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OFFSHORE OCEANOGRAPHIC AND ENVIRONMENTAL MONITORING SERVICES FOR THE STRATEGIC PETROLEUM RESERVE

Annual Report for the Bryan Mound Site from September 1982 through August 1983

March 1984

Work Performed Under Contract No. AC96-83PO10850

Texas A&M University
College Station, Texas

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OFFSHORE OCEANOGRAPHIC AND ENVIRONMENTAL MONITORING SERVICES

FOR THE STRATEGIC PETROLEUM RESERVE

Annual Report for the Bryan Mound Site

from September 1982 through August 1983

VOLUME I

March 1984

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Texas A&M University
through
Texas A&M Research Foundation

Prepared for the Department of Energy
Strategic Petroleum Reserve Project Management Office
under Contract No. DE-AC96-83PO10850

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ACKNOWLEDGEMENTS

The program manager and the principal investigators would like to acknowledge the assistance and work of the many personnel required to complete a project of this magnitude. It is their hard work, perseverence, long days offshore, tedious laboratory and data analysis which has made possible the presentation of the results reported in this document.

The management staff on this project are involved in purchasing, report writing, and clerical duties which are most critical to the satisfactory performance of the technical aspects discussed in this report. The assistance of Ms. Charlene Miller and Ms. Susan Gandy in coordinating project business with the Texas A&M Research Foundation is most appreciated. Acknowledgement is given to Ms. Cindy Denton and Ms. Frances Kahlich for their contribution in organizing, editing, and typing this report. Mr. Steve Beekman was responsible for a majority of the drafting for this report, and his fine work is appreciated.

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Lynn Pokryfki and the student technicians in the collection and analysis of plume tracking and monthly hydrographic data has been invaluable.

The assistance in the collection and laboratory analysis of Water and Sediment Quality data by research associates Dr. H. Edward Murray and Mr. Ben Pressly; research technician Mr. Anton Vos; research assistant Mr. James Martin; and the student laboratory technicians is greatly appreciated.

The collection of the large volume of nekton data is only possible through the assistance of a sizeable field staff, and their work is most appreciated. Thanks is given to Ms. Virginia Fay, Messrs. Michael Dentzau, Stephen Harding, and David Hata for collection and identification of nekton samples.

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Acknowledgement is given to research assistant Ms. Rebecca Bramlett and to the several student assistants for their invaluable assistance in data analysis, data compilation and tranmission of data to the National Environmental Satellite Data Information Service.

The excellent work of the project field staff and the captain and crew of the University's research vessel, R/V EXCELLENCE II, and other contract vessels is acknowledged. Mr. Donald Peavy is the Captain, Mr. Roger Robbins is the Relief Captain, and Mr. Robert Caraway is the Seaman on the R/V EXCELLENCE II. Mr. Mitch Mallory is the Field Coordinator and Divemaster, Mr. Bo Stanley is the Assistant Field Coordinator, and Ms. Penny Roberts is the Secretary for the project field staff located in

Surfside, Texas. Their assistance in the coordination of and participation in the field sampling cruises has been invaluable and greatly appreciated.

ABSTRACT

The Department of Energy's Strategic Petroleum Reserve Program began leaching the Bryan Mound salt dome and discharging brine into the coastal waters offshore of Freeport, Texas on March 10, 1980. This report describes the findings of a team of Texas A&M University scientists and engineers who have conducted a study to evaluate the effects of the Bryan Mound brine discharge on the marine environment. The study addresses the areas of physical oceanography, analysis of the discharge plume, water and sediment quality, nekton, benthos and data management. It focuses on the period from September 1982 through August 1983.

The ambient physical environment and its temporal and spatial variability were studied by means of continuously recording in situ current/conductivity/temperature meters and twelve, one-day synoptic hydrographic cruises. Monthly mean alongshelf currents were downcoast (southwest) in all months except July 1983 in the upper half of the water column and June and July 1983 in the lower part. The summer upwelling condition was much weaker and less persistent than in previus years. Low frequency current fluctuations up to about 0.2 cpd were strongly coherent with the alongshelf component of wind stress at all depths; cross-shelf currents were coherent with the alongshelf wind stress at these frequencies only near the bottom. The persistence of a near bottom current speed less than 6 cm/s, which results in a brine plume expansion, was found to be typically only a few hours and at most 27 hours, based on 8818 hours of data. Water temperature showed a large annual cycle with small short period variability and small spatial variability. The effect of brine discharge on the temperature of the bottom water was usually much

less than 1°C. Ambient salinity was highly variable both temporally and spatially because of the large amount of river discharge in 1983. The brine plume increased the salinty of the bottom water by less than 4 o/oo, typically, and absolute values were less than 40 o/oo.

