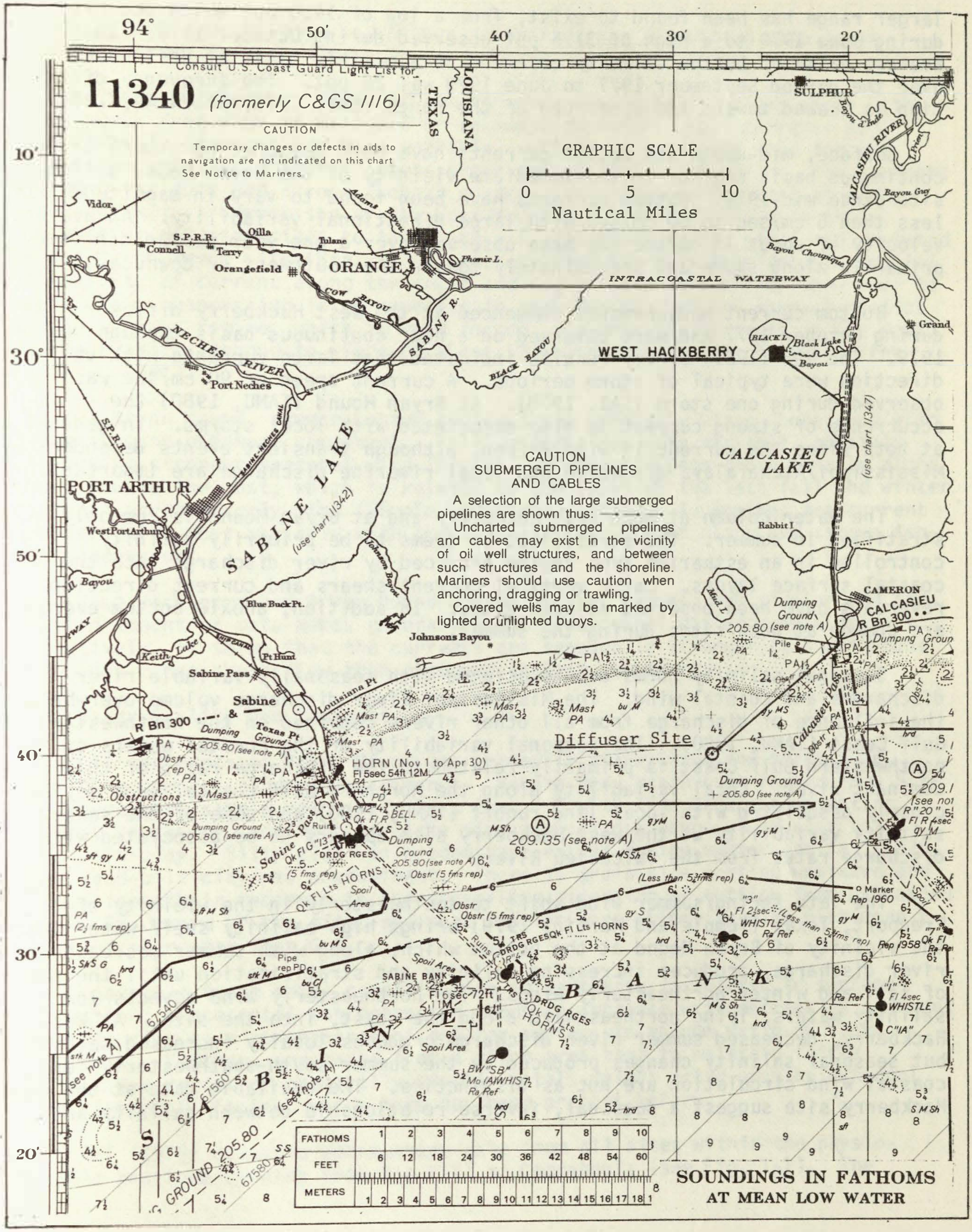


Figure 2-3. Chartlet showing West Hackberry diffuser site.

larger range has been found to exist, from a low of 14.0 ppt which occurred during June 1979 to a high of 31.5 ppt observed during October 1978. The average value of bottom salinity observed on a monthly basis at West Hackberry over the period September 1977 to June 1979 was 26 ppt. The frequency distribution is skewed toward the upper end of the range (SAI, 1978; NOS/NOAA, 1981).

Surface, mid-depth and bottom currents have been measured on a more or less continuous basis near or in the immediate vicinity of the Bryan Mound diffuser site since mid-1979. Bottom currents have been found to vary in magnitude from less than 5 cm/sec to 50 cm/sec with large directional variability. An average velocity of about 13 cm/sec has been observed over a one year period directed primarily along shore and predominately toward the southwest or downcoast.

Bottom current measurements commenced at the West Hackberry diffuser site during October 1977 and were observed on a near continuous basis through May of 1979. The NOS (1981) survey results indicated that large currents with variable direction were typical of storm periods. A current speed of 90 cm/sec was observed during one storm (SAI, 1978). At Bryan Mound (TAMU, 1980) the occurrence of strong current is also associated with local storms. In general, at both sites the current is wind driven, although transient events dependent on Mississippi/Atchafalaya discharge and local riverine discharge are important.

The water column at both West Hackberry and at Bryan Mound is commonly stratified in summer. The stratification seems to be primarily salinity controlled in an estuarine type regime produced by river discharge into the coastal surface layers. Large vertical current shears and current direction reversals have been observed at both sites. In addition, anoxic bottom events are common at both sites during the summer.

Seasonal salinity norms are associated with seasonally variable river discharges and coastal wind. The Mississippi River discharge volume overwhelms the influence of discharge from all other rivers combined on the northwestern Gulf Coast (TAMU, 1980). The seasonal variability of the coastal waters of the northwestern Gulf Coast is primarily related to the discharge rates of this dominant river. Local variability along the northern Gulf coastal area may be closely associated with local land runoff (TAMU, 1980) and some of the seasonal salinity variability at the West Hackberry site appears to be associated with discharge rates from the Calcasieu River.

The late spring/summer wind shift to southwesterly in the vicinity of Freeport, Texas (Temple and Martin, 1979) brings high salinity shelf water into the vicinity of Bryan Mound at the bottom which, along with summer decreases in river discharge, produces increasing salinity and stratification until the onset of fall and winter northeasterly winds. The northeasterly wind advects low salinity waters, lying northeastward along the coast, into the site. At West Hackberry, decreased summer river discharge produces locally increased salinity, but seasonal salinity changes produced by the summer south-southwesterly Texas coastal wind circulation are not as distinctive. The available data at the West Hackberry site suggest a seasonal, inverse relationship between salinity and bottom current speed; that is, higher salinities are associated with lower current speeds.

At West Hackberry, summer bottom currents are primarily along shore with about equal frequency of westward or eastward currents. Fall currents are significantly stronger and more variable, reflecting increased wind forcing. Winter currents are primarily along shore and westward. In spring, the currents are more variable and across isobath currents are about as frequent as along shelf currents. Comparison of the West Hackberry site currents with those measured at metering sites to the northeast, toward Calcasieu pass, and westward at the Black Bayou site (Fig. A-3), indicate that there is considerable spatial variability of current along the coast and significant variability from year to year. This observation is as expected in consideration of the characteristics of the current regime, which is wind forced. In general, currents at the West Hackberry site respond to winds of about 12 knots within several hours (Frey et. al., 1981).

At Bryan Mound, summer bottom currents are primarily along shore, but with a significant offshore component. Fall currents are more variable, possibly reflecting stronger seasonal wind forcing. Winter currents are primarily along shore toward the west, which is related to the onset of the late fall and winter seasonal northeasterly wind (Temple and Martin, 1979). In spring, the current is seasonally most variable with about equal frequency of along and across isobath components.

West Hackberry and Bryan Mound bottom current regimes are similar and the limited amount of data makes generalization of seasonal differences difficult. Tentatively, it seems that the currents are seasonally stronger at Bryan Mound with more cross-shelf flow than observed at West Hackberry.

2.3 Water Quality and Sediment

The sediments at Bryan Mound are primarily clayey sand and silty sand overlying compact sand-clay sediments. Sample mean grain size ranged from 5 to 7 ϕ where most sample means were less than 6 ϕ with fine sand predominating. At West Hackberry, sediment particle size composition ranges from clay to sand-silt-clay. Silty clay was predominant except during summer and fall 1978, when sand-silt-clay was predominant. There is grain size sorting westward and across isobath in response to the prevailing direction of outflow from Calcasieu Pass. Shoreward of the site, sediment samples were primarily clay with mean ϕ grain size greater than 6 ϕ.

Leachable trace metal concentration in sediments is related to surface adsorption; trace metal concentration tends to increase with decreasing sediment particle size as a consequence of greater surface-to-volume ratio of finer sediments. Further, sediments from a given area tend to maintain fairly distinctive ratios of chemically similar metals unless acted upon by external (environmental) factors which have not been present before.

SAI (1978) compared sedimentary data from all sites within the physiographic province ranging from Big Hill to Chacahoula (see Fig. 1-1). The sediments of these sites are from similar depths, 20 to 30 ft, and are exposed to similar coastal processes. Very high correlations were found between TOC and percent clay and between iron and percent clay. Iron concentrations in the sediments are on the order of tenths of a percent; at such high levels it is not subject to significant change in concentration by man's activities. Similar correlations with sediment particle size composition (clay content) should hold for the trace metals which share the chemical similarities of iron in the transition family of elements.

SAI (1978) found correlations between trace metals and iron that ranged from r = 0.88 for cadmium to r = 0.97 for lead and for zinc. By inference, apparent differences among the sites in baseline levels of sedimentary trace metals are attributable to differences in sediment particle size with the exception of high cadmium at Weeks Island Site A (see Fig. 1-1). Therefore, relatively high levels of trace metals at West Hackberry are probably not anthropogenic but relate to the finer sediments found there.

Similar relations are not found for all sedimentary heavy metals at Bryan Mound. It is not known to what extent this may be due to greater depth and other physiographic factors. Copper and zinc appear to be explainable by particle size composition but relative to sediments from depths of 20 to 30 ft, Bryan Mound sediments appear to be marginally deficient in cadmium, deficient in nickel and lead, and significantly enriched in chromium. In August 1979, shortly after construction of the diffuser, chromium was high at control stations inshore, offshore and upcoast but within expected concentration at the diffuser. Since November 1979, chromium has been high at the diffuser and the controls. The source for high chromium at Bryan Mound is not known; chromium has been undetectable in the water column (Slowey, 1980).

Under reducing conditions, that may arise during anoxic periods, larger concentrations of adsorbed material may be expected to be released into the water column at West Hackberry than at Bryan Mound. In general, the soluble trace metals (ion concentration) in waters of West Hackberry are greater than the concentrations measured at Bryan Mound where cadmium, chromium, mercury, nickel and lead have been undetected.

Little difference in the concentration of trace metals in white shrimp were found at Bryan Mound and West Hackberry. With respect to mixed zooplankton samples, mixed results occur in the body burden comparison. This is most likely caused by differences of the zooplankton making up the samples from the two sites. As with trace metals, the sediment hydrocarbon concentration at West Hackberry was observed to be greater than the concentration at Bryan Mound (TAMU, 1978). The primary source of hydrocarbons for Bryan Mound sediment are biogenic although petrogenic input is indicated by the presence of a complex mixture of compounds in the hexane fraction of the samples. At West Hackberry, the hydrocarbons in the sediments are primarily from petrogenic sources (Boehm and Fiest, 1980).

Dissolved nutrient data (ortho- and total phosphate, reactive silicate, nitrate, nitrite and ammonia) from the West Hackberry and Bryan Mound discharge sites indicate the importance of local river discharge.

Brooks (1980) found that nitrate at West Hackberry was inversely correlated with salinity and inferred that the major source is river runoff. Ammonia, silicate and phosphate were inversely correlated with DO which suggested that the process of bacterial regeneration from decaying organic detritus may be a significant factor at West Hackberry. SAI results (1978) were consistent and showed that a very high discharge event in the Calcasieu River during January and February 1978 was associated with a nitrate maximum at West Hackberry; this maximum was twice as high as the seasonal maximum observed by Brooks (1980) in the following year. During the time of SAI's observation of high nitrate at West Hackberry, Dames and Moore's sampling at Weeks Island and Chacahoula produced seasonally typical nitrate concentrations (Weissberg, et al, 1980a and 1980b). This suggests that nitrate concentration at West Hackberry is dependent primarily on Calcasieu River discharge. While Mississippi River discharge dominates the salinity as far away as Bryan Mound, its influence on nitrate concentration in coastal waters is more limited. Salinity is conservative, whereas nitrate is consumed relatively quickly by the phytoplankton.

Slowey (1980) found a similar nutrient pattern at Bryan Mound with one qualification: the relation between nitrate and local discharge does not hold for floods caused by tropical depressions in late summer. This may be due to the fact that nitrate in the soil is at a seasonal minimum and due to sheer dilution from excessive runoff.

Aside from discrete discharge events, especially related to normal rainfall in winter and early spring, the coastal waters at West Hackberry and Bryan Mound do not appear to be especially fertile based on nutrient data. Generally, nitrate appears to be the limiting nutrient at each site except during local river discharge events when phosphate may be limiting. At West Hackberry, nitrate and phosphate were both depleted at times.

Other factors of water quality, such as total suspended solids, oil and grease, and at West Hackberry, heavy metals, appear to reflect dependence on local discharge similar to that of nutrients.

2.4 Biota

2.41 Assemblages

The species composition of the biotic assemblages occurring in the vicinity of the West Hackberry Diffuser site are representative of the shallow (3-20 m), inshore, sandy-mud bottomed coastal habitats of the northwest Gulf of Mexico. The nekton is composed of and dominated by typical species of the nearshore white shrimp community, notably white shrimp and sciaenid finfish (Atlantic croaker, star drum, sand seatrout and silver seatrout). Atlantic bumper, Gulf menhaden and bay anchovy dominate the pelagic finfish. The benthic community is dominated by polychaete annelids such as *Paraprionospio pinnata, Cirriformia* and *Magelona* with juveniles of the dwarf surf clam *Mulinia lateralis* being seasonally abundant. The majority of megabenthic species are tolerant of wide salinity ranges and can be classified as euryhalinic organisms with estuarine affinities. The low numerical presence of peracarid crustaceans (amphipods in particular) is indicative of highly variable physical environmental conditions characteristic of the West Hackberry diffuser site.

The planktonic communities of the West Hackberry diffuser area are composed of typical neritic forms common to the coastal and estuarine waters of the northwest Gulf of Mexico. The zooplankton is overwhelmingly dominated by copepods of which Acartia tonsa, Labidocera aestiva, Paracalanus crassirostris and Temora turbinata are the most abundant. With the exception of the tunicate, Oikopleura, non-copepod forms are poorly represented in the West Hackberry zooplankton. This is especially true of the meroplanktonic ichthyofauna (finfish eggs and larvae).

Diatoms of the genera Biddulphia, Rhizosolenia, Nitzchia, Skeletonema, Chaetoceros, Coscinodiscus and Asterionella dominate the phytoplankton community. The dinoflagellate Ceratium may be the dominate form in the spring assemblage. The vast majority of phytoplankton taxa can be classified as estuarine to neritic forms. Many can be further classified as ubiquitous with respect to their spatial and temporal distributions in coastal waters.

The Bryan Mound diffuser site, at a depth of 70 feet, is a region of ecological transition between shallower inshore and deeper offshore habitats, which is reflected in the biotic assemblages. The nekton community represents a transition between the nearshore white shrimp community and the offshore brown shrimp community; it is dominated by typical inshore species (white shrimp, sand seatrout and silver seatrout) and offshore species (brown shrimp, shoal flounder, long-spined porgy and blackfin searobin). Atlantic bumper, Gulf butterfish rough scad and striped anchovy are dominant pelagic species. Brown shrimp are abundant year-round while white shrimp are common year-round and abundant in winter when they have moved offshore from the inshore coastal waters and estuaries. The Bryan Mound diffuser is located at the outer bathymetric limit of the white shrimp.

The Bryan Mound benthic community is similar in species composition to the West Hackberry benthic community. The major difference between the two sites is the high abundance of peracarid crustaceans at Bryan Mound. Corbula operculata, a bivalve mollusc characteristic of deep offshore habitats, is also an abundant species at Bryan Mound.

Species composition of the Bryan Mound plankton is also similar to that of the West Hackberry zooplankton and phytoplankton communities. Copepods overwhelmingly dominate the zooplankton, and the phytoplankton is dominated by diatoms. This close similarity between the sites is not unusual since the majority of occurring taxa are ubiquitous within the neritic zone of the northwest Gulf of Mexico.

2.42 Population Densities and Diversities

Overall densities of the biotic assemblages at both sites are generally highest in the late spring - early summer when water temperatures are increasing and nutrient inputs via riverine runoff are high. Zooplankton and phytoplankton densities are maximal and representative of spring bloom conditions typical of coastal waters. Benthic invertebrate densities are high as a result of recruitment of juveniles to the populations. Brown shrimp increase greatly in abundance as they move out of the estuaries. Finfish abundance peaks as species move into the warming coastal waters and estuaries to feed and spawn.

Secondary peaks of abundance occur in the fall as species migrate out of the estuaries and a second reproductive/spawning cycle takes place as water temperature decreases and turn-over of the water column replenishes depleted nutrients.

White shrimp are most abundant at both sites in winter when post-juveniles move out of the estuaries and into the Gulf.

Rigorous comparison between the two sites of population densities and species abundances cannot be made because of the disparity in sampling and data analysis techniques of the respective site surveys. However, several generalities may be inferred from the data. Population densities at Bryan Mound appear to be several times greater than those at West Hackberry.

Zooplankton and phytoplankton densities at Bryan Mound average two to four times higher than those from West Hackberry, and nekton densities average 1.5 to 2 times higher. The greatest density difference between the two sites is in the benthic invertebrate assemblage. Comiskey (1978) recorded mean monthly benthic densities of 210-1307 individuals/m^2 at West Hackberry while Harper (1980) recorded mean monthly benthic densities of approximately 600 to 5400 individuals/m^2 at Bryan Mound. These lower population densities at West Hackberry are most likely associated with that site's highly variable environment.

In addition to higher population densities, the Bryan Mound nekton and benthic invertebrate assemblages contain considerably more species than do the West Hackberry assemblages. Chittenden (1980) recorded 122 finfish species from Bryan Mound; the combined data of Comiskey (1978) and Landry and Armstrong (1980) yield only 56 finfish species occurring at West Hackberry. Harper (1980) collected 232 taxa at West Hackberry. A reason for the greater number of species at Bryan Mound is the ecological overlap of the inshore and offshore communities at this site. Also, the greater environmental stability at Bryan Mound is more conducive to higher species diversity.

A basic tenet of ecology is that species diversity and richness are directly related to environmental stability: the more stable an environment is, the higher the species diversity and species abundance (richness). In this context, the West Hackberry environment is considerably less stable than the Bryan Mound environment. This is reflected in the lower species diversity and species richness at the West Hackberry site. Only a few tolerant and adaptable species are numerically abundant year-round. However, low species diversity and richness do not imply low densities. In fact, low species diversity and richness often coincide with high densities as a result of reduced competition for resources and niche space. Thus, the lower densities at West Hackberry in comparison to Bryan Mound are possibly due to environmental stress factors, either natural, anthropogenic or both, which limit the survival and reproductive adaptability of the occurring species. Again, it is noted that for all practical purposes many of the West Hackberry species are seasonal residents only.

2.43 Stress Factors

Two natural stress factors or perturbations which strongly influence the biotic communities of the Texas-Louisiana coastal waters are hypoxia (dissolved oxygen levels below 2 mg/l) of the bottom waters and tropical storms/hurricanes.

Hypoxia, a previously unrecorded condition in the northwest Gulf of Mexico, impacted the east Texas-west Louisiana nearshore ecosystem in the summer of 1978. The condition recurred in the summer of 1979 and extended offshore to include the region of the Bryan Mound diffuser site. In both cases, the hypoxia developed in association with a strong vertical stratification of the water column and persisted until the vertical stratification was disrupted. Heavy spring rainfall and concomitant riverine run-off are factors which caused the vertical density gradient of the water column. The 1978 hypoxia was not fully documented, but in June, dissolved oxygen levels of 0.0 mg/l were recorded for West Hackberry bottom water; whereas densities and species diversities of the faunal assemblages were reduced inshore of the Bryan Mound diffuser site.

At Bryan Mound in 1979, the severe impact of hypoxia on the biotic assemblages at the diffuser site and shoreward was well documented. Inshore, dissolved oxygen levels were less than 1 mg/l by early June, then spread offshore to the Bryan Mound site where dissolved oxygen levels dropped to about 1 mg/l in July. Massive mortalities of benthic invertebrates were observed and benthic, nektonic and planktonic populations were severely depressed. Peracarid crustaceans, indicators of stable, non-stressed conditions, disappeared from the diffuser site in June and July. Benthic diversity was at a minimum in July. Hypoxia disappeared in August, but the biotic assemblages did not fully recover until November. Effects of the hypoxia on the benthic community were still apparent in January and February 1980.

Comparison of the hypoxic effects on the inshore and diffuser benthic communities indicates that the inshore community is more resilient and recovered more quickly than the diffuser community. In conjunction with this assessment is the observation that the hypoxia persisted longer in the offshore area because of the greater water depth and stronger stratification of the water column.

Tropical storms/hurricanes can impact the benthic community by scouring, burying and resuspending of surficial sediments. These perturbations will be felt most strongly in the shallow, nearshore environment where turbulence extends to the bottom. Tropical Storm CLAUDETTE, which struck the upper Texas coast in July 1979, did not generate sufficient vertical turbulence to disrupt the hypoxia at the Bryan Mound site. In contrast, Tropical Storm DEBRA, which struck the upper Texas coast in August 1978, strongly impacted the proposed Weeks Island diffuser site which is situated in 10 m of water. Bottom current meters were torn loose from their moorings and completely buried. Fall biomasses, densities and species abundances of the benthic invertebrate assemblage were much lower than those recorded in the summer (June) quarterly sampling period (Parker and Crowe, 1980).

The effects of elevated trace metal and hydrocarbon concentrations in sediments (see Section 2.3) on West Hackberry biota compared to Bryan Mound is not known. However, it is likely that the relatively low species diversities and paucity of peracarid crustaceans are partially attributable to physiological and environmental stresses induced by these contaminants (e.g., sediment stirring).

2.44 Commercial Fisheries

Menhaden, shrimp (primarily white shrimp and brown shrimp), blue crabs, and oysters are the major commercial fisheries in Louisiana coastal waters. In 1977, these four fisheries accounted for 87 percent of the total Louisiana catch by weight and 98 percent by dollar value. Other important coastal water fisheries are red drum (redfish) and spotted seatrout. All of the above species, with the exception of the oyster, occur in the vicinity of the West Hackberry diffuser site. However, there is nothing unique about the diffuser site region as a fisheries ground.