The quarterly water and sediment quality data show a small increase in salinity, sodium and chloride ions occurs in the bottom waters and sediment pore waters near the diffuser relative to those values measured at stations farther away. Increases in the ion levels with time appears to have stabilized at about 6% over ambient. In the sediments, lead levels near the diffuser continued to increase slightly relative to ambient, and since lead was found to be higher in the brine than in offshore waters, these increases could be related to brine discharge. Hydrocarbon levels in the offshore waters show no evidence of crude oil hydrocarbons. However, sediment hydrocarbons in August were found to be from a crude oil source. Gas chromatography/mass spectra data comparison between sediment and brine pit hydrocarbons strongly suggest brine as the source.

Data from the brine plume study for this reporting study show the largest areal extent within the +1 o/oo above ambient salinity contour was 40.0 km^2 which occurred on August 11, 1983. The longest distance to the +1 o/oo above ambient salinity contour was 7.4 km on January 11, 1983. The largest vertical extent of the brine jets was 5.6 and 8.1 m when the average exit velocity was 7.3 and 12.6 m/s, respectively. The highest above ambient salinity contour (+5 o/oo) was measured in September 1982 which was less than the +6 o/oo value measured in previous studies. Plume measurements indicate the higher brine exit velocity has increased the areal and vertical extent and decreased the above ambient salinity values.

It appears that brine disposal at Bryan Mound has had neglible if any influence on the nekton community surrounding the diffuser. The responses of nekton to the plume have not been constant, brine contrasts generally have been non-significant and variability attributable to among stations or to brine effects usually small. The lack of impact seems related to several factors including the intrinsic dynamism of shrimp and fish populations, the negligible area covered by the brine plume in comparison to the areas which stocks may range over, the rapidity with which the brine plume dilutes and disperses, and the fact that maximum brine elevations measured are well below those that evoke mortality or avoidance in laboratory tests.

The benthic quarterly data from 26 stations, including 7 collections made after the diffuser outflow rate was increased to 1,000,000 barrels/day, show the total numbers of species at the diffuser station were higher than most other nearfield stations as well as many farfield stations in both the pre- and post-1,000,000 barrels/day brine flow periods. In contrast, the total abundances at the diffuser station were depressed, although not significantly so, compared with intermediate and farfield stations. Statistical analysis indicated that mean abundances were significantly higher at control stations in November and February, and no differences were noted in May or August. Species diversity around the diffuser remained significantly lower than at control stations throughout the year except in November. Hypoxia was noted in the study area in August and it severely impacted the Crustacea. Negative redox were correlated with lower abundances.

INTRODUCTION

Brine discharge began on March 10, 1980 from the Bryan Mound site of the Department of Energy's Strategic Petroleum Reserve. The brine discharge is the result of leaching large storage caverns in an underground salt dome located near Freeport, Texas. Subsequently, these caverns are being used for the storage of crude oil. Prior to the discharge, a team of scientists and engineers at Texas A&M University conducted an environmental study of the coastal waters offshore of Freeport, Texas from September 1977 through February 1980, and the results were presented in a report edited by Hann and Randall (1980 and 1981a). This 30-month study provided an unusually large baseline for comparison with the postdisposal results. During March and April 1980, an intensive postdisposal study was conducted to evaluate the immediate effect of brine disposal, and a final report (Hann and Randall, 1981b) was submitted to the Department of Energy.

Brine discharge has continued on a near continuous basis to the present time, and three reports have been published which describe the project team's findings. The first report, Hann and Randall (1981c), was published in July 1981, and it discussed the results of the analysis of the postdisposal data collected during the first 12 months of discharge. In March 1982, the second report edited by Hann and Randall (1982) was published which described the results obtained during the first 18 months of study after initiation of brine discharge. The third report, Hann and Randall (1983), presented the results obtained during the period September 1981 through August 1982.

The purpose of this report is to describe the findings of the project team during the 12 months of postdisposal study conducted from September 1982 through August 1983. A composite of the sampling station locations for all components of the project team are illustrated in Figure 1. The areas of investigation are benthos, brine plume, data management, nekton, physical oceanography, and water and sediment quality. The specific objectives of this report are:

1) to describe the physical oceanographic and meteorological conditions which have been measured at the offshore diffuser site and in the surrounding waters;

2) to describe the effect of brine discharge on the benthic community in the diffuser site area;

3) to discuss the effect of the brine discharge on the quality of the water and sediment in the vicinity of the diffuser site;

4) to describe the measurement of the areal and vertical extent of the brine plume;

5) to characterize the effect of brine discharge on the nekton community in the vicinity of the diffuser.

The meteorological and physical oceanographic data are presented to determine the degree to which the brine discharge altered the ambient conditions and to provide basic physical oceanographic data to other components of the study. Discussions are focused for the most part on the data obtained from the in situ instruments at the diffuser site (site C) and the monthly hydrographic data collected at the stations shown in Figure 1. A special presentation is given for the current velocity, temperature and salinity time series data from the near-bottom instrument on the days when the brine plume was measured.

A measurement system used in tracking the brine plume and the

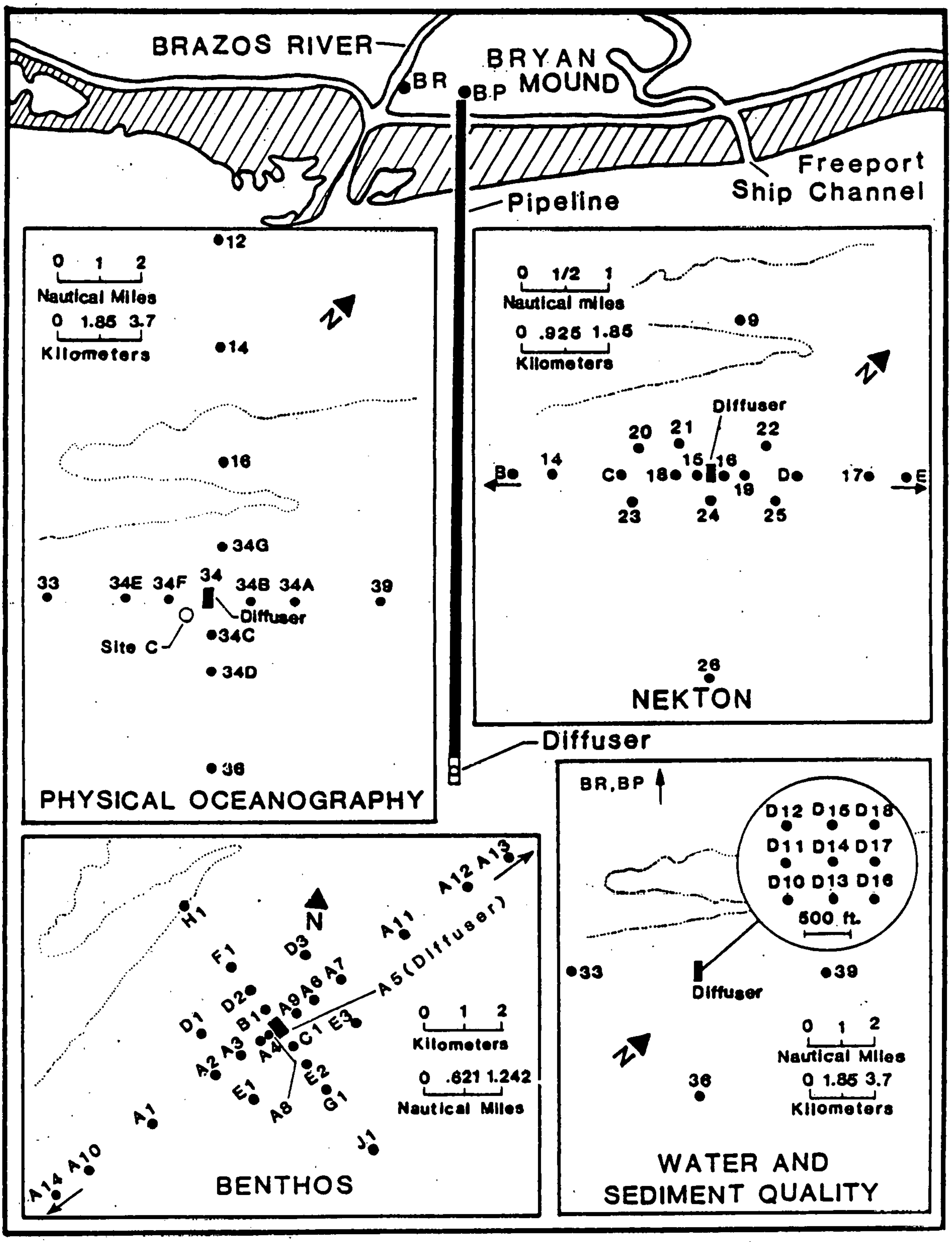

Figure 1. Composite of project sampling station locations.

procedures employed to evaluate the areal and vertical extent and above ambient concentration of the brine plume located 25 cm above the bottom are summarized. The results of monthly measurements of the areal and vertical extent are described in detail. Brine plume exposure rosettes which show the predicted percent time that specific bottom areas in the vicinity of the diffuser were exposed to above ambient salinity concentrations during the study period are discussed. These exposure rosettes were obtained using empirical prediction techniques which were developed from actual plume areal and vertical extent measurements.