Shrimp (primarily brown shrimp, white shrimp, and pink shrimp) are the single most important commerical fisheries of Texas coastal waters. In 1977, the shrimp fisheries accounted for 85 percent of the total Texas catch by weight and 95 percent by dollar value. Red drum, black drum, spotted seatrout, blue crabs, and oysters are the other commercial fisheries of importance.

The 1977 fishery data for Louisiana and Texas coastal waters are summarized in Table 2-1.

Table 2-1. Commercial fisheries data for 1977 for Louisiana and Texas. Numbers are landings for each state[1].

Louisiana

Fishery	Pounds	Value ($)
Menhaden	751,273,502	28,660,441
Shrimp (heads-on)	104,018,431	87,213,455
Blue Crabs (all)	16,378,892	4,334,711
Oysters (meat only)	10,056,767	10,353,530
All Other Fisheries Combined	13,412,408	1,756,185
Total	895,140,000	132,318,322

Texas

Fishery	Pounds	Value ($)
Shrimp (heads-on)	91,577,966	125,678,249
All Other Fisheries Combined	16,156,982	7,281,780
Total	107,734,948	132,960,029

[1] Based on data provided in Current Fisheries Statistics for 1977 Louisiana and Texas (U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service).

3.0 BRYAN MOUND DISCHARGE EXPERIENCE

3.1 Summary of Discharge Chronology

The following brine discharge summary information has been provided by DOE. Leaching began on a limited scale at Bryan Mound on March 10, 1980. Discharge generally ranged from 100 thousand barrels per day (MBD) to 200 MBD until mid-July when more wells were brought on line and leaching expanded to full scale operation, 680 MBD as limited by the Bryan Mound NPDES permit.

During the first four months, recurring plugging of wells by the insoluble mineral, anhydrite, frequently reduced leaching flows such that brine discharge to the Gulf was discontinuous. To maintain design discharge velocity from each brine diffuser port, all but the seaward 15 ports were closed.

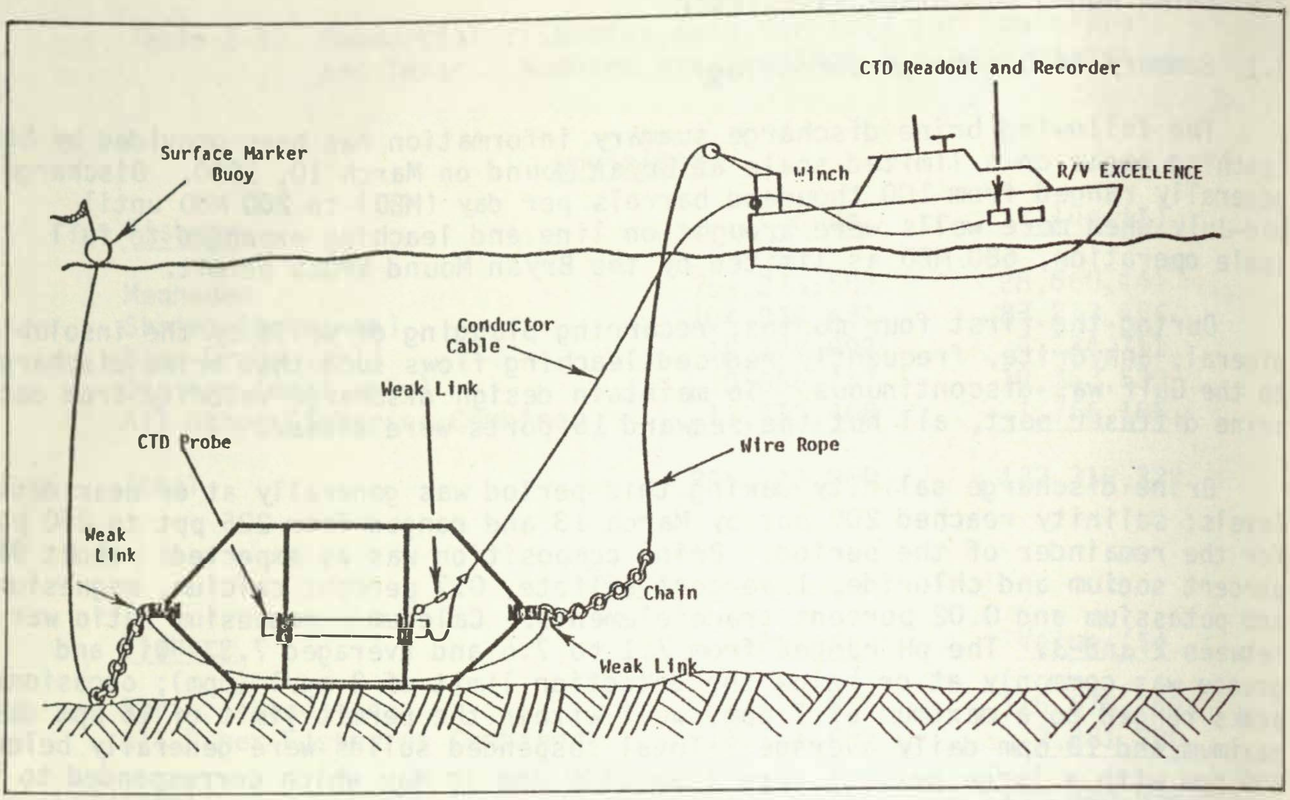
Brine discharge salinity during this period was generally at or near design levels; salinity reached 200 ppt by March 13 and ranged from 225 ppt to 250 ppt for the remainder of the period. Brine composition was as expected: about 98 percent sodium and chloride, 1 percent sulfate, 0.7 percent calcium, magnesium, and potassium and 0.02 percent trace elements. Calcium : magnesium ratio was between 2 and 3. The pH ranged from 7.1 to 7.6 and averaged 7.3. Oil and grease was commonly at or below the detection limit of 2 mg/l (ppm); occasional peaks ranged to a maximum of 7 ppm, well within the permit limit of 15 ppm daily maximum and 10 ppm daily average. Total suspended solids were generally below 200 ppm with a large peak of more than 1400 ppm in May which corresponded to high flow and turbidity in the Brazos River water at the intake. The stage of cavern development was too early to evaluate the assumption that the caverns will act as clarifiers, thereby reducing the suspended loads in the brine discharge relative to the intake.

On July 16, 1980, wells for three additional caverns were brought on line and a total of 31 diffuser ports were opened. With increased brine flow, brine discharge salinity dropped well below 200 ppt. Salinity increased to 200 ppt by August 19, 1980, and to 220 ppt by September 12, 1980, as residence time of water inside the caverns increased slowly with cavern growth. Subsequently, the composite salinity of the discharge has generally ranged between 225 and 250 ppt depending on the mix of leaching and oil fill operations and the relative stages of development among the caverns.

Since expanded leaching operations began in mid-July, there have been only occasional interruptions in brine flow out the diffuser, and these have been on the order of four hours or less with the exception of a 3-day period in August when the Bryan Mound facility was secured in anticipation of Hurricane ALLEN. Flow has ranged between 500 and 680 MBD. After normal brine salinity was reached, brine quality became similar to that previously discussed.

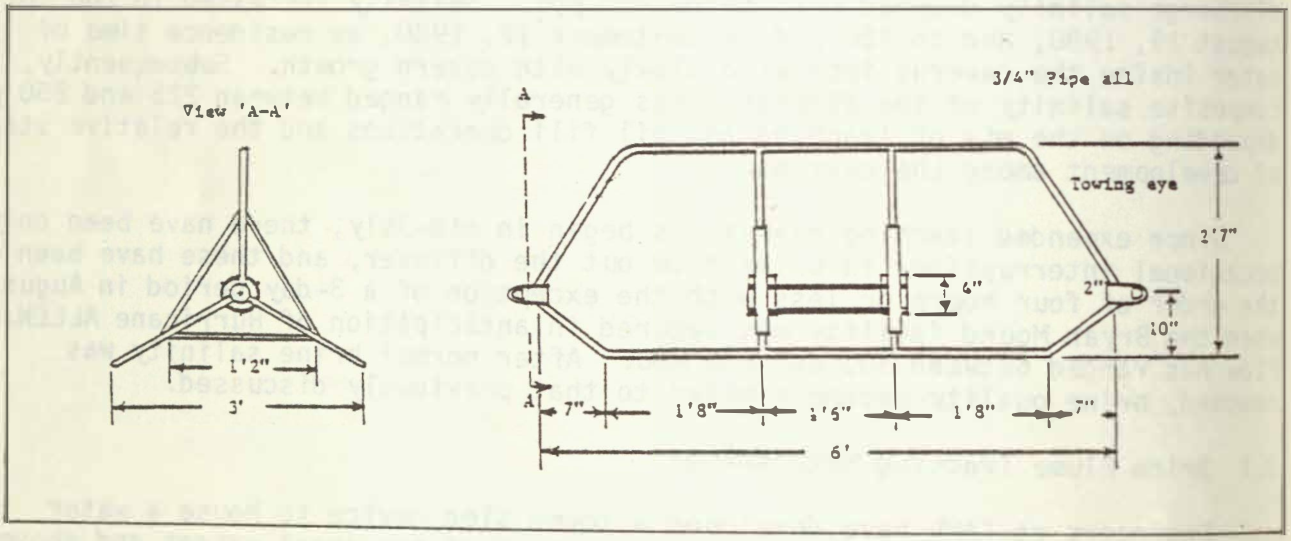
3.2 Brine Plume Tracking Methodology

Engineers at TAMU have developed a towed sled device to house a water quality probe (Hydrolab 8000) for determination of the areal extent and above ambient salinity concentrations of the brine plume on the ocean bottom in the vicinity of the Bryan Mound diffuser. Figure 3-1 shows a schematic diagram of the probe monitoring system. Figure 3-2 is a detailed drawing of the towing



After Texas A&M

Figure 3-1. Schematic of probe monitoring system.



After Texas A&M

Figure 3-2. Detailed drawing of towing sled.

sled which indicates the height of the sensor above the bottom during tracking operations. At the beginning of each plume tracking event, ambient bottom salinity is determined at Station 39 (see Fig. A-2) and an over-the-side bottom current measurement is made near the end of the diffuser. In plume tracking, a system of roughly parallel lines are run on both sides of the diffuser with the sled device towed along the bottom. During tracking, conductivity, temperature, and depth are recorded continuously by a strip chart recorder along with measurements of time and LORAN C determined position. These data permit immediate conversion of conductivity to salinity, the plotting of the vessel's track and sled location, and determination of salinity isopleths (TAMU, 1981).

The above procedures are used to delineate the far-field plume dimensions. (See Appendix B for 13 TAMU plume tracking events covering the period March 30 to October 22, 1980). After the far-field tracking is completed, the vessel returns to the diffuser and near-field measurements are made. This consists of measuring vertical conductivity profiles which permits the evaluation of the vertical extent of the plume in the near-field. Additional bottom salinity data very close to the diffuser (within 100 feet) are also obtained. The time required for any particular plume tracking event is 8 to 10 hours.

3.3 Brine Diffusion Plume Modeling

The MIT Transient Plume Model as used by the NOAA is a numerical approximation tool for estimating the distribution of excess salinity concentrations resulting from the discharge of negatively buoyant brine from a diffuser (Adams et al., 1975). It assumes three regions in the area of the diffusing brine plume (Fig. 3-3). The near-field includes the jets from the diffusers and extends downstream to the point where the falling plume makes contact with the sea floor. The intermediate-field is considered to be the region further downstream where momentum of the falling brine produces lateral spreading and the plume fall rate exceeds the vertical diffusion rate. The far-field is beyond the down stream boundary of the intermediate-field and is the primary focus of the MIT numerical model results. Near and intermediate-field mixing is approximated by a dilution equation derived from laboratory experiments.

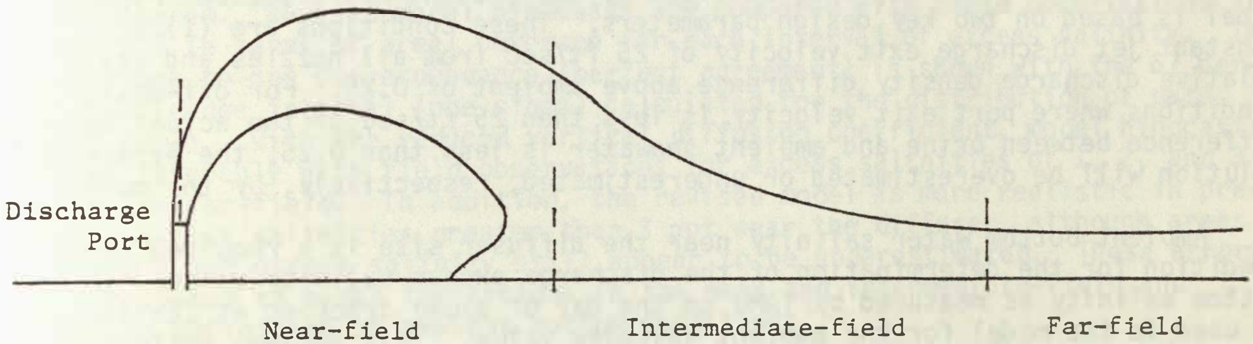


Figure 3-3. Regions of brine discharge for a bottom diffuser (diagrammatic only).

It is assumed that in the far-field the mechanisms responsible for additional dilution of the brine plume are advection and turbulent diffusion. Continuous discharge of brine is approximated by the generation of discrete puffs of brine at small time intervals. Each time interval is related to the ambient current velocity. Model output is an hourly instantaneous snapshot of the excess salinity concentration within a specified gridded region. To generate a snapshot, the previous 310 hours of discharge conditions are required. This 310 hour period contains all the puffs that contribute to the excess salinity distribution within the gridded model area. Model inputs are:

(1) discharge flow rate (ft^3/sec),
(2) discharge excess salinity (ppt), and
(3) bottom currents (ft/sec).

This discharge flow rate and excess salinity are defined by the average daily diffuser discharge rate and the difference between the daily average brine pit salinity and the ambient bottom salinity at the diffuser site for the days requiring modeled output. Discharge rate and ambient salinity are held as constants for the entire 310 hour calculation period required to generate a snapshot. This may account for some of the error which occurs between monitoring results and modeled brine plumes.

The most suitable current data to drive the model would be the ambient current velocity and direction, preferably within 1.5 feet of the bottom, as a function of time. The currents are assumed to be spatially uniform over the entire area of interest (i.e., that area over which the brine plume can be advected during the 310-hour calculation period). However, because of instrumentation constraints, the current data being utilized are collected by TAMU near the diffuser approximately 6 feet above the bottom. No correction for the theoretical decrease in velocity towards the bottom has been performed on this data which may lead to another source of error in realistically simulating actual brine plume conditions.

The dilution equation, which estimates the mixing or dilution in the near and intermediate field regions, utilized by the present MIT Transient Plume Model is based on two key design parameters. These conditions are (1) a constant jet discharge exit velocity of 25 ft/sec from all nozzles and (2) a relative discharge density difference above ambient of 0.25. For off-design conditions where port exit velocity is less than 25 ft/sec or the actual density difference between brine and ambient seawater is less than 0.25, the estimated dilution will be overestimated or underestimated, respectively, by the model.

Ambient bottom water salinity near the diffuser site is a required model condition for the determination of the discharge excess salinity value. The bottom salinity as measured by TAMU on the day of plume tracking at Station 39 is used in the model for the ambient salinity value. This ambient salinity is then utilized in the determination of excess salinity, as well as for contouring of the TAMU plume tracking data. The degree of uncertainty in ambient salinity is indicated in the predisposal data (TAMU, 1980) where spatial differences of 1 ppt to 2 ppt were observed between control Station 39 and diffuser Station 34 for a given time. Temporal variations of 1 to 2 ppt were also observed to occur over a 24 hour period at each of these locations (Randall and Kelley, 1981).

This spatial and temporal variability in the true ambient bottom water salinity does not affect the MIT model output. The effect of a 2 ppt uncertainty in ambient salinity of 32 to 36 ppt in relation to 128-240 ppt brine pit salinity is negligible. However, it does have a pronounced effect on the ability to meaningfully contour the TAMU plume tracking data. A 1 ppt underestimation of the true ambient conditions can result in predicting 4 or 5 ppt salinity excess intervals when 3 or 4 ppt is the true maximum excess. Because the field of ambient bottom salinity cannot be observed in the presence of discharge, the ambient salinity is necessarily assumed to be constant. This is an unavoidable source of error which can lead to large uncertainties in the area of coverage by the 1 and 2 ppt salinity excesses.

3.31 Model Validation: Spatial Distribution of Salinity

Model runs or hindcasts were performed for comparison with 13 TAMU plume monitoring exercises (Appendix B). Table B-1 summarizes the discharge conditions for each event from March 30 to October 22, 1980. Figures B-1 to B-13 depict the TAMU field measurements. Three of the TAMU plume plots (selected to show the plume at full scale discharge under a representative range of ambient current conditions) are mapped in Figures 3-4 to 3-6 and recontoured to show salinity excess above ambient. Modeling and monitoring results were compared with respect to:

(1) area of impact for specific contour intervals (1,2,3...ppt) above ambient and

(2) radial extent of selected salinity levels.

Initial comparison indicated discrepancies between the modeling and monitoring results. Therefore, the vertical diffusion coefficient was reduced from 1×10^{-3} to 1×10^{-4} ft^2/sec (based on personal communication with Dr. Keith Stolzenbach, Ralph M. Parsons Laboratory, MIT) and the model hindcasts were repeated. Revised model hindcasts are compared with field observations in Figure 3-7 in terms of areal coverage for each interval of excess salinity. The line of one-to-one correspondence (perfect agreement) is shown with the 67 percent confidence interval (one sigma) calculated for the distribution of data points shown. With the reduced vertical diffusion coefficient, model hindcasts compare favorably with field observations for excess salinities of 1, 2, and 3 ppt in the far-field. In addition, the revised model is more realistic in predicting excess salinities greater than 3 ppt near the diffuser, although areas of 5 and 6 ppt excess salinity still appear to be underestimated. These errors are attributed to model limitations in the near and intermediate-field and imprecise definition of ambient bottom conditions.

In Figure 3-7, points plotted on the ordinate reflect predicted excess salinities which were not observed in the field; conversely, points plotted on

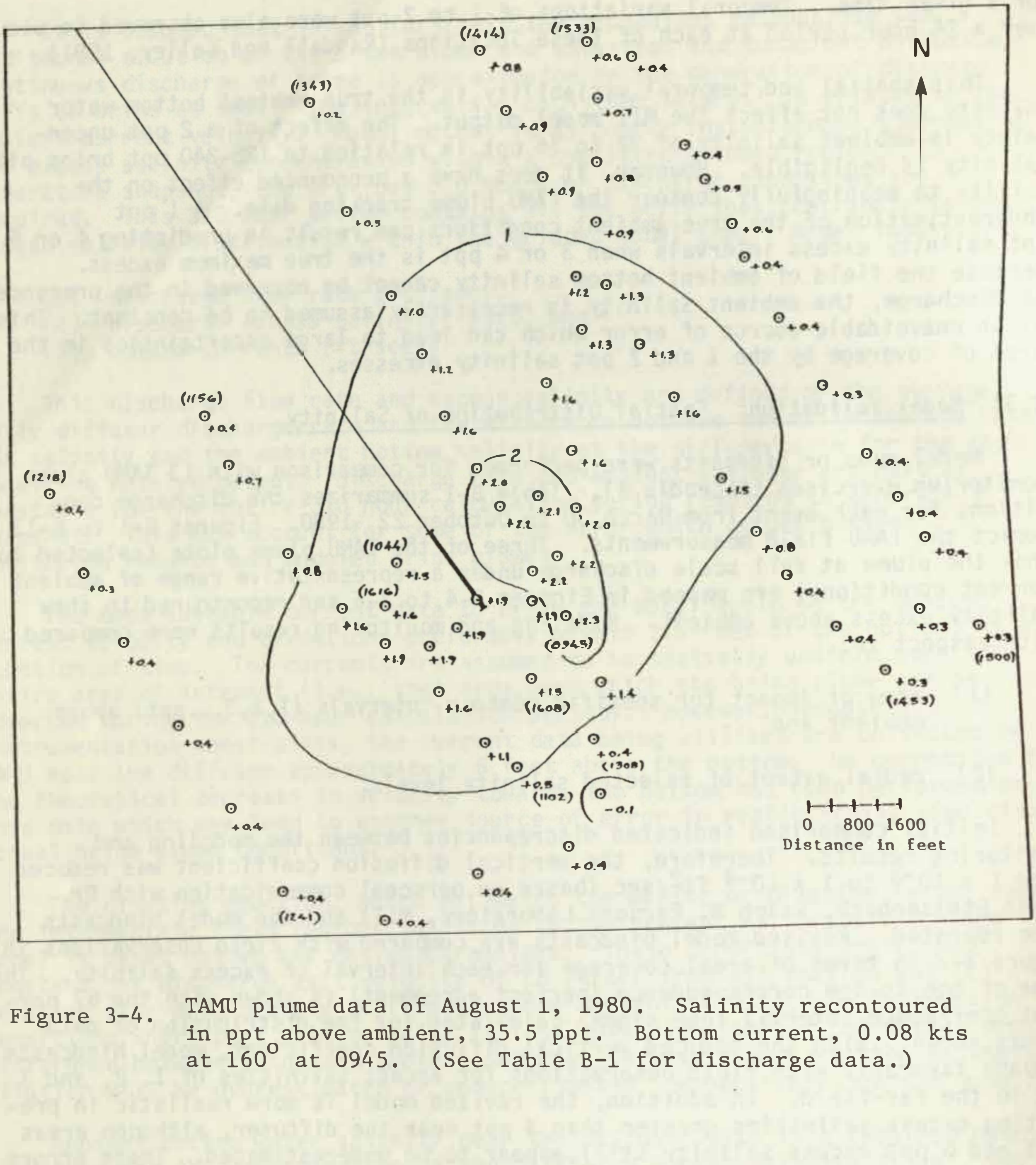


Figure 3-4. TAMU plume data of August 1, 1980. Salinity recontoured in ppt above ambient, 35.5 ppt. Bottom current, 0.08 kts at 160° at 0945. (See Table B-1 for discharge data.)

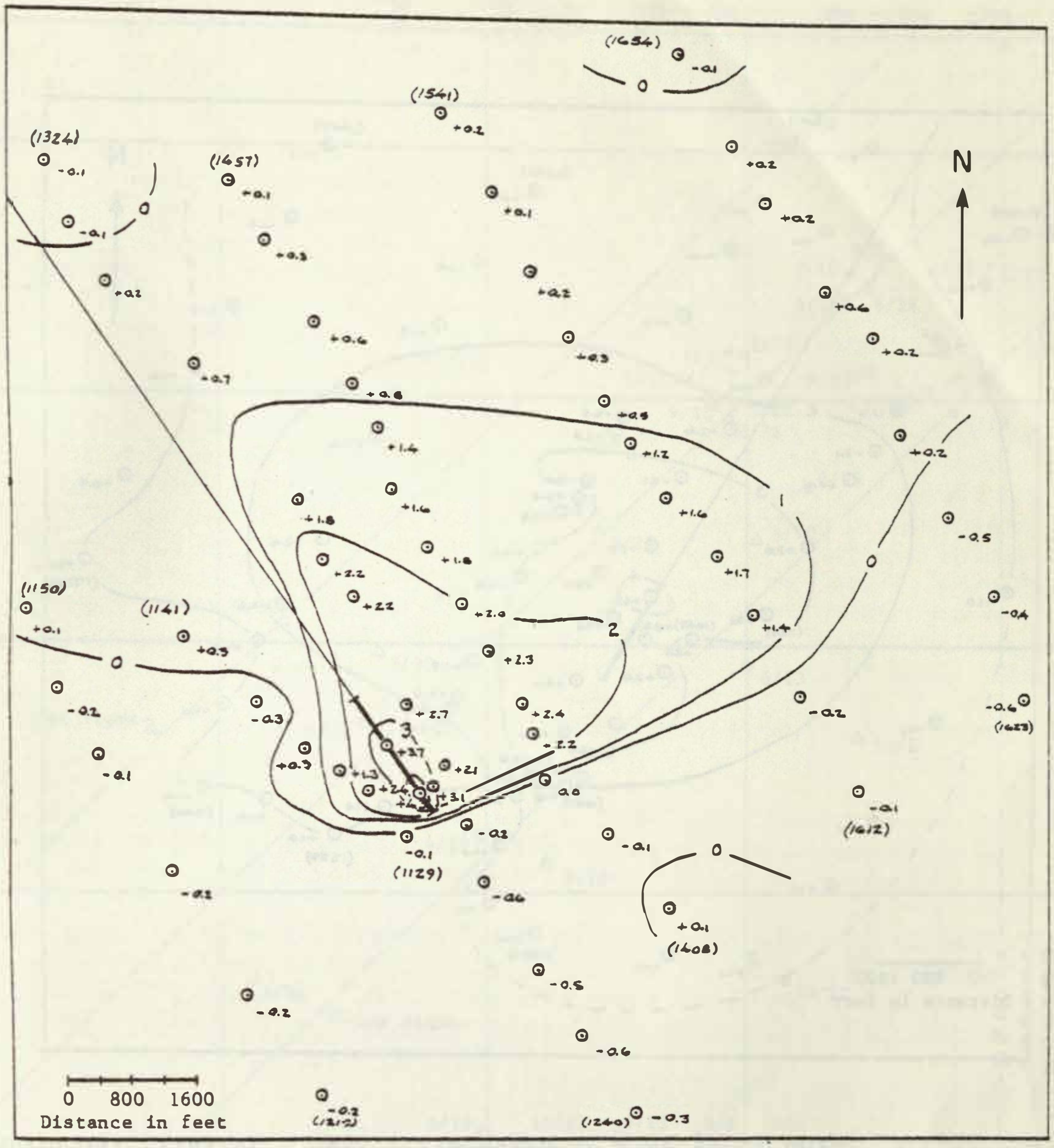


Figure 3-5. TAMU plume data of September 10, 1980. Salinity recontoured in ppt above ambient, 33.7 ppt. Bottom current, 0.63 kts at 010^{o} at 1115. (See Table B-1 for discharge data.)

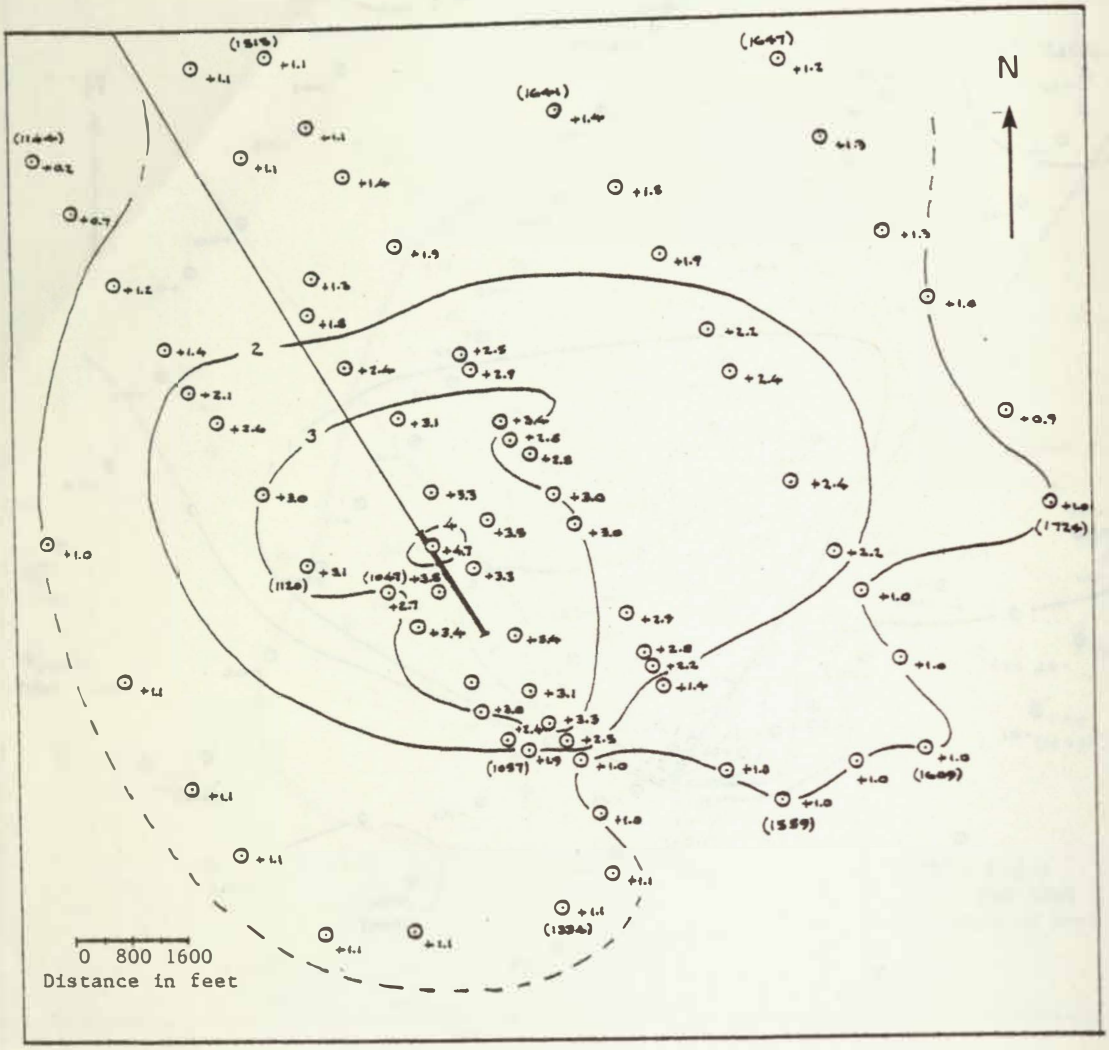


Figure 3-6. TAMU plume data of October 22, 1980. Salinity recontoured in ppt above ambient, 32.3 ppt. Bottom current, 0.30 kts at 045° at 1015. (See Table B-1 for discharge data.)

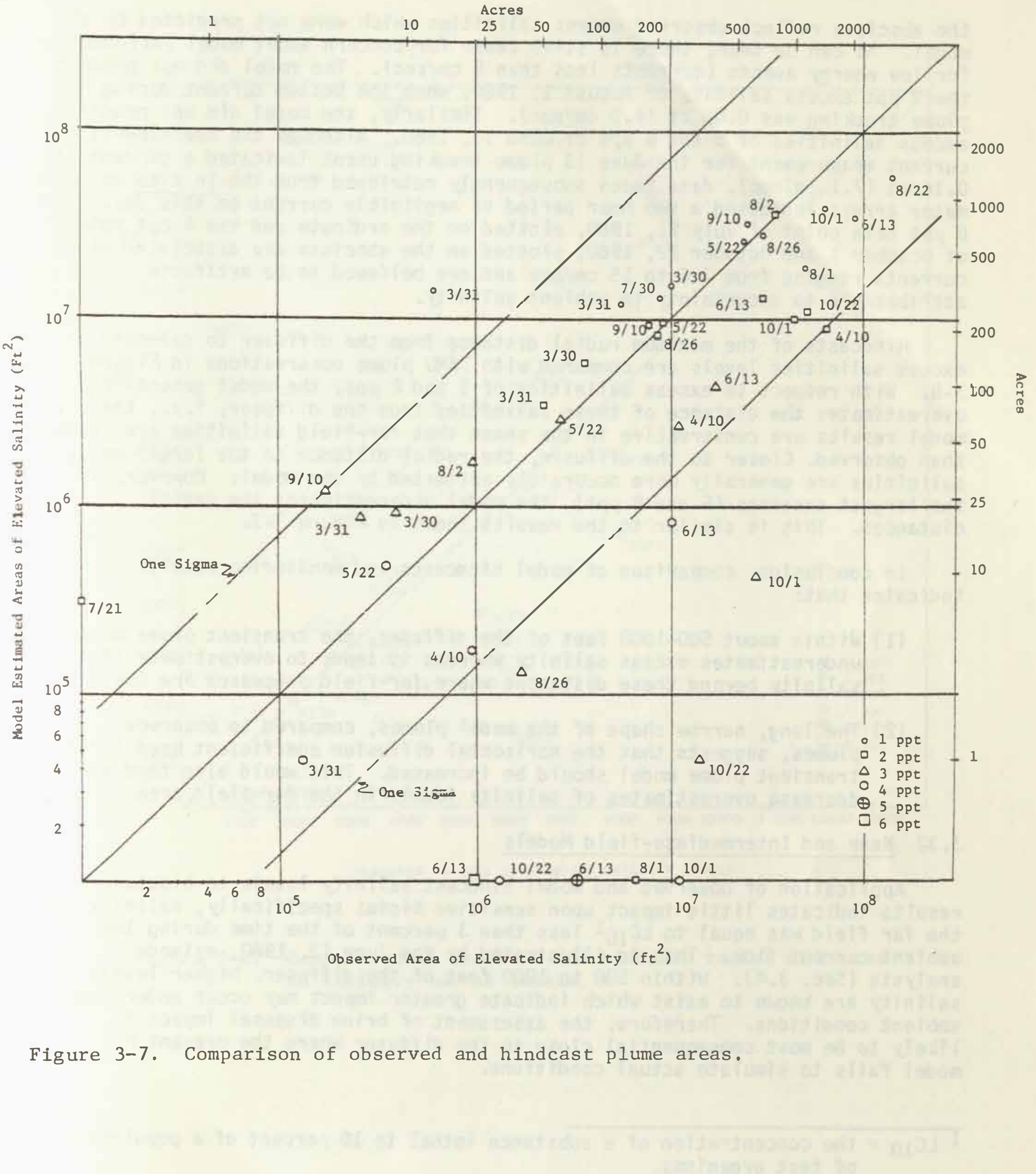


Figure 3-7. Comparison of observed and hindcast plume areas.

the abscissa reflect observed excess salinities which were not predicted by the model. As can be seen, there is still cause for concern about model performance for low energy events (currents less than 5 cm/sec). The model did not predict the 2 ppt excess salinity of August 1, 1980, when the bottom current during plume tracking was 0.08 kt (4.0 cm/sec). Similarly, the model did not predict excess salinities of 5 and 6 ppt of June 13, 1980. Although the over-the-side current measurement for the June 13 plume tracking event indicated a current of 0.14 kt (7.1 cm/sec), data tapes subsequently retrieved from the in situ current meter arrays indicated a two hour period of negligible current on this day. The 6 ppt data point of July 21, 1980, plotted on the ordinate and the 4 ppt points of October 1 and October 22, 1980, plotted on the abscissa are associated with currents ranging from 7.6 to 15 cm/sec and are believed to be artifacts attributable to uncertainty in ambient salinity.

Hindcasts of the maximum radial distance from the diffuser to selected excess salinities levels are compared with TAMU plume observations in Figure 3-8. With respect to excess salinities of 1 and 2 ppt, the model generally overestimates the distance of these salinities from the diffuser, i.e., the model results are conservative in the sense that far-field salinities are larger than observed. Closer to the diffuser, the radial distance to the larger excess salinities are generally more accurately estimated by the model. However, for the largest excesses (5 and 6 ppt), the model underestimates the radial distances. This is similar to the results shown in Figure 3-7.

In conclusion, comparison of model hindcasts and monitoring results indicates that:

(1) Within about 500-1000 feet of the diffuser, the transient plume model underestimates excess salinity whereas it tends to overestimate the salinity beyond these distances where far-field processes are found.

(2) The long, narrow shape of the model plumes, compared to observed plumes, suggests that the horizontal diffusion coefficient used in the transient plume model should be increased. This would also tend to decrease overestimates of salinity levels in the far-field area.

3.32 Near and Intermediate-field Models

Application of observed and model hindcast salinity levels to bioassay results indicates little impact upon sensitive biota; specifically, salinity in the far field was equal to LC_{10}[1] less than 3 percent of the time during low ambient current flow. This is illustrated by the June 13, 1980, episode analysis (Sec. 3.4). Within 500 to 1000 feet of the diffuser, higher levels of salinity are known to exist which indicate greater impact may occur under some ambient conditions. Therefore, the assessment of brine disposal impact is likely to be most consequential close to the diffuser where the present MIT model fails to simulate actual conditions.

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1 LC_{10} = the concentration of a substance lethal to 10 percent of a population of test organisms.

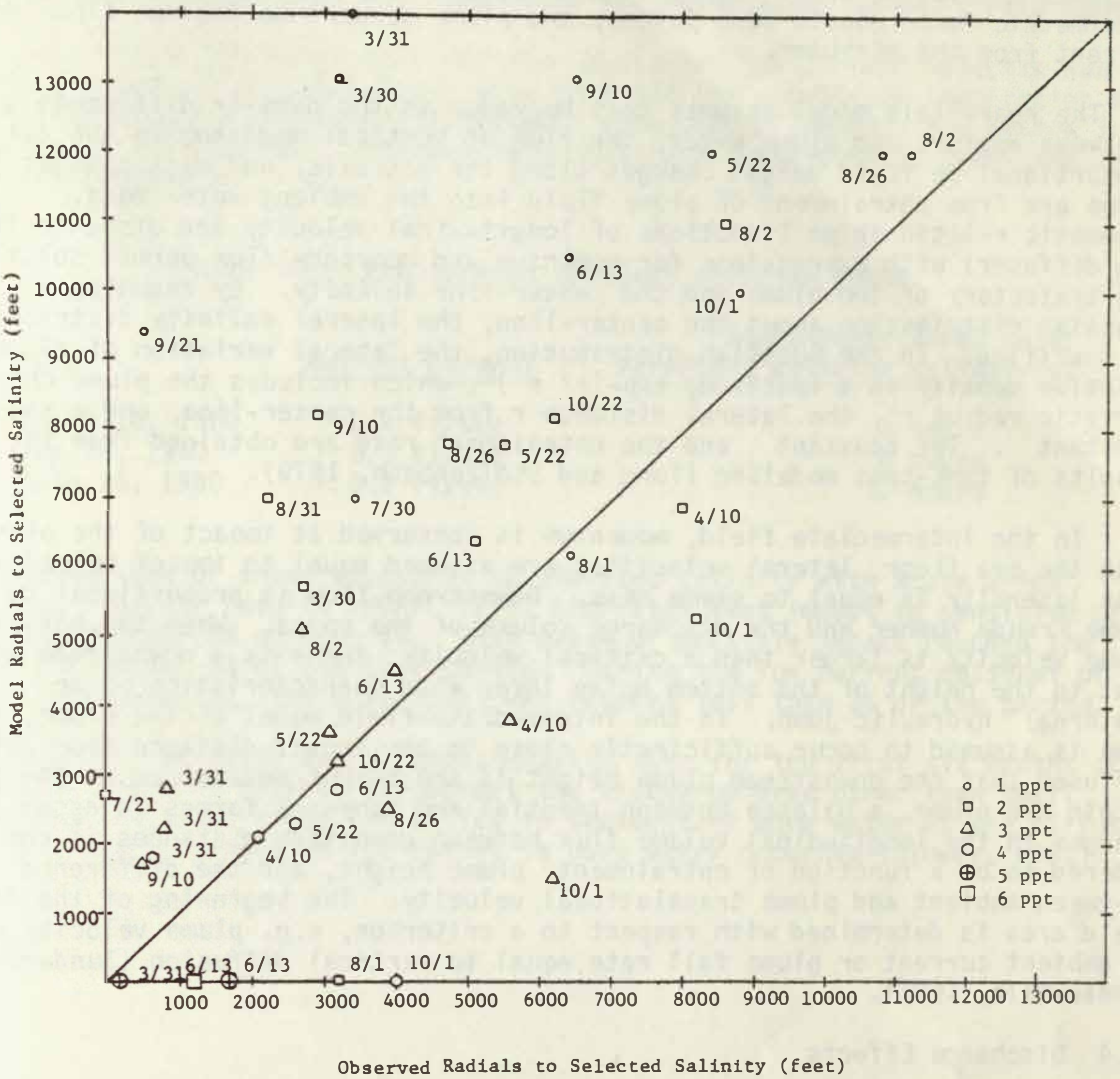

Figure 3-8. Comparison of observed and hindcast radial distances to salinity excess levels.

Present modeling research, by T.S. Associates of Columbia, MD, is directed toward development of near and intermediate-field models which will interface with the MIT far-field transient plume model. Conceptually, the near-field area includes the jet of brine from each diffuser port, plume rise to a level where gravimetric force equals pump forces, and plume descent to the sea floor down-current from the diffuser.

The near-field model assumes that buoyancy is the density difference be-tween ambient and plume water, the flux of vertical momentum in the jet is proportional to fluid weight changes along the jet axis, and mass changes in the plume are from entrainment of plume fluid into the ambient water mass. Kinematic relationships (functions of longitudinal velocity and distance from the diffuser) with expressions for momentum and buoyancy flux permit solution of the trajectory of the plume and the center-line salinity. By assuming a Gaussian distribution about the center-line, the lateral salinity distribution is specified. In the Guassian distribution, the lateral variation of plume relative density is a function, $\exp-(r/ r')^2$, which includes the plume characteristic radius r', the lateral distance r from the center-line, and a shape constant . The constant and the entrainment rate are obtained from the results of tank-test modeling (Tong and Stolzenbach, 1979).

In the intermediate field, momentum is conserved at impact of the plume with the sea floor, lateral velocities are assumed equal to impact velocity, and flux laterally is equal to plume mass. Downstream flow is proportional to the plume Froude number and the discharge volume of the ports. When the horizonal plume velocity is larger than a critical velocity, there is a downstream adjustment to the height of the bottom brine layer with characteristics of an "internal" hydraulic jump. In the intermediate-field model of the plume, the jump is assumed to occur sufficiently close to the impact-distance from the diffuser that the downstream plume height is the height determined at the jump. Within the plume, a balance between inertial and buoyancy forces is assumed, and changes in the longitudinal volume flux between downsteam distances is considered to be a function of entrainment, plume height, and the difference be-tween ambient and plume translational velocity. The beginning of the far-field area is determined with respect to a criterion, e.g. plume velocity equal to ambient current or plume fall rate equal to vertical diffusion (Sundaram and Sinnarwalla, 1981).

3.4 Discharge Effects

In comparing March and April predischarge temperature and salinity data of 1978 and 1979 with March and April postdischarge data of 1980, Kelly and Randall (1981) found only slight changes in water column salinity at the disposal site. Elevated salinity formed a dome shaped pool, detectable to mid-depth. At a depth of 15 meters, water column salinity was elevated in the pool less than 0.5 ppt compared to surrounding water. March 1980 salinity at this depth was less than the salinity observed during March 1978 or 1979, and April 1980 salinity was also lower than previously measured. Temperature changes attributable to brine discharge were not detectable. As these observations were made during discharge operation at design salinities and port exit velocities, it was concluded that the vertical extent of the brine plume at the diffuser would be within the bottom 24 ft of water as predicted.

Dissolved oxygen measurements at the Bryan Mound disposal site and in the surrounding area (within 2.5 km of the diffuser) during TAMU October 1979 (predischarge) and April 1980 (postdischarge) cruises indicated that dissolved oxygen concentrations were not lowered by increased water column stratification.

Three brine discharge episodes with prolonged low current velocity and salinity excess of at least 4 ppt were selected for a Eulerian application of the MIT Transient Plume Model to estimate exposures of benthos and nekton in the vicinity of the diffuser. Current velocities and corresponding exposures are shown in Table 3-1.

Table 3-1. Low current episodes at Bryan Mound.

Date	Ambient Current	Approximate duration of far-field eularian salinity of $\geq$ 4ppt
April 10, 1980	0.4 ft/sec	3 hours
May 22, 1980	0.3 ft/sec	8 hours
June 13, 1980	$<$ 0.2 ft/sec	10 hours

Comparison of these exposures to elevated salinity with acute brine toxicity bioassay results (NOAA, 1978) indicates that impact to sensitive biota could have occurred on June 13. This event of possible impact reached the LC_{10} level about 3% of the test period. During the low current episodes of April 10 and May 22, the LC_{10} level was reached less than 3% of the period.

Analysis of water and sediment quality data for the first six months of discharge shows no effects throughout the discharge area other than small elevations in total dissolved solids in sedimentary pore water at the diffuser. No significant changes in ion ratios in pore water occurred (Slowey, 1981).

4.0 BRINE DISCHARGE AT WEST HACKBERRY

4.1 Simulated Salinity Distributions

Brine diffuser performance criteria at West Hackberry will be similar to those used at Bryan Mound. Therefore, the modeling applications which were used for Bryan Mound have been used to predict excess salinity patterns about the West Hackberry diffuser utilizing field measurements of currents and ambient salinity. Based on a comparison of physical characteristics between the West Hackberry site and the Bryan Mound site (Section 2.2), there are some differences in potential effects. Sediment stirring and decreases in water column stratification at West Hackberry are commonly associated with wind forced mixing in the relatively shallow depths. The forced mixing could promote increased dispersion of a brine plume, leading to generally lower on-site salinity levels. The largest excess salinity observed at the Bryan Mound diffuser site is about 6 ppt on the bottom (June 13, 1980), well below a salinity level of 70 ppt that has been reported to be the limit of tolerance for euryhalinic marine fauna (Carpelan, 1957). Therefore, comparing the physical characteristics of the West Hackberry site with those at Bryan Mound, it is unlikely that the maximum salinity at West Hackberry will be much different from the maximum at Bryan Mound. Further, since the efficiency of brine dispersion at West Hackberry should be comparable to that at Bryan Mound, it is valid to extrapolate modeling capability from Bryan Mound to West Hackberry.

In the Texoma Group FEIS (DOE, 1978), the brine disposal assessment for West Hackberry was based on runs of the Transient Plume Model using SAI current meter data from the site of typical currents and passage of a storm front:

FEIS RUN	TIME PERIOD COVERED	CONDITION
WH-3	1200, 1/3/78 to 0000, 1/6/78	"typical" currents (.3 ft/sec)
WH-4	0000, 1/25/78 to 0000, 1/27/78	storm passage currents (.6 ft/sec)

For this analysis, the same current meter record was used, the discharge rate was increased from 1.0 MMB per day to 1.1 MMB per day, and the vertical turbulent diffusion coefficient was reduced by an order of magnitude (see Section 3.3.1).