The water and sediment quality monitoring activities consisted of quarterly water and sediment sampling at the stations shown in Figure 1. Water samples were analyzed for salinity, dissolved oxygen, nutrients, major bulk ions, soluble heavy metals and estimates of organic matter, turbidity and productivity. The sediment samples were analyzed for Eh, pH, oil and grease, selected pesticides and PCBs, high molecular weight hydrocarbons, and the same heavy metals as for the water samples as well as the major ions and total dissolved solids present in the interstitial, or pore, waters of the sediments.

The nekton sampling cruises during this postdisposal study were conducted quarterly during the day with trawls made at the stations shown in Figure 1. Each of these cruises normally required three days of at-sea work. The data from these cruises were used to determine the abundance, composition, and diversity of the nekton during the period. These results are compared with similar data collected during the predisposal and postdisposal periods in order to evaluate the effect of brine discharge on the nekton community.

The benthic sampling for this postdisposal study was conducted quarterly at the stations shown in Figure 1. Areal and temporal distributions of populations and species and cluster analyses are used to evaluate the effect of the brine discharge.

The brine from the Bryan Mound site is discharged through a 0.9 m diameter pipeline which is buried beneath the sea floor from Bryan Mound to a point 20 km off the Freeport, Texas coast in 21.6 m of water (Figure 1). The location of the end of the pipeline is latitude 28°44'00.4"N and longitude 95°14'26.0"W. The last 933 m of the pipeline is a diffuser which consists of 52 diffuser ports which extend vertically 1.2 m above the bottom. These ports are 7.6 cm in diameter and are 18 m apart. The brine is discharged through the multiport diffuser, and it is diluted initially due to jet mixing. Since the brine is more dense than the receiving waters, it falls to the bottom and spreads over the sea floor. Finally, it is further diluted and advected away by the natural ocean bottom currents and turbulent diffusion.

Brine discharge from Bryan Mound began on March 10, 1980, through the 15 furthest offshore ports. During the first four months of operation, the brine discharge was continuous for approximately 10 to 16 hours per day. The nominal flowrate and brine pit salinity were 230,000 barrels/day and 240 o/oo respectively.

In mid-July 1980, 16 additional ports were opened for a total of 31 open diffuser ports. The discharge rate was increased to over 500,000 barrels/day with an ultimate goal of 680,000 barrels/day. New caverns were being leached at this time which caused the salinity to be less than 160 o/oo, and continuous discharge was maintained for approximately 20 hours/day. As the cavern size increased, the brine salinity increased and was continually over 200 o/oo by the end of August.