Figures 4-1 and 4-2 compare the areal coverage for various salinity excesses in the FEIS with the present analysis. Contours of 0.1 and 0.5 ppt are not included in this analysis because the daily natural variability of ambient bottom salinity at the West Hackberry diffuser site is as much as 1 ppt. As a result of the revised model inputs, the acreage for excess salinity of 1 ppt or greater increased from 1860 to 6600 acres while the 3 ppt or greater area increased from 207 to 1500 acres. Worst case downstream advection distances

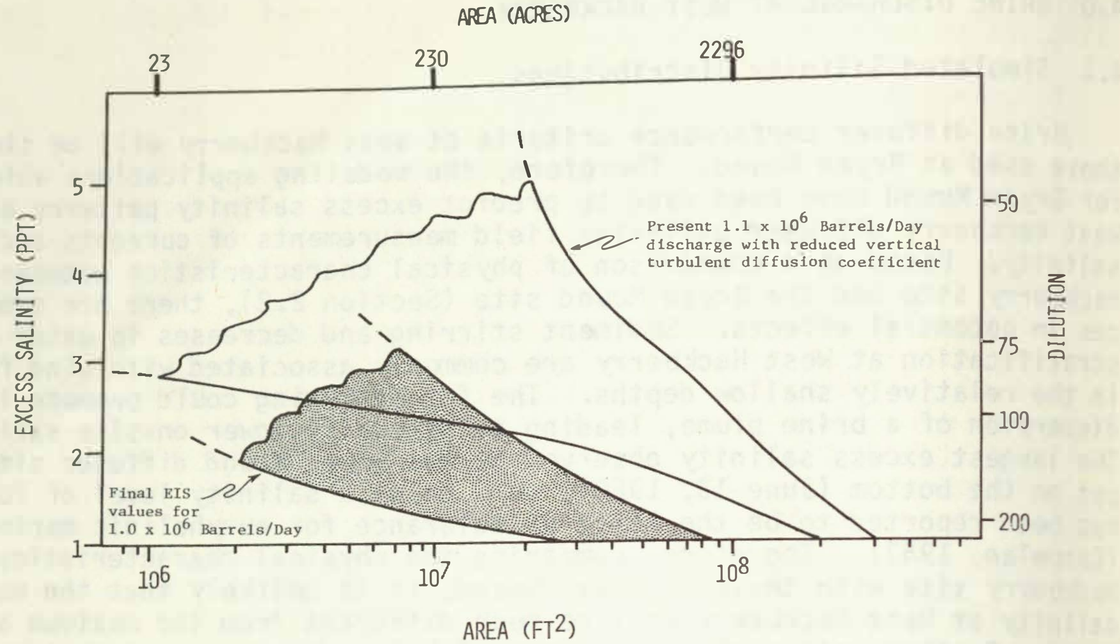

Figure 4-1. Comparison of excess salinity versus impacted bottom area as predicted by the MIT model for the West Hackberry diffuser site for typical current conditions (January 3-5, 1978). Stippled plot is for a vertical diffusion coefficient of 0.001 ft^2/sec. Open plot is for a reduced vertical diffusion coefficient of 0.0001 ft^2/sec.

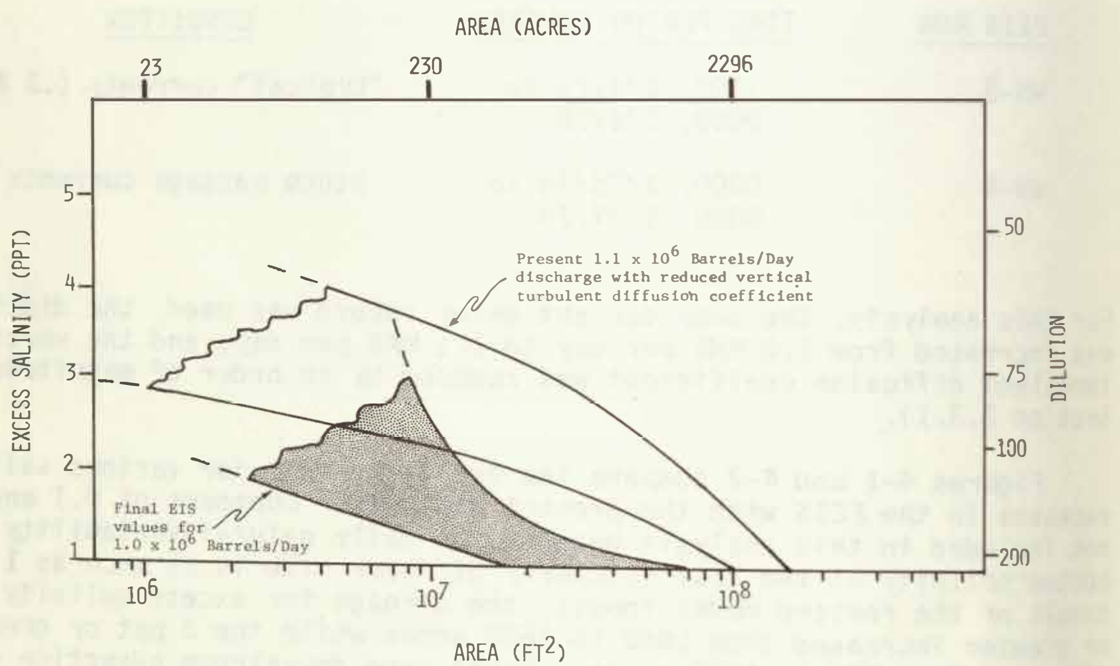

Figure 4-2. Comparison of excess salinity versus impacted bottom area as predicted by the MIT model for the West Hackberry diffuser site for storm passage event (January 25-27, 1978). Stippled plot is for a vertical diffusion coefficient of 0.001 ft^2/sec. Open plot is for a reduced vertical diffusion coefficient of 0.0001 ft^2/sec.

associated with these area estimates and plume model changes are shown as estimates of salinity levels directed toward Calcasieu Pass (Fig. 4-3).

To assess possible brine discharge effects on salinity levels at the entrance to Calcasieu Pass, a series of steady state solutions of the MIT Transient Plume Model were developed using constant magnitude bottom currents. Bottom currents of varying magnitude (5 cm/sec to 100 cm/sec) were held fixed for the entire 310 hour calculation period with brine discharge at 1.1 MMB per day and discharge salinity of 230 ppt.

Distances (directed toward Calcasieu Pass) to the 1, 2, and 3 ppt excess salinity contours were determined from various model runs over the range of assumed ambient current (Fig. 4-3). As expected the 2 and 3 ppt contours are limited to within 1 or 2nm of the diffuser while the 1 ppt contour extends to greater distances (7nm) from the diffuser. The MIT model has been found to be conservative for this region of the far-field (see Section 3.3), tending to overestimate the maximum distances to the 1, 2, and 3 ppt excess salinity contours.

The time necessary for the 1 ppt excess salinity contour to reach its steady state maximum distance from the diffuser is approximately equal to the travel time required for water to traverse that steady state maximum distance at the specified bottom current velocity. Thus, approximately 36 hours of 10 cm/sec bottom current is required to arrive at the steady state solution while 14 hours is necessary for a 25 cm/sec bottom current.

Bottom current meter data collected by SAI at the West Hackberry Replacement site over the period of December 1977 through October 1978 (approximately 7700 hours of recorded, validated data) were scanned for all possible events which could lead to transport of brine directly from the diffuser site to Calcasieu Pass. A frequency histogram (Fig. 4-4) was constructed to show the frequency of current direction in the range 035° to 055° (the direction toward Calcasieu Pass). Current speeds were examined for all transporting events of 5 hours duration or greater. A maximum advection potential existed during a 6 hour period with an average current magnitude of 25 cm/sec. Therefore, it can be concluded from this 11 month baseline data and results of diffusion modeling that brine in excess of 1 ppt above ambient, transported directly from the diffuser, will probably never reach Calcasieu Pass.

4.2 Site Biology

Comparison of the biological communities at Bryan Mound and West Hackberry (Section 2.4) indicates a lower biological species diversity at all trophic levels existing at West Hackberry. While species at the site are typically euryhaline, lower species diversity may be related to existing environmental stress. The presence of elevated salinities associated with brine discharge may produce added stress on the existing biocommunity but effects of the stress cannot be specified at this time. However, euryhalinic organisms are, in general, tolerant of elevated salinities as well as lowered salinities.

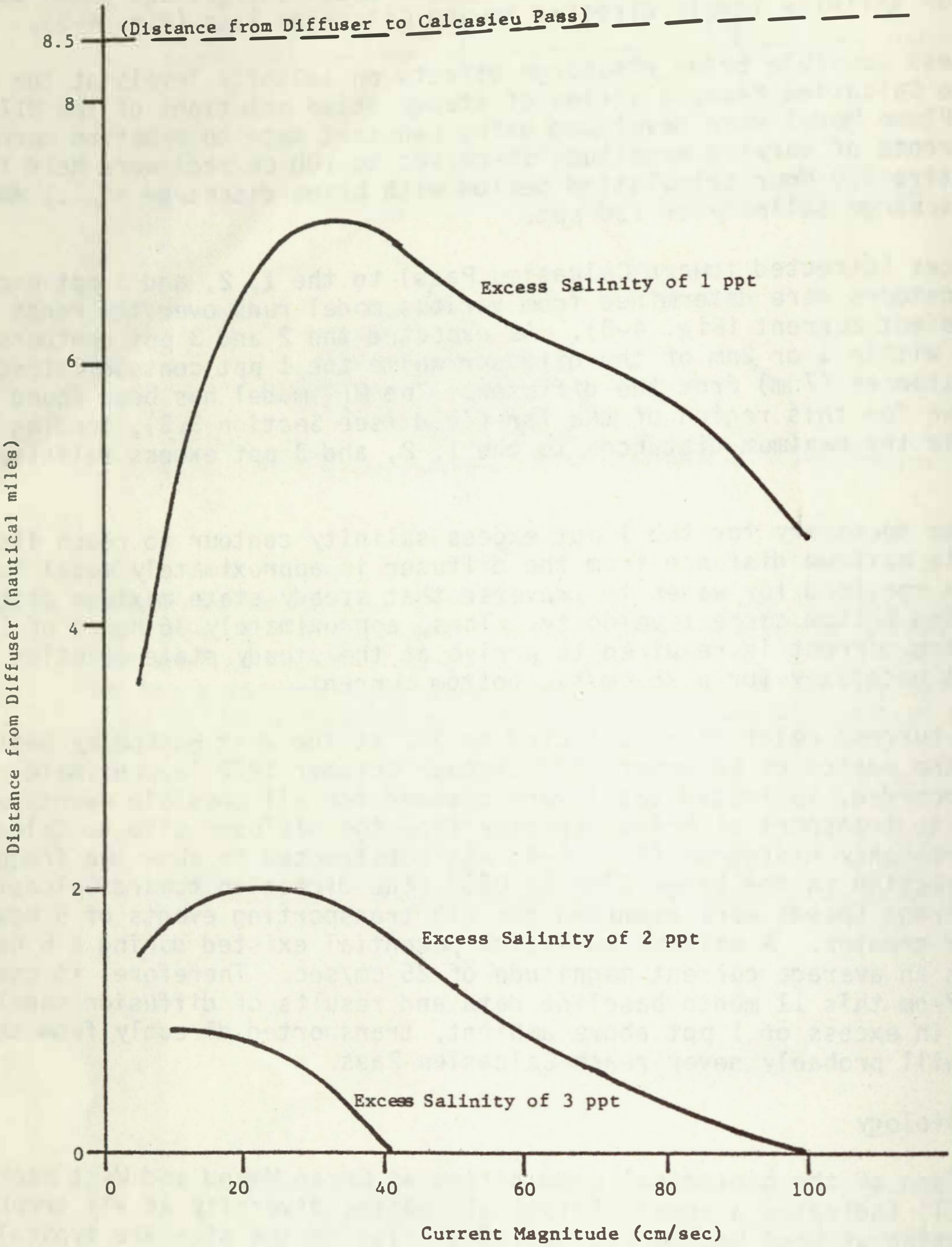

Figure 4-3. Steady state (constant current magnitude and direction) MIT model predictions of maximum radial distance from the center of the diffuser to the specified excess salinity contour.

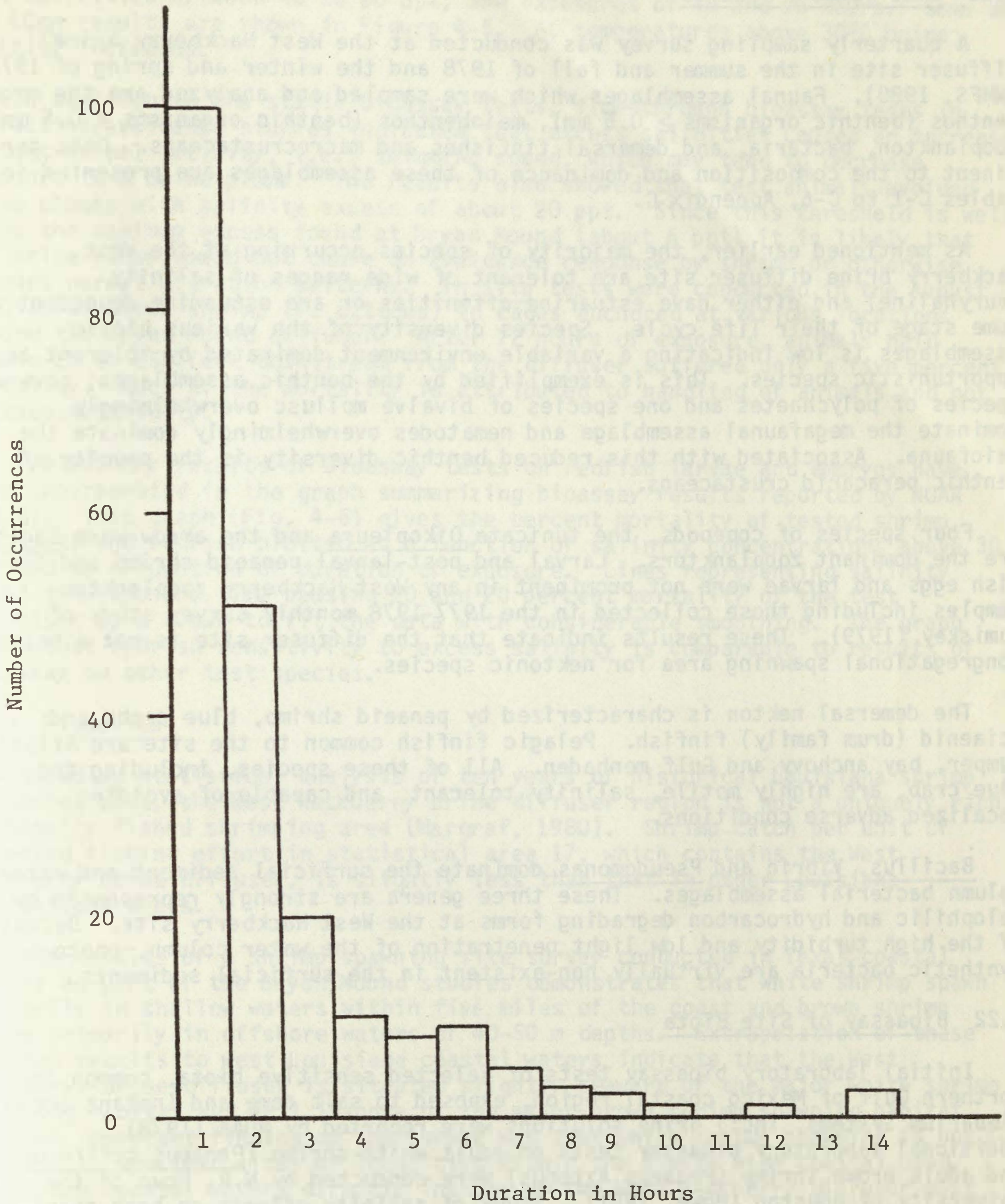

Figure 4-4. Frequency histogram of currents heading towards Calcasieu Pass (heading 35-55^{o}) using SAI replacement currents for West Hackberry. Based on 7700 hours of continuous current record for the period of December 1977 - October 1978.

4.21 Site Summary Results

A quarterly sampling survey was conducted at the West Hackberry brine diffuser site in the summer and fall of 1978 and the winter and spring of 1979 (NMFS, 1980). Faunal assemblages which were sampled and analyzed are the megabenthos (benthic organisms ≥ 0.5 mm), meiobenthos (benthic organisms < 0.5 mm), zooplankton, bacteria, and demersal finfishes and macrocrustaceans. Data pertinent to the composition and dominance of these assemblages are presented in Tables C-1 to C-6, Appendix C.

As mentioned earlier, the majority of species occurring at the West Hackberry brine diffuser site are tolerant of wide ranges of salinity (euryhaline) and either have estuarine affinities or are estuarine dependent at some stage of their life cycle. Species diversity of the various biotic assemblages is low indicating a variable environment dominated by tolerant and opportunistic species. This is exemplified by the benthic assemblages; several species of polychaetes and one species of bivalve mollusc overwhelmingly dominate the megafaunal assemblage and nematodes overwhelmingly dominate the meiofauna. Associated with this reduced benthic diversity is the paucity of benthic peracarid crustaceans.

Four species of copepods, the tunicate *Oikopleura* and the arrow-worm *Sagitta* are the dominant zooplanktors. Larval and post-larval penaeid shrimp and finfish eggs and larvae were not prominent in any West Hackberry zooplankton samples including those collected in the 1977-1978 monthly survey study of Comiskey (1979). These results indicate that the diffuser site is not a major congregational spawning area for nektonic species.

The demersal nekton is characterized by penaeid shrimp, blue crabs and sciaenid (drum family) finfish. Pelagic finfish common to the site are Atlantic bumper, bay anchovy and Gulf menhaden. All of these species, including the blue crab, are highly motile, salinity tolerant, and capable of avoiding localized adverse conditions.

Bacillus, *Vibrio* and *Pseudomonas* dominate the surficial sediment and water column bacterial assemblages. These three genera are strongly represented by halophilic and hydrocarbon degrading forms at the West Hackberry site. Because of the high turbidity and low light penetration of the water column, photosynthetic bacteria are virtually non-existent in the surficial sediments.

4.22 Bioassay of Site Biota

Initial laboratory bioassay tests of selected sensitive biota, common to the northern Gulf of Mexico coastal region, exposed to salt dome and Instant Ocean (Aquarium Systems, Inc.) brine solutions were reported by NOAA (1978). Additional laboratory bioassay tests on adult white shrimp (*Penaeus setiferus*) and adult brown shrimp (*Penaeus aztecus*) were conducted by N.R. Howe of the University of Houston (Howe, 1981). Study of salinity effects on both species (Venkataramiah et al., 1974) indicate that tolerance to extremes of salinity may decrease with increasing size up to 75 mm. In his tests, Howe used animals measuring 6-11 cm in abdomen length, test temperatures between 15°C and 31°C, test salinities between 40 to 50 ppt, and exposures of 48 and 96 hours. Some of the LC_{50} results are shown in Figure 4-5. At temperatures above 30°C brine toxicity increases.

In addition to the static bioassay tests, flow-through bioassay tests in attraction/avoidance studies indicated that excess salinities caused an increase in test animal activity, i.e., swimming speed, which may tend to decrease exposure to a brine plume. The results also showed that test animals avoided brine plumes with salinity excess of about 20 ppt. Since this threshold is well above the maximum excess found at Bryan Mound (about 6 ppt) it is likely that the brine plume would not cause an avoidance response by shrimp or otherwise disrupt normal migration patterns. In situ tests were conducted in the August of 1980 on brown shrimp (P. aztecus) in cages anchored at various locations around the Bryan Mound diffuser. After 72 hours of exposure, animals held within 25 to 250 feet downstream from the diffuser suffered only a five percent mortality. Much of the mortality is attributed to handling of animals and not to excess salinity.

Preliminary results of bioassay tests on redfish larvae and embryos have been incorporated in the graph summarizing bioassay results reported by NOAA (1978). This graph (Fig. 4-6) gives the percent mortality of tested shrimp, seatrout, and redfish plotted as a function of salinity concentrations above 30 ppt and as a function of duration of exposure. Lines representing salinity level and exposure time causing 10 and 20 percent mortality of the test organisms were drawn to fit the data with considerable smoothing. The graph shows that redfish sensitivity to excess salinity is comparable to results of bioassay on other test species.

4.23 Fisheries

Based on statistical analysis of ten years of historical Louisiana shrimp fisheries data, the West Hackberry brine diffuser region is not a uniquely rich or heavily fished shrimping area (Margraf, 1980). Shrimp catch per unit of directed fishing effort in statistical area 17, which contains the West Hackberry brine diffuser, is slightly less than that in other Louisiana statistical areas.

The results of a shrimp spawning site survey conducted in Texas coastal waters as part of the Bryan Mound studies demonstrates that white shrimp spawn primarily in shallow waters within five miles of the coast and brown shrimp spawn primarily in offshore waters of 40-50 m depths. Extrapolation of these limited results to west Louisiana coastal waters indicate that the West Hackberry brine diffuser is situated slightly seaward of the major white shrimp spawning habitat and well inshore of the major brown shrimp spawning habitat. Another important finding of the survey was that white shrimp spawning is not limited to specific sites or localities within the 5 mile wide coastal band. Thus, the coastal waters directly inshore of the West Hackberry diffuser most likely are not uniquely productive in terms of shrimp recruitment to the adult populations; spawning should be dispersed along the west Louisiana coast with no site-specific congregation of spawning adults.