In November 1980, the brine discharge rate was consistently between 600,000 and 680,000 barrels/day, and by December the brine pit salinity was being maintained between 240 and 250 o/oo. In general, these conditions were maintained through August 19, 1981, except for a few batching and no operation days. On August 20, 1981, the discharge operation was shut down for pipeline maintenance, and three additional ports were opened for a total of 34 diffuser ports. The brine discharge was increased to near 750,000 barrels/day on August 23, 1981, and the brine discharge was nearly continuous at this rate through December 1981. In January 1982, the discharge was increased to nearly 1,000,000 barrels/day, and it has remained at this rate through August 1983.

For the period of this report from September 1982 through August 1983 the total daily average brine discharge, hours of operation, average brine salinity, and average brine temperature are illustrated in Figure 2, and these values are also tabulated in Appendix Table E-1.

The data for this postdisposal study, as well as previous predisposal and postdisposal studies, were compiled on tape by the data management group and submitted to the National Oceanic and Atmospheric Administration's National Environmental Satellite Data and Information Service in Washington, D.C.

The complexity of the Strategic Petroleum Reserve Program on brine disposal evaluation has required a multidisciplinary research effort which is coordinated by a management staff headed by Dr. Roy W. Hann, Jr., Program Manager, Dr. Charles P. Giammona and Dr. Robert E. Randall, Deputy Program Managers. The objectives of the management staff are to oversee the fiscal aspects of the project, act as liaison between principal investigators and sponsor, to coordinate program output such as reports