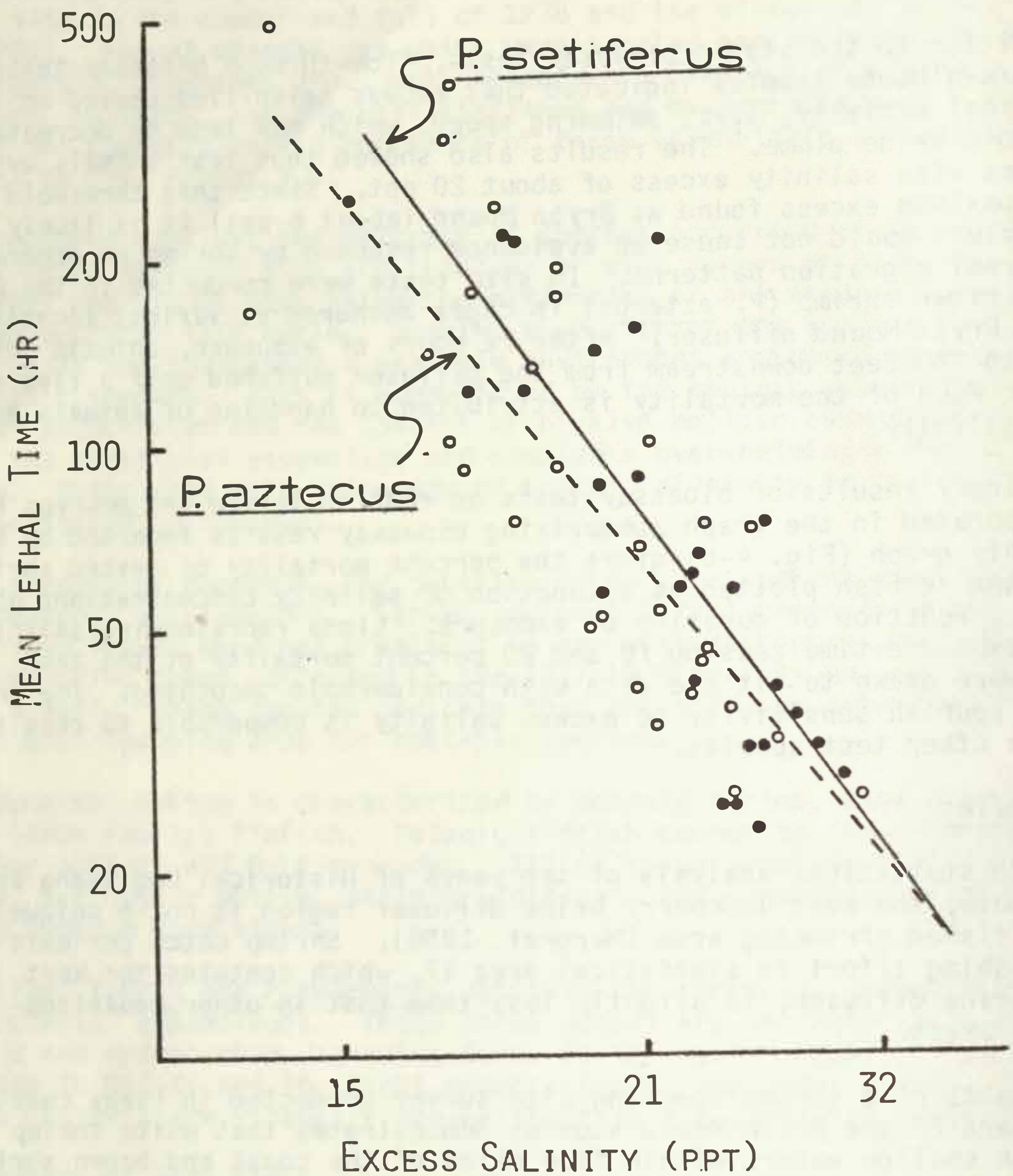

Figure 4-5. Median lethal time (LC50) as a function of excess salinity for P. setiferus (closed circles) and P. aztecus (open corcles) with least squares regression lines for each species. Both axes are logrithmic. (After Howe, 1981).

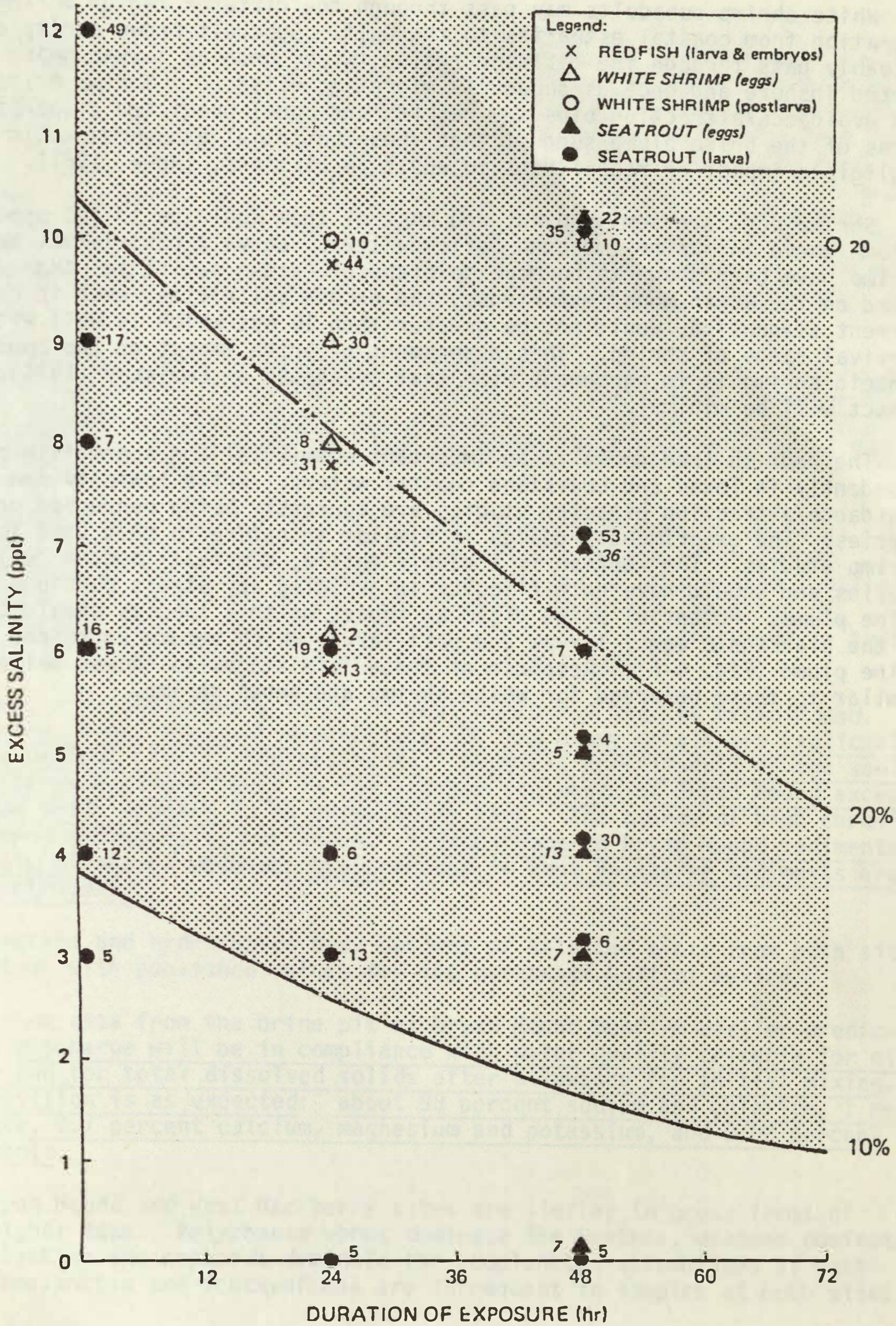

Figure 4-6. Mortality from hypersaline exposure in laboratory tests. Mortality expressed as percent of total number of tested specimens.

White shrimp subadults may pass through the diffuser region during their migration from coastal estuaries to the Gulf. Subadult brown shrimp could conceivably pass through the diffuser region twice, once as larvae being transported inshore and once as subadults migrating offshore. Shrimp brine toxicity and avoidance/attraction bioassay results and model predicted dispersion patterns of the brine plume suggest that these potential exposures would have negligible impact on recruitment to adult populations. (Howe, 1981).

Shrimp eggs are semi-buoyant and most of them would be in the upper water column above the brine-impacted bottom waters. Larval, post-larval and juvenile shrimp have been shown to be more tolerant of excess salinities than are adults. Based on the Bryan Mound experience, the excess salinities, even in cases of current stagnation, would not be greater than 10 ppt which is well within the survival range of shrimp. This assessment of brine impact on the commercial penaeid shrimp is in agreement with that presented by Comiskey (1979); brine impact will be minimal.

The redfish (red drum) is an important commercial and sport fish occurring abundantly in Texas and Louisiana coastal waters. Brine toxicity and avoidance/attraction bioassay studies are currently being conducted on this species. The experimental design is similar in nature to that used for the shrimp studies. The redfish is a highly motile, demersal (bottom dwelling) species and should have no difficulty in avoiding any stress portions of the brine plume. Potential brine disposal impact on this species should be limited to the planktonic eggs, larvae and post-larvae which become entrained in the brine plume (Fig. 4-6). Response of these life stages to excess brine should be similar to those observed for white shrimp and brown shrimp.

5.0 SUMMARY AND CONCLUSIONS

The regions of the Bryan Mound and West Hackberry brine discharge sites are under the influence of local river runoff and, most significantly, the discharge from the Mississippi and Atchafalaya Rivers. Stratified hydrographic regimes at West Hackberry can occur to a limited extent during winter resulting from local runoff and to a greater extent during summer as a result of weak wind forced circulation. Given similar meteorological conditions at both sites, the water column at West Hackberry is more likely to mix due to the shallower depth. Therefore, although stratification of the water column is common at both sites, duration of a stable regime is likely to be shorter at West Hackberry. Anoxic conditions may attend stratification creating biotic stress of consequence at either site.

Generally, a westward, along shore current prevails at both sites throughout the year with the degree of variability depending on the season. Similarity of physical disposal operations and the potential for similar physical dispersion permits extrapolation of brine plume modeling experience from Bryan Mound to the West Hackberry site.

Water and sediment quality at both sites reflects dependence on local riverine runoff, particularly with regard to nitrate in the water column. Differences between the sites are essentially related to physiographic differences in depth, distance from shore, and climate. With the exception of discrete discharge events related to normal rainfall in winter and early spring, neither site is especially fertile based on nutrient data.

Sediments are consistently finer at West Hackberry than at Bryan Mound. At West Hackberry, high levels of sedimentary TOC and heavy metals are explicable in terms of percent clay in the sediments. Chemical constituents of the sediments are correspondingly lower in the coarser sediments of Bryan Mound except for chromium which appears to be anomolously high. The source of high chromium in Bryan Mound sediments is not known. Hydrocarbons in Bryan Mound sediments are primarily biogenic: whereas, hydrocarbons in West Hackberry sediments are primarily petrogenic.

Heavy metals and hydrocarbon body burdens of selected biota from both sites are consistent with published values for the northwest Gulf of Mexico.

Monitoring data from the brine pit at Bryan Mound confirm earlier predictions that discharge will be in compliance with water quality criteria for oil and grease and for total dissolved solids after allowance for initial mixing. Brine composition is as expected: about 98 percent sodium and chloride, 1 percent suflate, 0.7 percent calcium, magnesium and potassium, and 0.02 percent trace elements.

The Bryan Mound and West Hackberry sites are similar in gross terms of dominant higher taxa. Polychaete worms dominate the benthos, diatoms dominate the phytoplankton and copepods dominate the zooplankton assemblages at both sites. Meroplankton and ichthyofauna are infrequent in samples at both sites.

The consistent paucity of peracarid crustaceans at West Hackberry is indicative of a highly variable and stressful environment relative to Bryan Mound. Species-specific differences between the sites reflect the shallow, sandy-mud bottomed inshore environment at West Hackberry versus the deeper, muddy-sand bottomed offshore environment of Bryan Mound.

The Bryan Mound site is in a region of ecological transition between the shallow water, white shrimp community and the deep water, brown shrimp community; whereas, the West Hackberry site is wholly within the white shrimp community.

Densities of organisms, species diversity and species richness are low at West Hackberry in comparison to Bryan Mound. This is partially attributable to the greater environmental variability and stress occurring at the West Hackberry site. Again, the postulated environmental stress at the West Hackberry site is further substantiated by the paucity of peracarid crustaceans and the preponderance of eurytolerant species. It is quite conceivable that the eurytolerant species will be minimally impacted by virtue of their adaptability to the wide range of environmental conditions occurring at the West Hackberry site.

Comparison of MIT Transient Plume Model hindcasts with field observations of the Bryan Mound brine plume led to an order of magnitude reduction in the vertical diffusion coefficient. The model still overestimates the area covered by the 1 and 2 ppt excess salinities and underestimates the area covered by excess salinities greater than 4 ppt near the diffuser. Model imprecision is attributed to: poor representation of diffusion processes in the near and intermediate-fields of diffusion; difficulty in specification of ambient salinity; and the inability to obtain current measurement less than 6 ft from the bottom. Monitoring at Bryan Mound proved that the maximum salinity increase in the diffuser area, 6 ppt, was well below the tolerance limits for euryhalinic marine fauna.

Model application at West Hackberry, using the reduced vertical diffusion coefficient, a brine discharge of 1100 MBD, and field measurements of current and salinity, showed that areas of excess salinity of 1 ppt or more may be on the order of 5 times larger than previously predicted. The revised model is now more realistic in predicting excess salinities of 3 to 4 ppt near the diffuser. It is concluded, however, that the brine plume will probably never reach Calcasieu Pass.

Recently conducted bioassay tests of brine toxicity on white and brown shrimp indicated that LC_{50} exposure conditions are well beyond the eularian and lagrangian conditions experienced by modeling and monitoring at Bryan Mound.

Avoidance studies of shrimp indicated that the excess salinity detection threshold was 20 ppt. The maximum excess (6 ppt) observed at Bryan Mound site indicates that the brine discharge plumes produce no barrier to shrimp migration. Preliminary bioassay toxicity test results on redfish larvae and embryos are similar to those reported for other ichthyofauna common to the northwest Gulf of Mexico.

IN CONCLUSION:

(1) It is expected that the brine plume will cover a bottom area greater than previously predicted;

(2) brine concentrations near the diffuser will be higher than previously predicted;

(3) the threshold of observed biological effects from elevated salinity has been shown to be higher than worst case discharge conditions; and

(4) brine disposal will have minimal, if any, impact on the biota.

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APPENDIX A

GUIDE TO VALIDATED ARCHIVED DATA AT EDIS

Appendix A - Guide to Validated Archived Data at EDIS

Bryan Mound - Texas A&M University (TAMU)

Over-the-side Observations	Salinity, Temperature, Current Speed and Direction.
Rutherford Site A (RA)	Current Speed and Direction at 2 depths commencing 12/23/77, at 3 depths commencing 5/15/79.
Site B (RB)	Current Speed and Direction at 3 depths commencing 5/15/79.
Site C (RC)	Current Speed and Direction at 3 depths commencing 9/10/79.
Nekton	Species, counts/unit length in whole mm.
Benthic	Species, counts/young and adult. Bottom Salinity and Temp as available.
Water Quality	Temp, Salinity, pH, Total Suspended Matter, Volatile Suspended Solids, Nitrate, Nitrite, Ammonia, SiO_2 $T\text{-}PO_4\text{-}P$ $O\text{-}PO_4\text{-}P$ Chlorophyll a Pheophytin a
Phytoplankton	Species, counts.
Zooplankton	Species, counts

Bryan Mound - NOAA Data Buoy Office (NDBO)

SADEMS/OPEMS (Rutherford Platform)	Wind Speed and Direction, Water Temp. (2 depths), Air Temp, Current Speed and Direction.
	Air Pressure and Bottom Salinity added 3/1/79.

(see Fig. A-1 for time distribution of archived data)

West Hackberry - Science Applications, Incorporated (SAI)

Currents	Current Speed and Direction.
Meiofauna	Species, counts.
Primary Productivity	Chlorophyll, Phaeopigment Concentration.
Geo-Sediments	% Sand, Silt, Clay, Organic Carbon, Calcium Carbonate.

West Hackberry - National Ocean Survey (NOS)

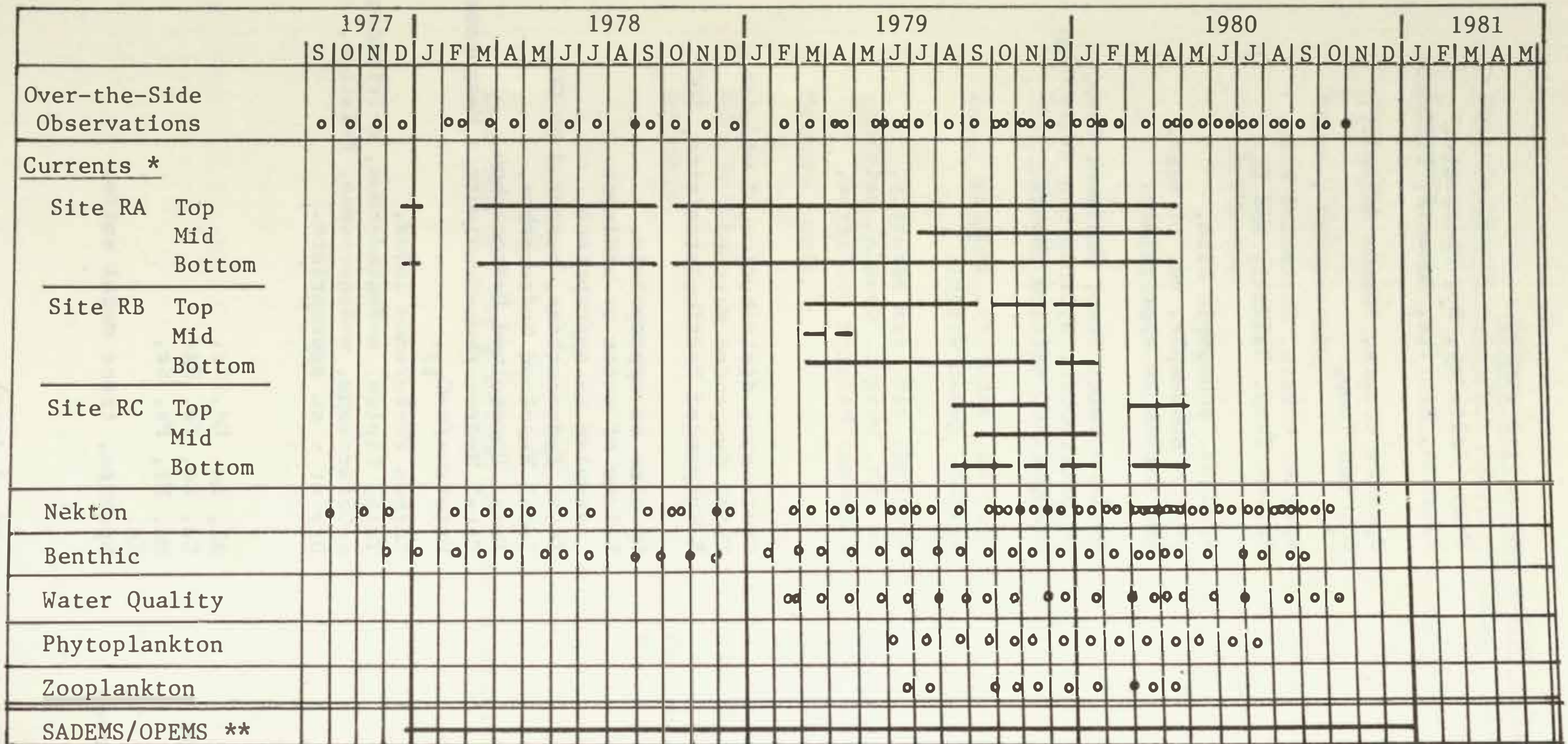
Water Chemistry	Salinity, Dissolved Oxygen, Surface Water Temp, Water Temp at depth.
Water levels	Total pressure.
Meteorological	Wind Speed and Direction, Air Temp and Pressure.
Wave Heights	Significant Wave Height.
Currents	Current Speed and Direction, Water Temp, and Salinity.

(See Fig. A-3 for time distribution of archived data)

West Hackberry - National Marine Fisheries Service (NMFS)

Chemistry/Inorganic Nutrients	Temp, Salinity, DO, Phosphate, Nitrate, Nitrite, Ammonia, Silicate.
Benthic fauna meio/	Species counts, Bottom Salinity, O_2, and Temp.
mega	Species counts, Corrected Mass, Bottom Temp, Salinity and O_2.
Zooplankton	Species, subsample size, no. in subsample, no. of eggs, and larvae as appropriate.
Bacteria	Surface Water Temp, Sediment Temp, Heterotrophic, Hydrocarbon degrading, Halophilic, Species counts.
Finfish	Species, maturity, length, weight, gonad weight.
Macro Crustacean	Species, sex, sex maturity, length, weight, Gonadal weight Patesma/Thelycum Condition.
Suspendeds and Sediments	
Sediments	Grain size distribution, % wt/size.
Suspendeds	Total Suspended Matter, % Suspended Particulates/size, TOC.
Hydrocarbons	Species as appropriate, Volume of water or sediment sampled as appropriate, Total Hydrocarbons, measured by GC, Total Resolved Hydrocarbon, Total Unresolved Hydrocarbon, Total Hydrocarbon-Gravimetric Measurement, Pristane/n-C_{17}, Carbon Preference Index, Total Lipids, n-Pentadecane, n-Tridecane, n-Octacosane, n-Nonacosane, Pristane, Dry wt - as appropriate.
Trace Metals	
Sediments Suspended Particulate Matter Total Suspended Matter and Sediment Totally Digested	Al, Ba, Cd, Cr, Cu, Co, Fe, Hg, Mn, Ni, Pb, Sr, Zn.
Epibenthic and Macrocrustacean	Species, trace metal suite.

(See Fig. A-4 for time distribution of archived data)



All of the above are being measured on a continuing basis in compliance with the DOE/EPA Monitoring Plan as part of the NPDES Permit for Bryan Mound.

* Currents have been measured on a continuous basis since April 1980. Data archival at EDIS has been delayed due to emphasis on biological data. However, time series data for Site RC have been provided on an as-needed basis to hind-cast plume tracking events for validation of the MIT transient plume model.

Observations by TEXAS A&M UNIVERSITY

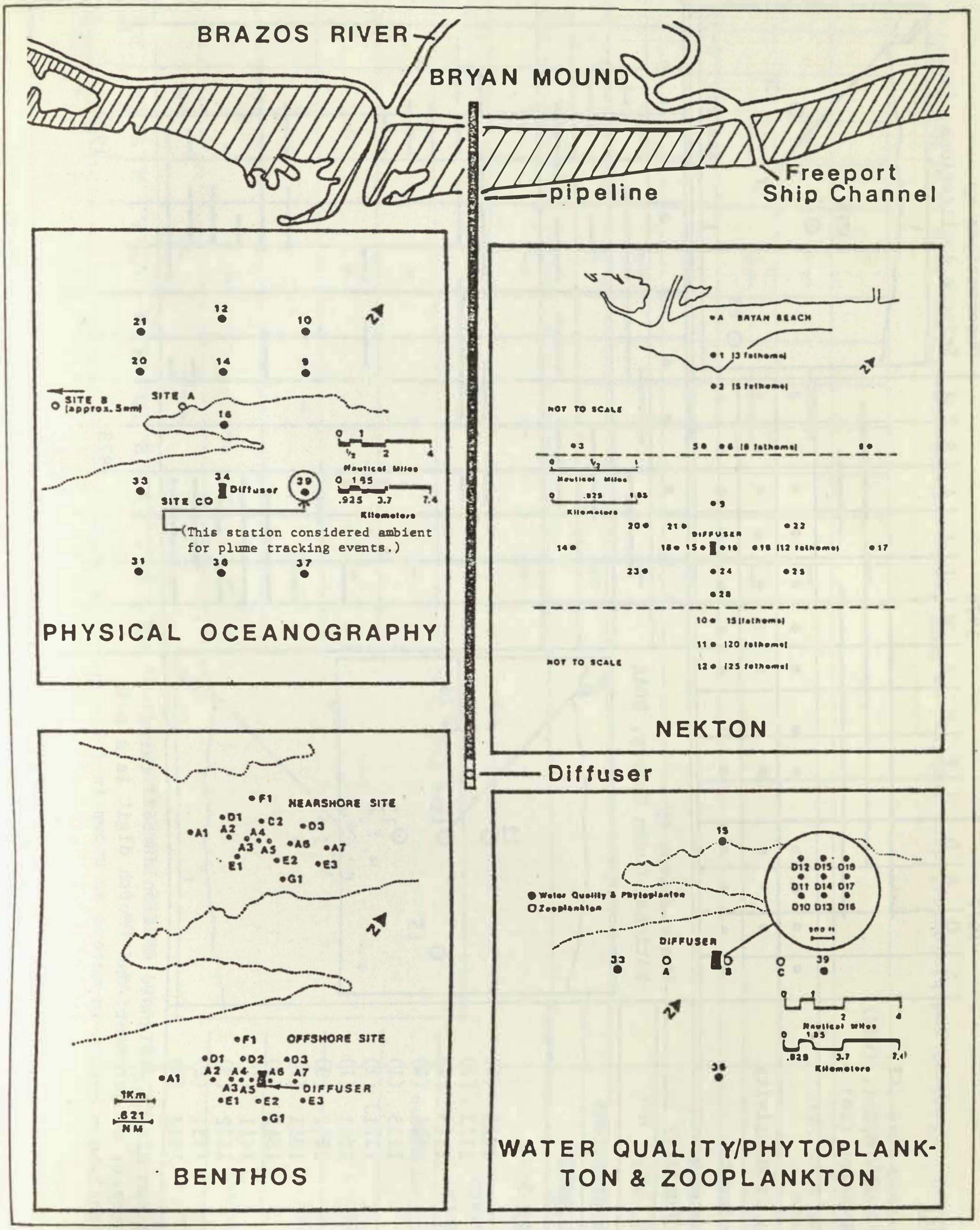
(See Fig. A-2 for station locations)

** Observations at Rutherford Platform (Site RA) by NOAA Data Buoy Office (NDBO)

Data Availability

All of the above data are available from the National Oceanographic Data Center, EDIS/NOAA - Washington, D.C. 20235. All data except for phytoplankton and zooplankton are available in the EPA Bio STORET/STORET System.

Figure A-1. Oceanographic data archived at EDIS from Bryan Mound diffuser site as of March 1981.



After Texas A&M

Figure A-2. Station Locations for Observations by Texas A&M University.

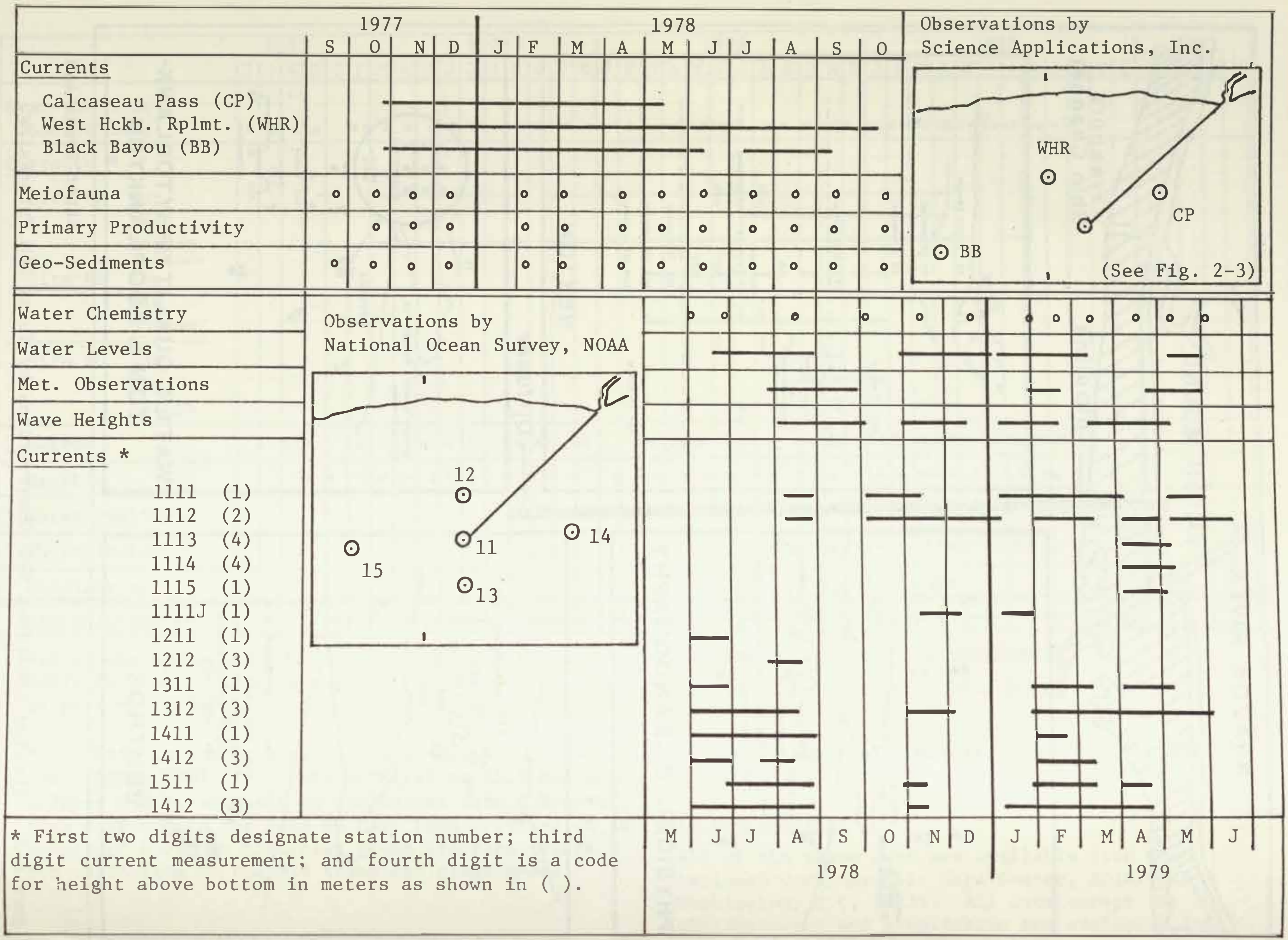


Figure A-3. Oceanographic data archived at EDIS for West Hackberry diffuser site as of March 1981.

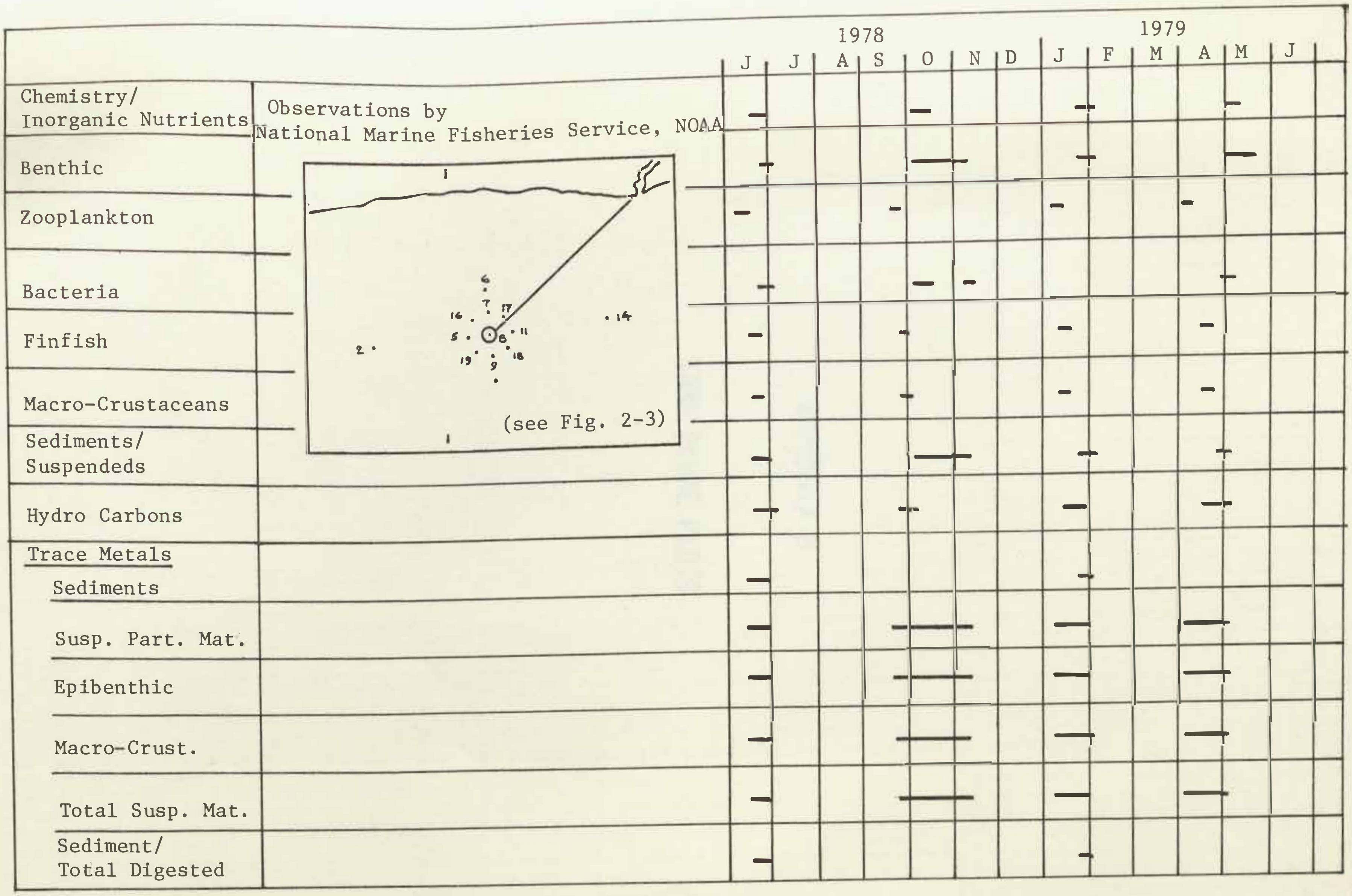


Figure A-4. Chemical and biological data archived at EDIS for West Hackberry diffuser site as of March 1981.

APPENDIX B

TAMU PLUME PLOTS

Table B-1. Brine discharge inputs to model hindcasts.

Event No.	Date (1980)	Snapshot Times	Brine Pit Salinity (ppt)	Ambient Salinity (ppt)	Brine Discharge Rate (MBD)	Model Inputs: Brine Discharge Rate (ft^3/sec)	Model Inputs: Excess Salinity Concentration (ppt)
1	3-30	1100-1700	228	32.7	215	14.0	195
2	3-31	1100-1600	228	32.8	215	14.0	195
3	4-10	1100-1700	245	33.3	340	22.1	212
4	5-22	1200-1600	245	32.7	292	19.0	212
5	6-13	1100-1600	247	32.4	273	17.8	215
6	7-21	1100-1700	147	36.0	443	28.8	111
7	7-30	1000-1500	131	35.8	523	34.0	95
8	8-1	1000-1600	129	35.5	658	42.8	94
9	8-2	1000-1800	163	35.5	612	39.8	128
10	8-26	1200-1800	216	34.4	633	41.4	182
11	9-10	1100-1700	218	33.7	511	33.2	184
12	10-1	1300-1800	228	34.1	489	31.8	194
13	10-22	1100-1800	205	32.3	672	43.7	173

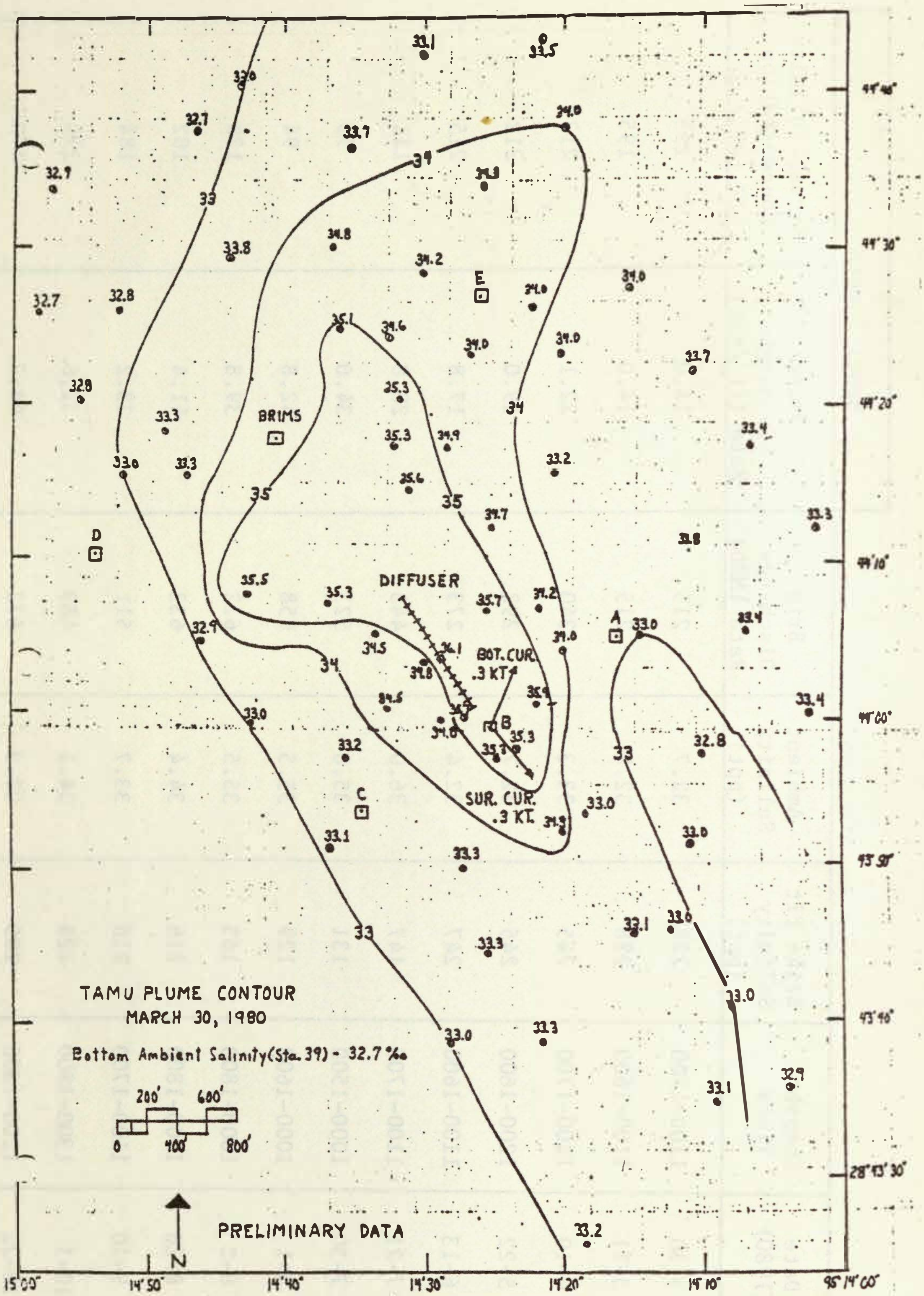


Figure B-1. TAMU plume contour of March 30, 1980.

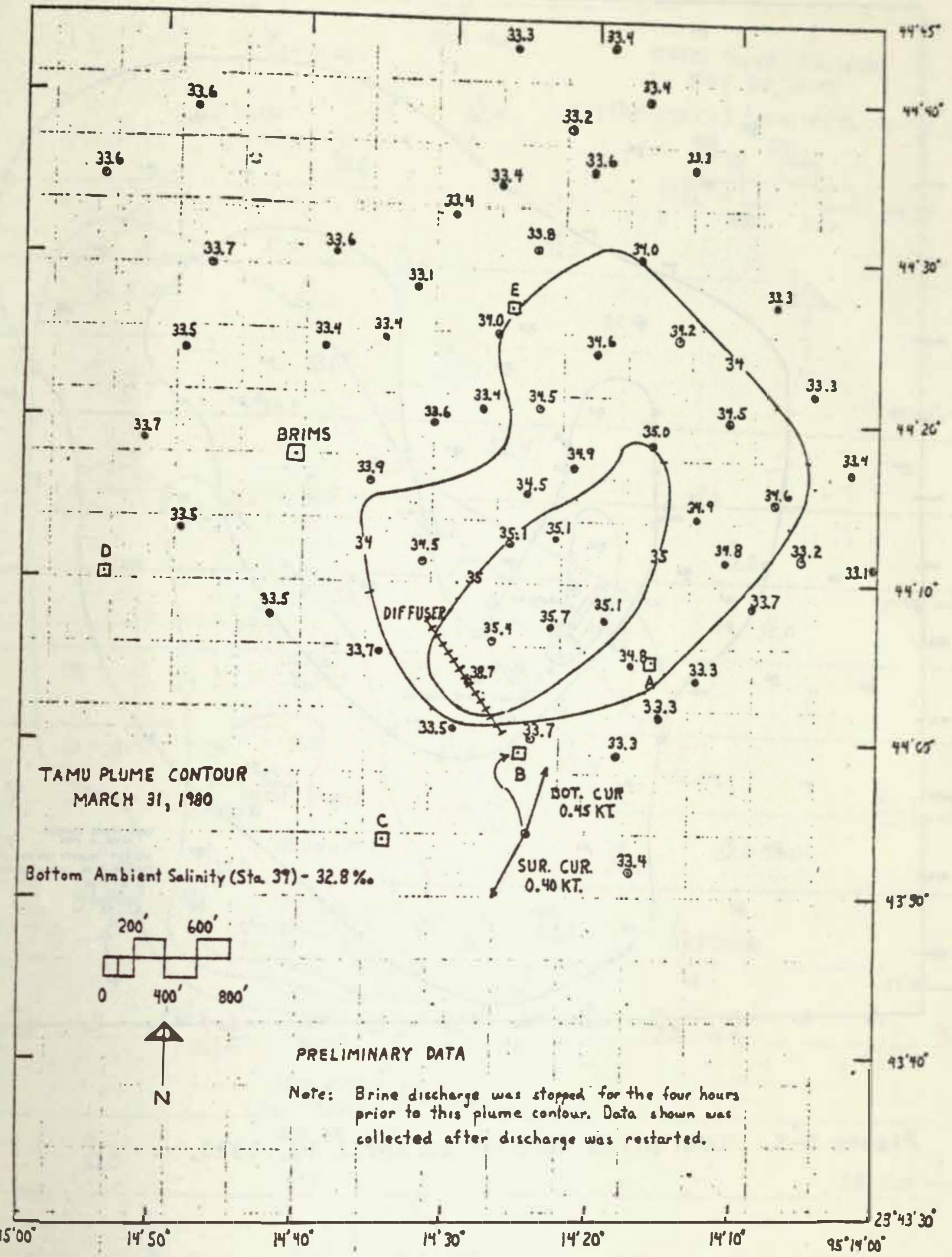


Figure B-2. TAMU plume contour of March 31, 1980.

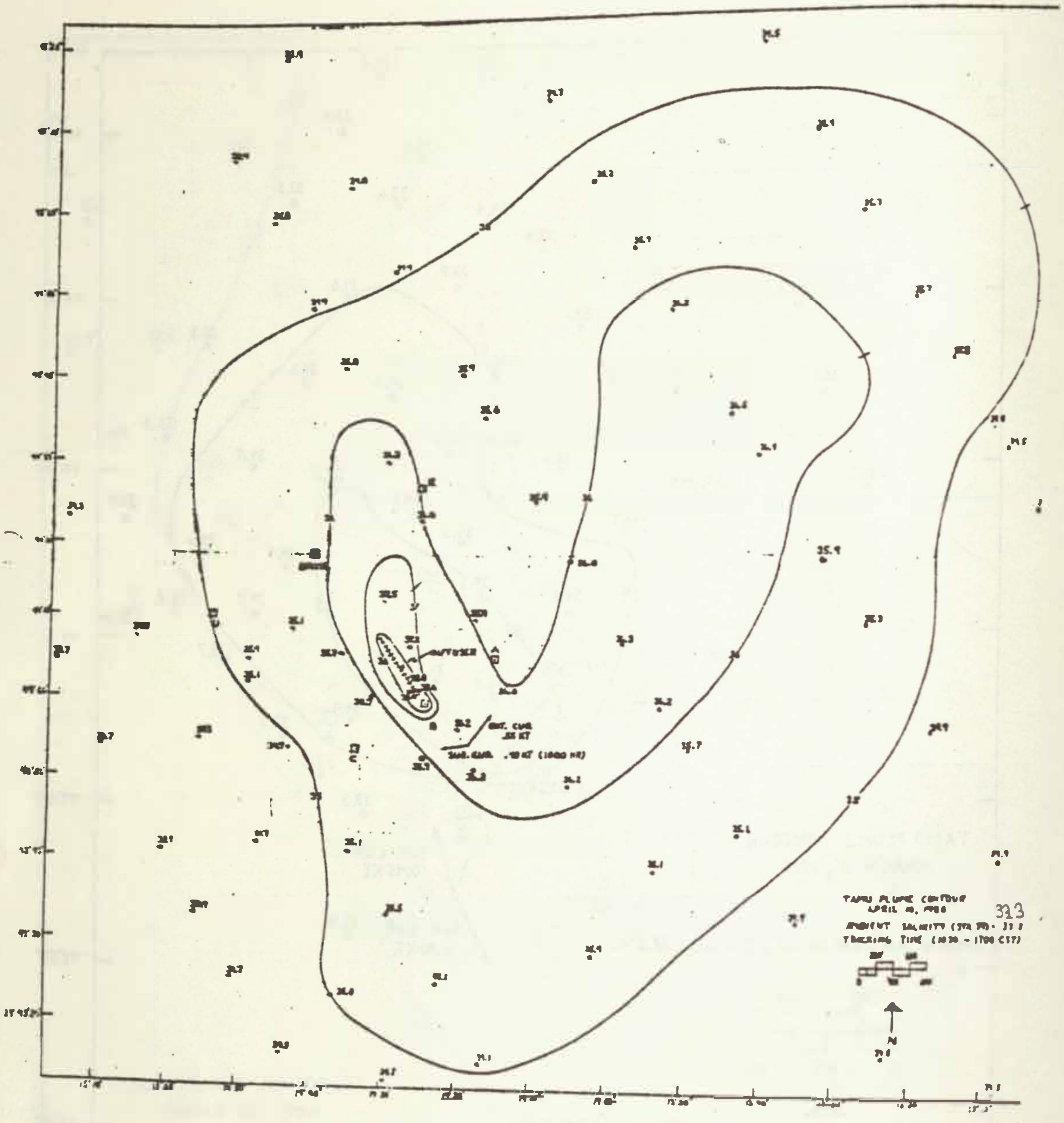


Figure B-3. TAMU plume contour of April 10, 1980.

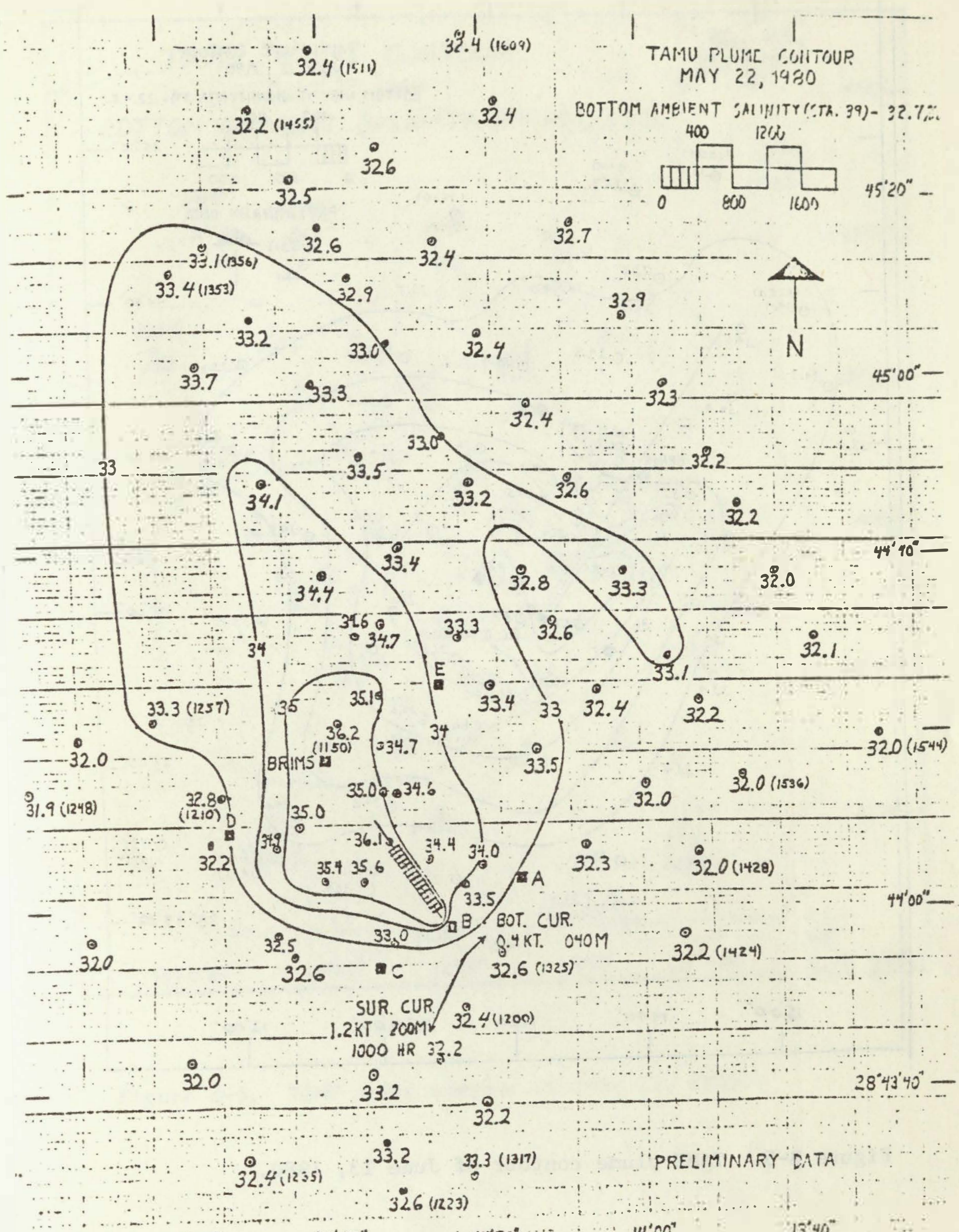


Figure B-4. TAMU plume contour of May 22, 1980.

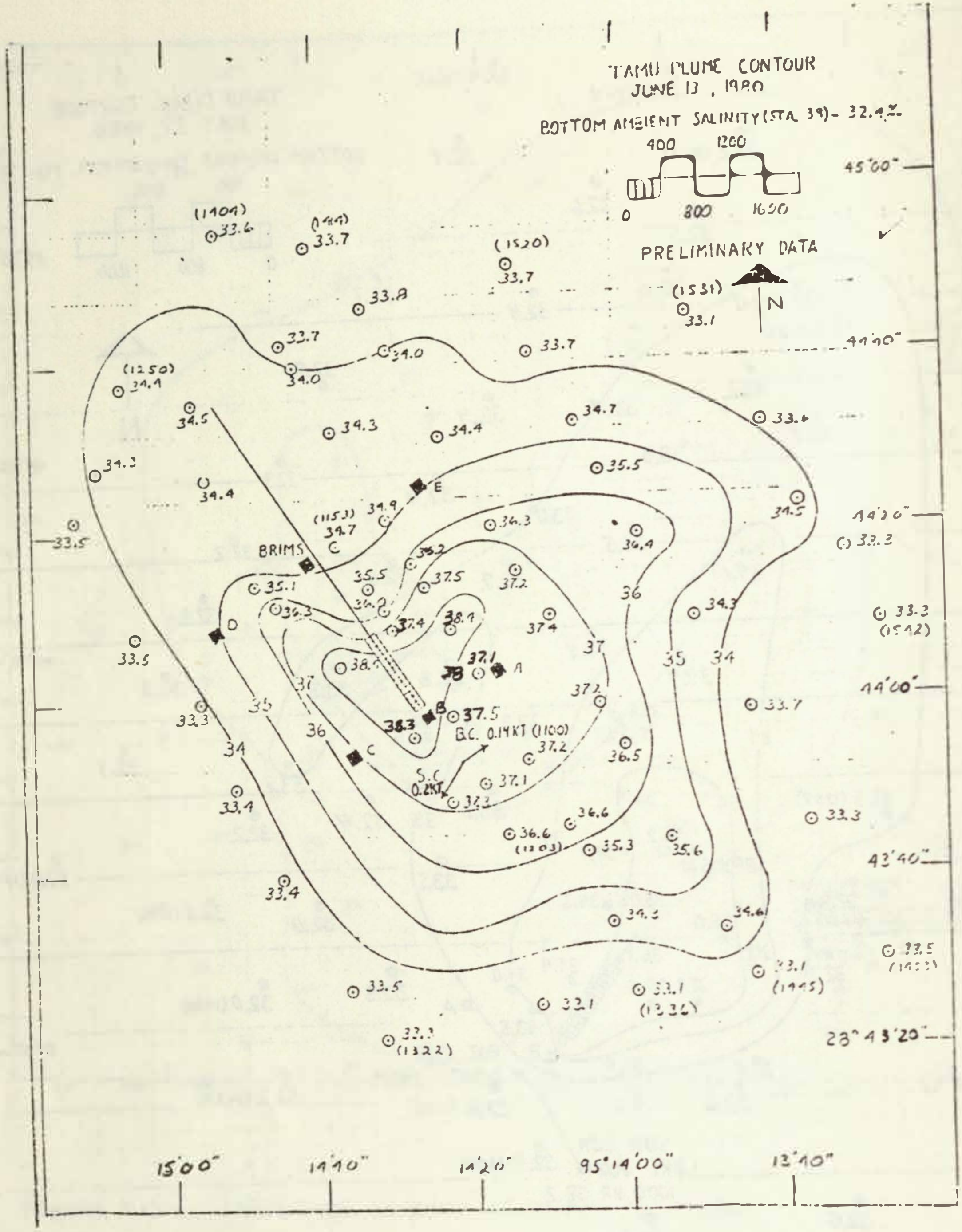


Figure B-5. TAMU plume contour of June 13, 1980.

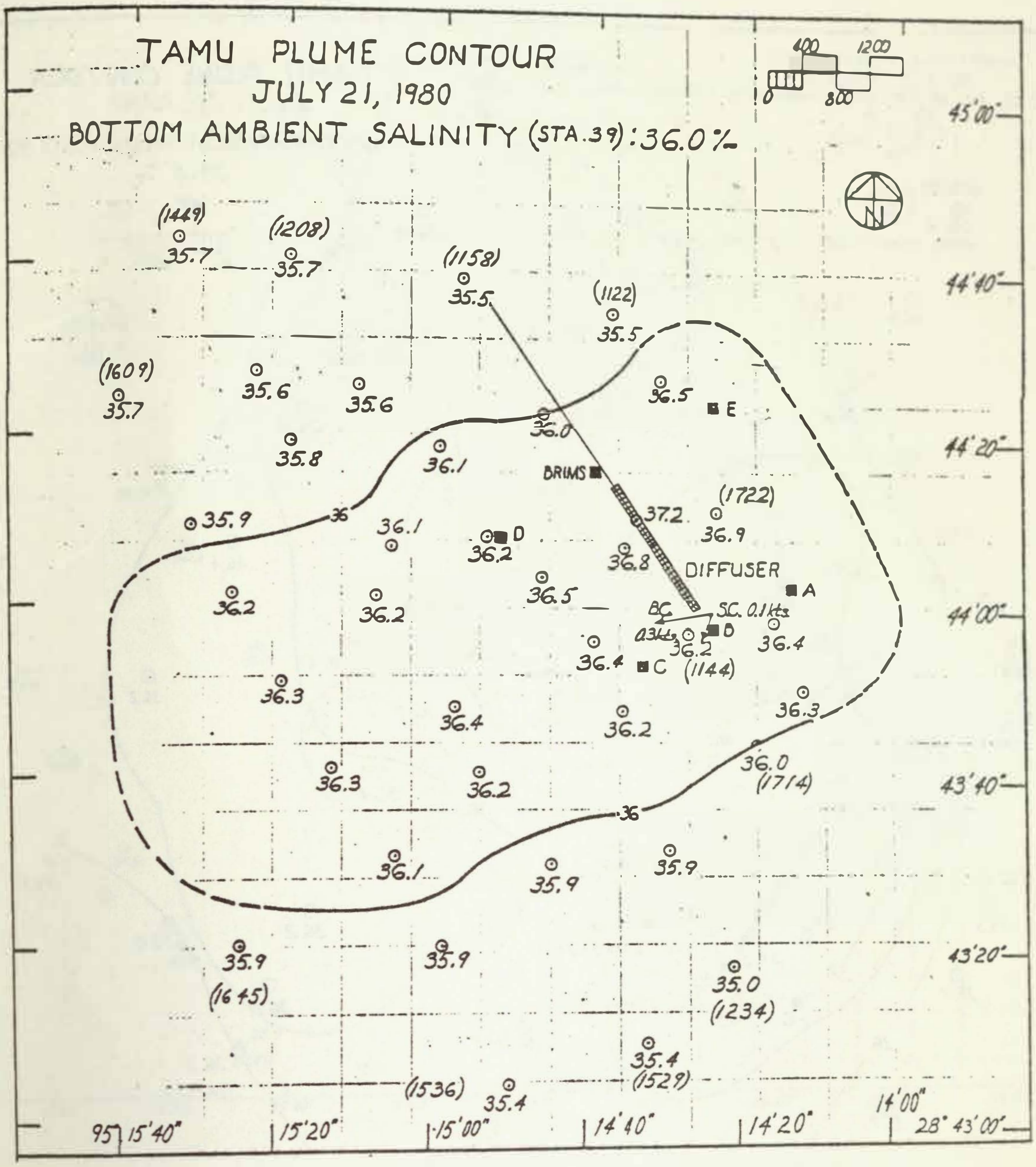


Figure B-6. TAMU plume contour of July 21, 1980.

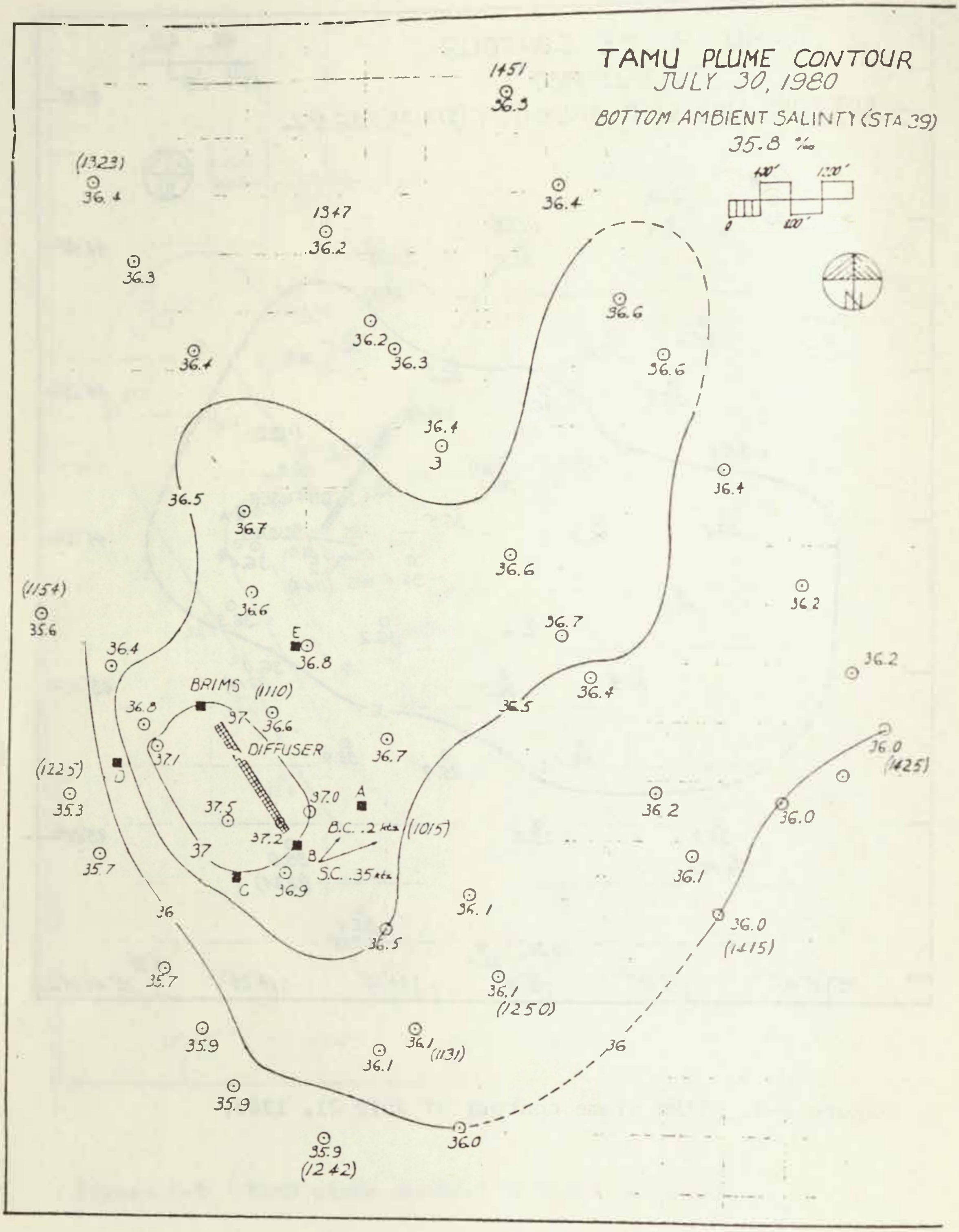


Figure B-7. TAMU plume contour of July 30, 1980.

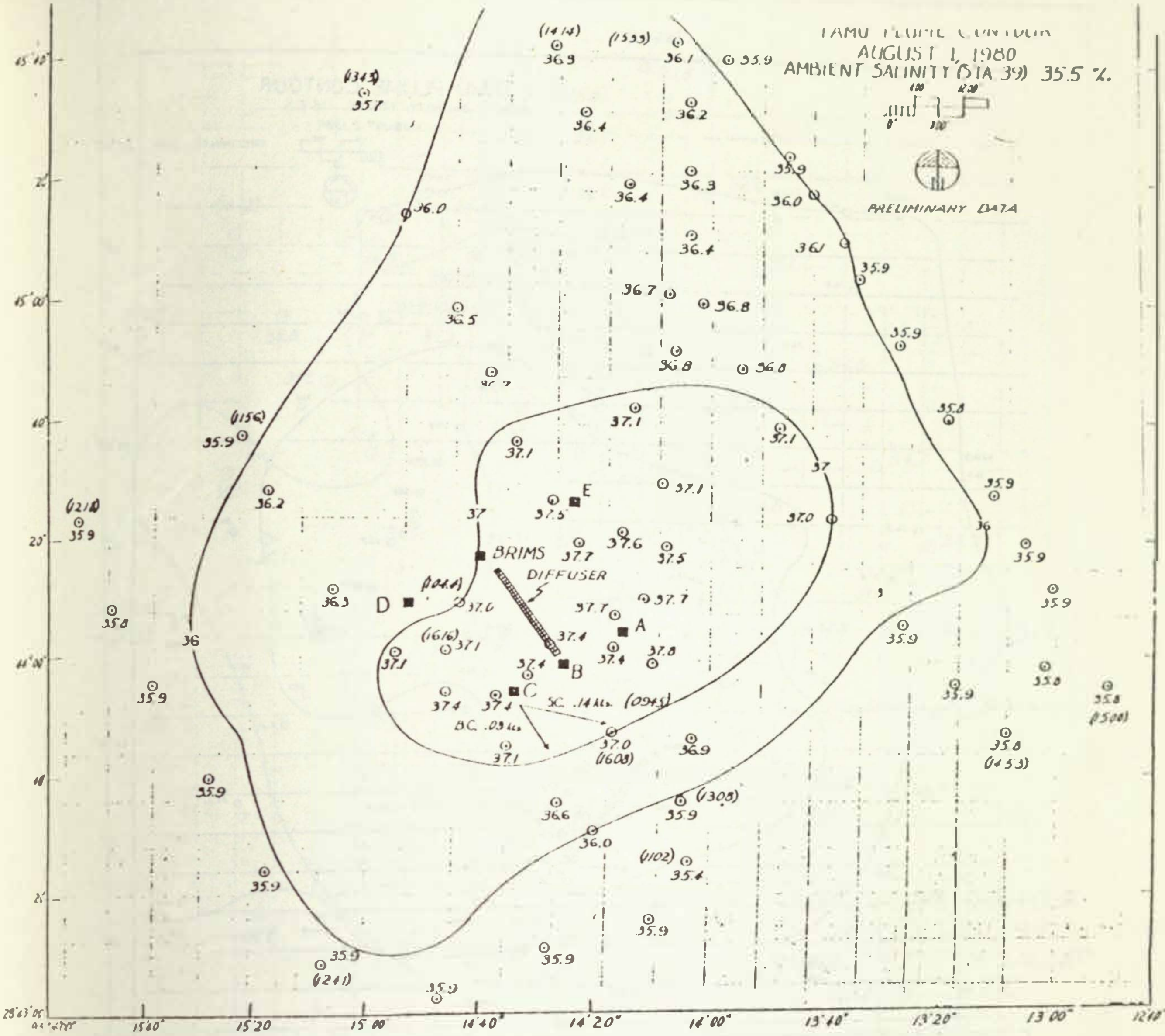


Figure B-8. TAMU plume contour of August 1, 1980.

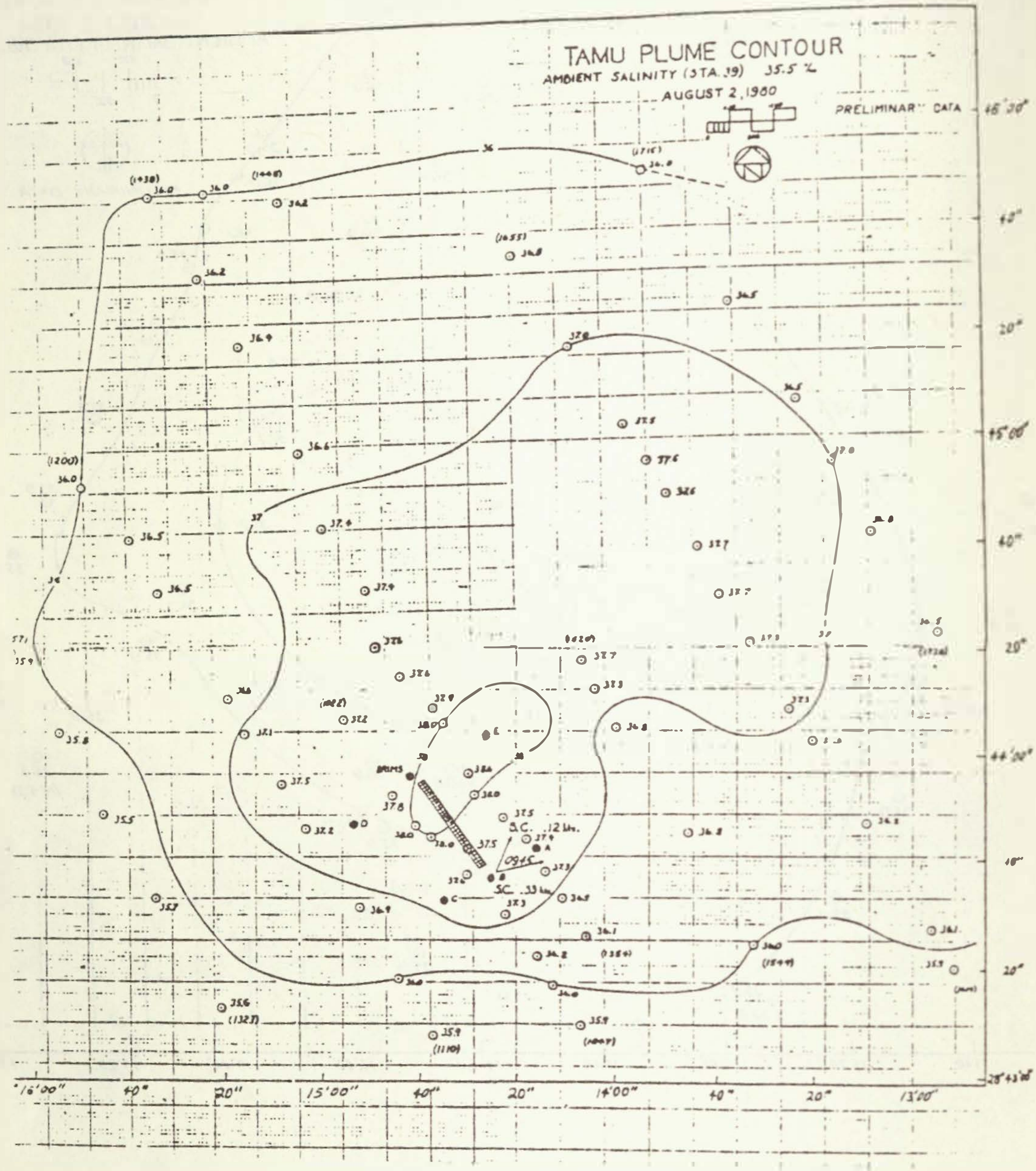


Figure B-9. TAMU plume contour of August 2, 1980.

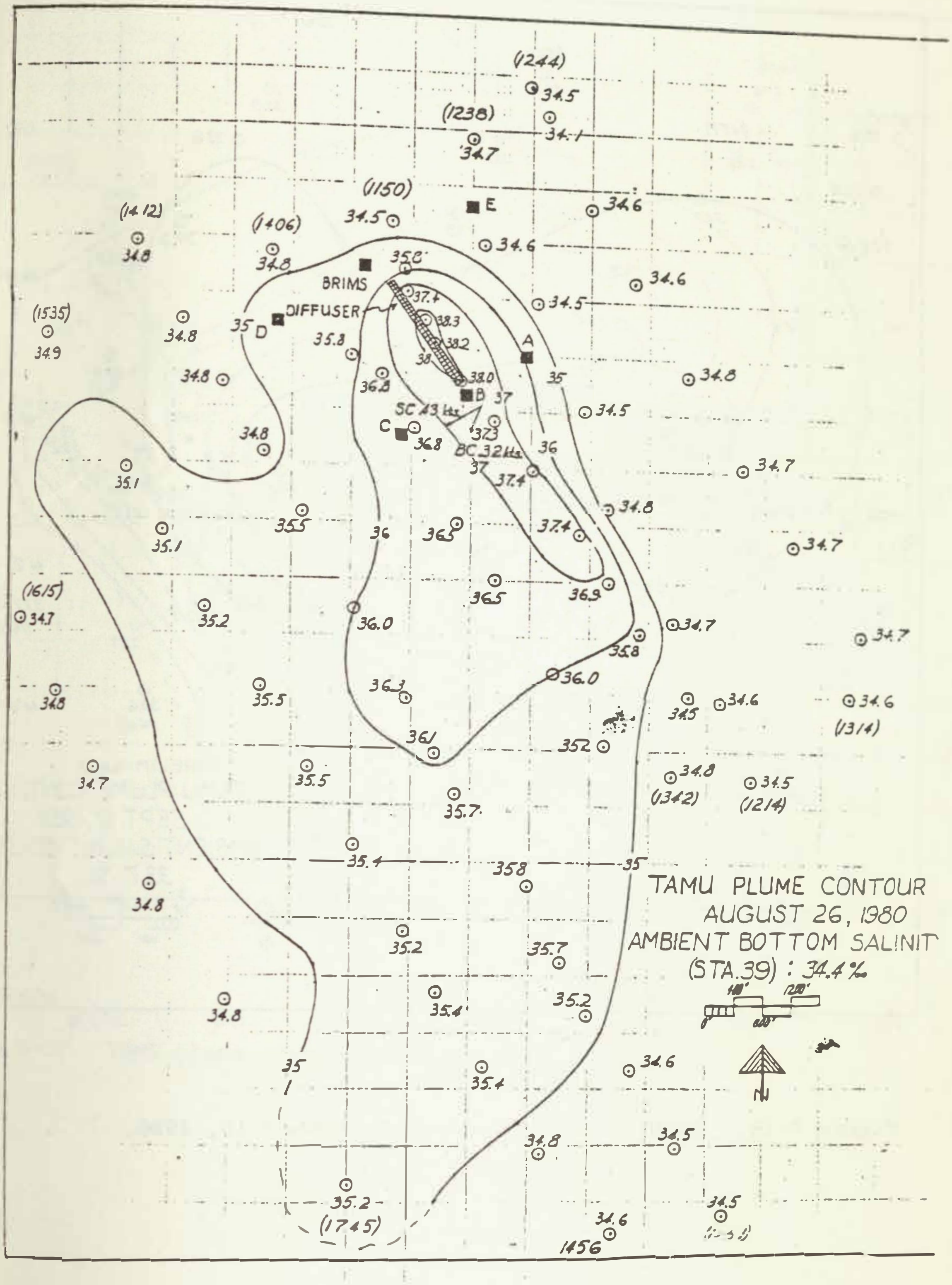


Figure B-10. TAMU plume contour of August 26, 1980.

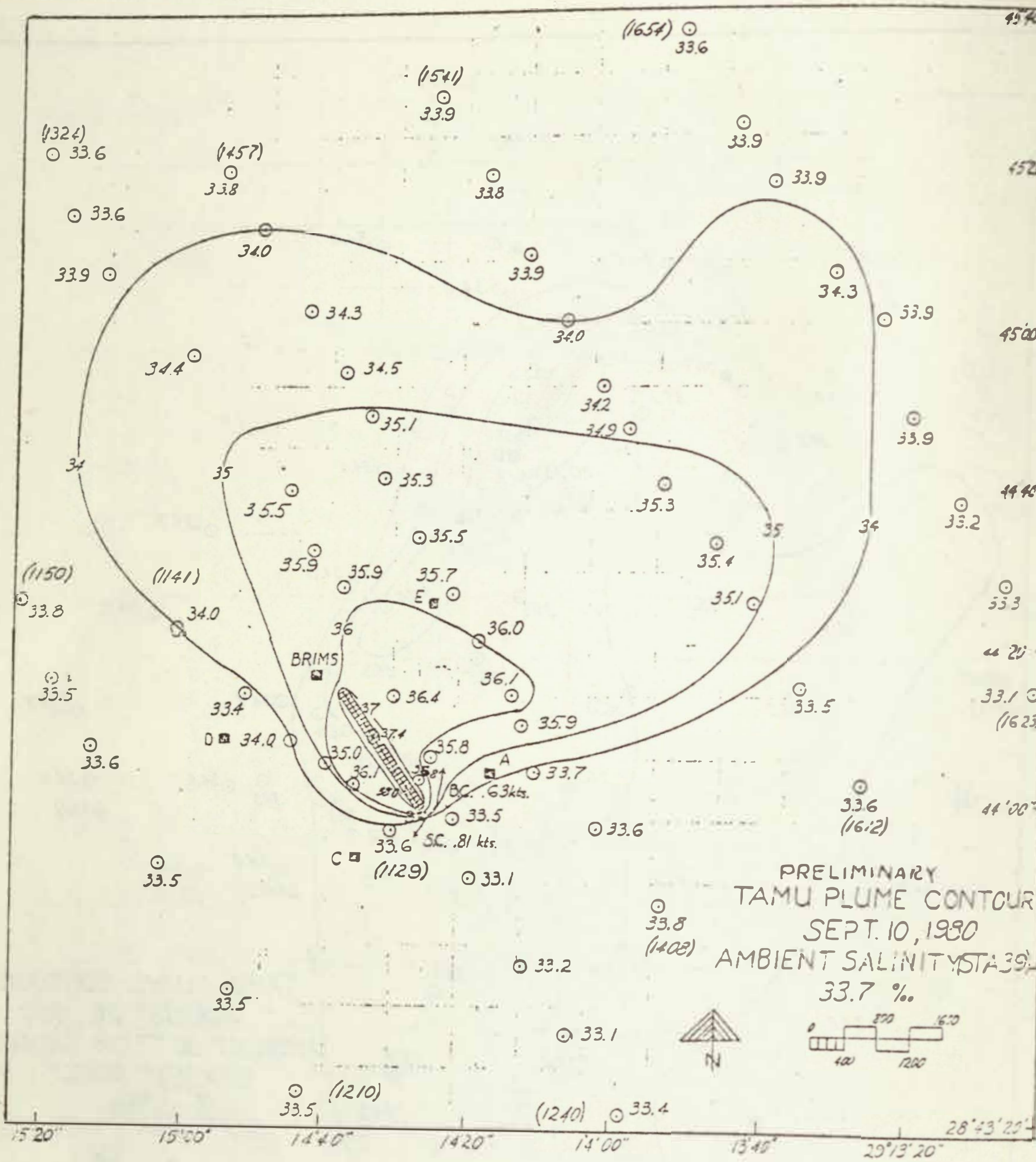


Figure B-11. TAMU plume contour of September 10, 1980.

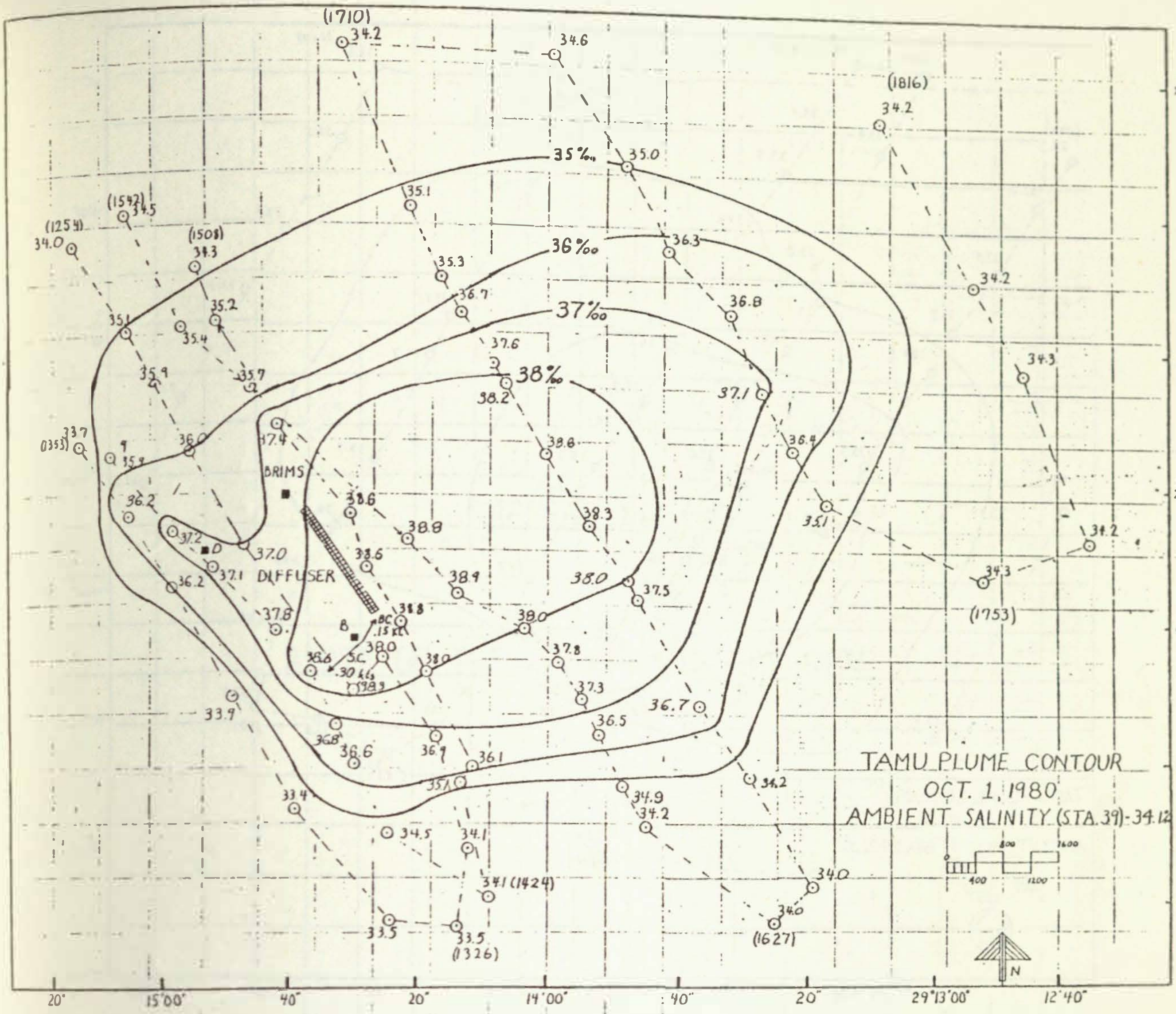


Figure B-12. TAMU plume contour of October 1, 1980.

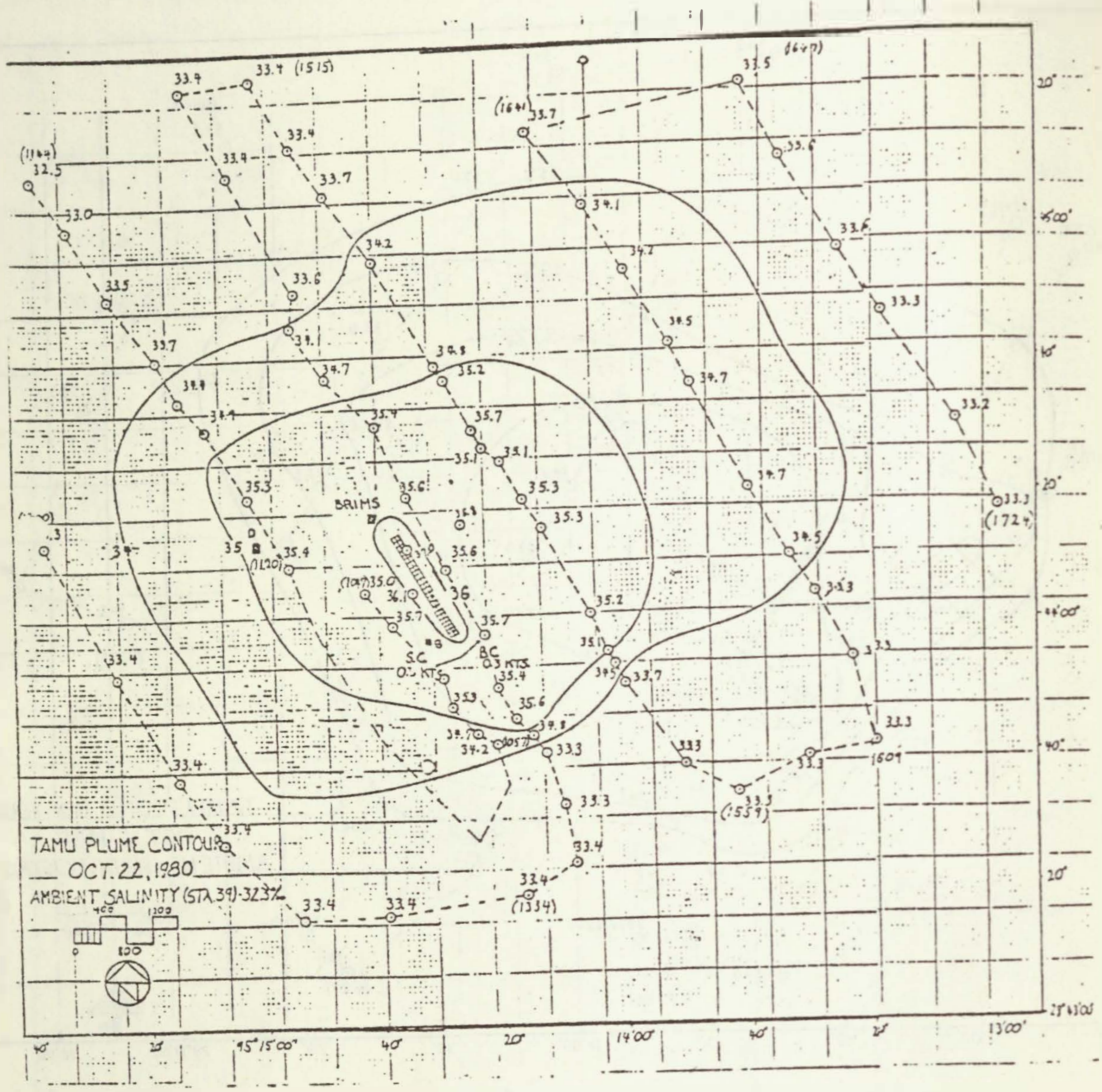


Figure B-13. TAMU plume contour of October 22, 1980

APPENDIX C

BIOTA OF THE WEST HACKBERRY SITE

Table C-1. Relative (% composition) and absolute (individuals/m^2) numerical abundance of dominant megabenthic species.

Dominant Species	Summer 1978		Fall 1978		Winter 1979		Spring 1979	
	% comp.	ind/m^2	% comp.	ind/m^2	% comp.	ind/m^2	% comp.	ind/m^2
Paraprionospio pinnata	54.4	593	47.5	640	*	*	*	*
Cirriformia sp.	*	*	*	*	7.1	798	15.9	1012
Magelona sp.	14.7	160	*	*	*	*	*	*
Sigambra tentaculata	*	*	12.7	171	*	*	*	*
Glycera dibranchiatan	*	*	7.2	97	*	*	*	*
Mediomastus californiensis	*	*	*	*	*	*	6.0	380
Cossura delta	7.0	76	*	*	*	*	*	*
Sabellides oculta	*	*	*	*	*	*	8.5	543
Mulinia lateralis	*	*	*	*	79.0	8825	51.6	3283
Cumulative of dominant species	76.2	829	67.4	908	86.1	9623	82.0	5218
Comulative of non-dominant species	23.8	259	32.6	438	13.9	1548	18.0	1141
Total number of species collected	41		48		60		52 (89)**	

* denotes species was not dominant at this season.

** total number of species collected for all four sampling periods combined.

Table C-2. Relative composition (%) and density (individuals/m^2) of meiofaunal taxa (after Parker and Crowe, 1980).

Taxon	Summer 1978	Fall 1978	Winter 1979	Spring 1975
		WEST HACKBERRY		
Nematodes (%)	61.00	99.48	95.78	93.35
Tintinnids (%)	27.56	---	---	---
Harpacticoid copepods (%)	0.30	---	0.69	1.51
Kinorhynchs (%)	3.79	---	1.80	0.91
Polychaetes (%)	0.27	0.35	0.99	0.85
Turbellarians (%)	1.55	---	---	---
Pelecypods (%)	0.05	0.01	0.24	0.16
Tardigrades (%)	2.90	---	---	2.26
Individuals/m^2	16,130	7170	7610	5090

Table C-3. Relative (% of total) and absolute (individuals/100m^3) of major zooplankton taxa collected in a 0.333 mm mesh bongo net (after Reitsema, 1980).

SUMMER

Taxon	% Total Density	Mean Density (No/100 m^3)
*Acartia tonsa*0	77.7	82,535
Labidocera sp.0	11.60	12,294
Oikopleura sp.0	2.70	2,856
Cladocerans	1.80	1,932
Copepods (Unidentified)0	1.50	1,568
Crab zoea (Unidentified)0	1.40	1,482
Coelenterates0	1.00	1,080
Polychaete "D"0	0.60	651
Sagitta sp.	0.30	356
Amphipoda (Unidentified)	0.30	348
Lucifer faxoni	0.30	299
SITE TOTAL	>99.00	106,200

FALL

Taxon	% Total Density	Mean Density (No/100 m^3)
Temora sp.	39.8	12,936
Copepods (Unidentified)0	26.7	8,673
Eucalanus sp.	10.0	3,257
Sagitta sp.	7.2	2,357
Labidocera sp.	6.10	1,981
Acartia tonsa	2.60	863
Oikopleura sp.	2.30	758
Crab zoea (Unidentified)	0.90	281
Creseis sp.	0.50	170
Ogyrides sp. zoea	0.30	97
SITE TOTAL	>96.00	32,500

WINTER

Taxon	% Total Density	Mean Density (No/100 m^3)
Acartia tonsa	58.6	68,640
Temora sp.	26.3	30,803
Sagitta sp.	8.6	10,070
Labidocera sp.	2.0	2,315
Copepods (Unidentified)	1.3	1,501
Crab zoea (Unidentified)	0.3	336
Coelenterates	0.1	161
Gastropod meroplankton	0.1	150
Mysidopsis bigelowi	0.1	135
Eucalanus sp.	-	70
SITE TOTAL	>97.0	117,100

SPRING

Taxon	% Total Density	Mean Density (No/100 m^3)
Acartia tonsa	96.1	661,552
Copepods (Unidentified)	2.8	19,365
Labidocera sp.	0.2	1,303
Sagitta sp.	-	417
Cladocerans	-	256
Polychaetes (Unidentified)	-	225
Temora sp.	-	208
Crab zoea (Porcellanid)	-	208
Sergestid postlarvae	-	15
Mysidopsis bigelowi	-	3
SITE TOTAL	>99.00	688,172

Table C-4. Major bacterial genera isolated from surficial sediment and water column (after Schwarz et al., 1980).

1. Aerobic heterotrophic bacteria of sediment	Bacillus (63)* Vibrio (41) Pseudomonas (23) Enterobacteriaceae (3) Acinetobacter (1) coryneform (1) Flavobacterium (1)
2. Hydrocarbon degrading bacteria of sediment	Pseudomonas (34) Vibrio (1)
3. Halophilic bacteria of sediment	Bacillus (49) Pseudomonas (19) Vibrio (18) coryneforms (2)
4. Aerobic heterotrophic bacteria of water	Vibrio (52) Pseudomonas (47) Bacillus (26) Flavobacterium (11) Enterobacteriaceae (9) Acinetobacter (3) coryneforms (2) Staphylococcus (2)

*numbers in parentheses are the total isolates identified.

Table C-5. Relative numerical abundance (% of total catch of the dominant finfish species (after Landry and Armstrong, 1980).

	Su	F	W	Sp
Atlantic croaker	66.5	14.5	*	81.9
Banded drum	*	*	*	*
Star drum	13.5	10.1	48.7	1.8
Sand seatrout	4.5	*	*	*
Silver seatrout	2.8	3.0	*	4.0
Southern kingfish	*	*	4.3	*
Sea catfish	*	13.5	*	1.6
Gulf menhaden	*	*	11.8	2.2
Bay anchovy	*	*	8.2	*
Atlantic bumper	*	45.6	*	*
Bighead searobin	*	*	4.3	*
Longspine porgy	*	*	*	*
Fringed flounder	*	*	*	*
Harvestfish	2.7	*	*	*
Least puffer	*	*	*	*
TOTAL	89.9	86.7	77.3	91.5

* denotes species not a numerical dominant at this season.

Table C-6. Relative numerical and biomass abundance (% of total catch) of dominant macro-crustacean species (after Landry and Armstrong, 1980).

Species	Relative Numerical Abundance					Relative Biomass Abundance				
	Su	F	W	Sp	Total	Su	F	W	Sp	Total
Penaeus setiferus	9.1	44.4	13.5	*	13.6	19.5	79.1	13.2	6.2	18.8
Penaeus aztecus	59.0	44.0	*	*	4.7	21.2	18.5	*	*	4.0
Trachypeneus similis	*	*	35.7	54.3	35.3	*	*	8.7	6.7	6.4
Xiphopeneus kroyeri	*	*	14.4	*	11.1	*	*	6.3	*	3.2
Callinectes sapidus	4.4	*	*	18.2	3.1	49.6	*	8.7	77.0	32.9
Callinectes similis	27.0	*	*	*	1.4	9.5	*	*	*	1.4
Portunus gibbesii	*	5.0	21.8	*	16.9	*	*	12.6	*	6.2
Libinia marginata	*	*	*	*	*	*	*	28.6	*	14.0
Squilla empusa	*	*	11.5	19.1	11.6	*	*	20.8	7.2	12.4
Total	99.5	93.4	96.9	91.6	97.7	99.8	97.6	98.9	97.1	99.3

* Not a dominant
at this season.