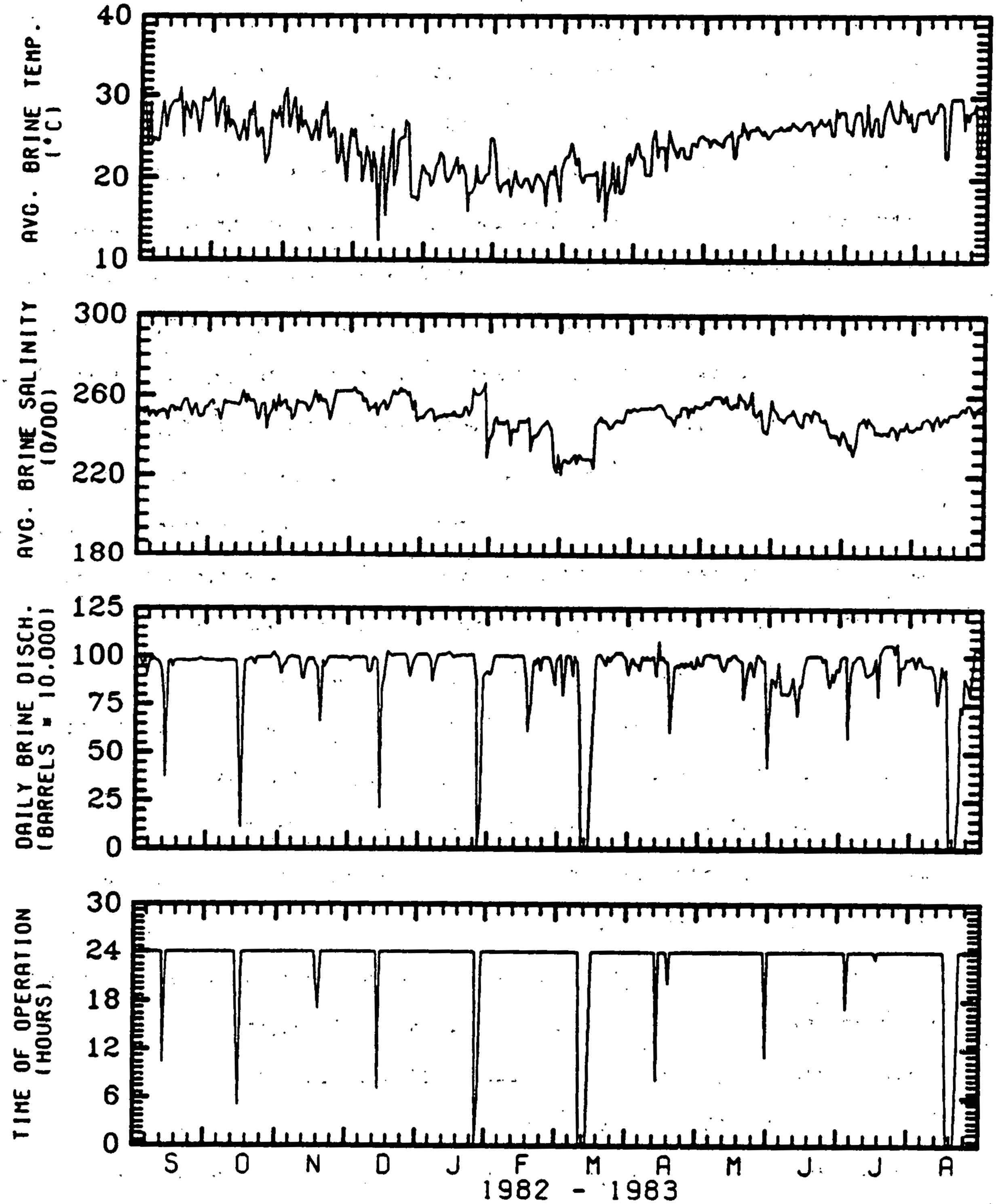

Figure 2. Brine discharge characteristics for the period September 1982 through August 1983.

and data transmittal, and to coordinate field operations. A separate unit of the management staff is the field organization located in Galveston, Texas. The field personnel are responsible for coordinating the use of the Texas Engineering Experiment Station's research vessels, the EXCELLENCE II and the QUEST, and other contract vessels. In addition, the field personnel assist the principal investigators in the collection of field data. The contractural matters of the project are the responsibility of the Texas A&M Research Foundation.

This report is divided into three volumes. Volume I contains the presentation and analysis of the data collected during the period from September 1, 1982 through August 31, 1983, and it is divided into chapters which correspond to the areas of responsibility of the principal investigators. These chapters are entitled Physical Oceanography (Chapter 1), Brine Plume (Chapter 2), Water and Sediment Quality (Chapter 3), Nekton (Chapter 4), Benthos (Chapter 5), and Data Management (Chapter 6). Volume II contains the supporting data for the individual chapters of Volume I and is divided into Appendices A through E. Volume III contains the Executive Summary of this report.

The principal investigator for Physical Oceanography is Mr. Francis J. Kelly, who is a Research Associate in the Environmental Engineering Division of the Civil Engineering Department and a doctoral student in the Department of Oceanography. Dr. Robert E. Randall is the principal investigator for the Brine Plume Measurements and Hydrography (CTD/DO), and he is associated with the Ocean and Hydraulic Engineering Division of the Civil Engineering Department. He is also responsible for the collection and description of the monthly hydrographic data discussed in the Physical Oceanography chapter. The principal investigator for Water and Sediment Quality is Dr. J. Frank Slowey of the Environmental Engineering Division of the Civil Engineering Department. Drs. Andre Landry and Mark E. Chittenden are the principal investigators for the Nekton studies. Dr. Landry is the head of the Marine Biology Division at Texas A&M University at Galveston, and Dr. Chittenden is associated with the Wildlife and Fisheries Department in College Station. The principal investigators for the Benthos studies are Drs. Donald E. Harper and Larry D. McKinney who are associated with the Marine Biology Department at Texas A&M University at Galveston. Dr. Gary A. Wolff is a Research Associate in the Environmental Engineering Division of the Civil Engineering Department and he is the principal investigator for Data Management.

CHAPTER 1

PHYSICAL OCEANOGRAPHY

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1.1 Introduction

In this chapter, the physical oceanography of the Bryan Mound site is characterized, the magnitude of the brine plume is discussed and the results of the in situ instrumentation and synoptic hydrographic cruises are presented in a variety of ways for use by the other investigators. The focus is primarily on the period of September 1982 through August 1983. Section 1.2 describes the instruments and methods. The observations are described in section 1.3 from a time domain point-of-view. Results of observations in the brine plume layer and characteristics of the near bottom currents which affect the brine dispersion are noted throughout the discussions. The wind and currents and their relationship are discussed from a frequency domain point-of-view in section 1.4. The persistence of weak flow conditions near the bottom is analyzed in section 1.5. Several general topics of interest are discussed in section 1.6.

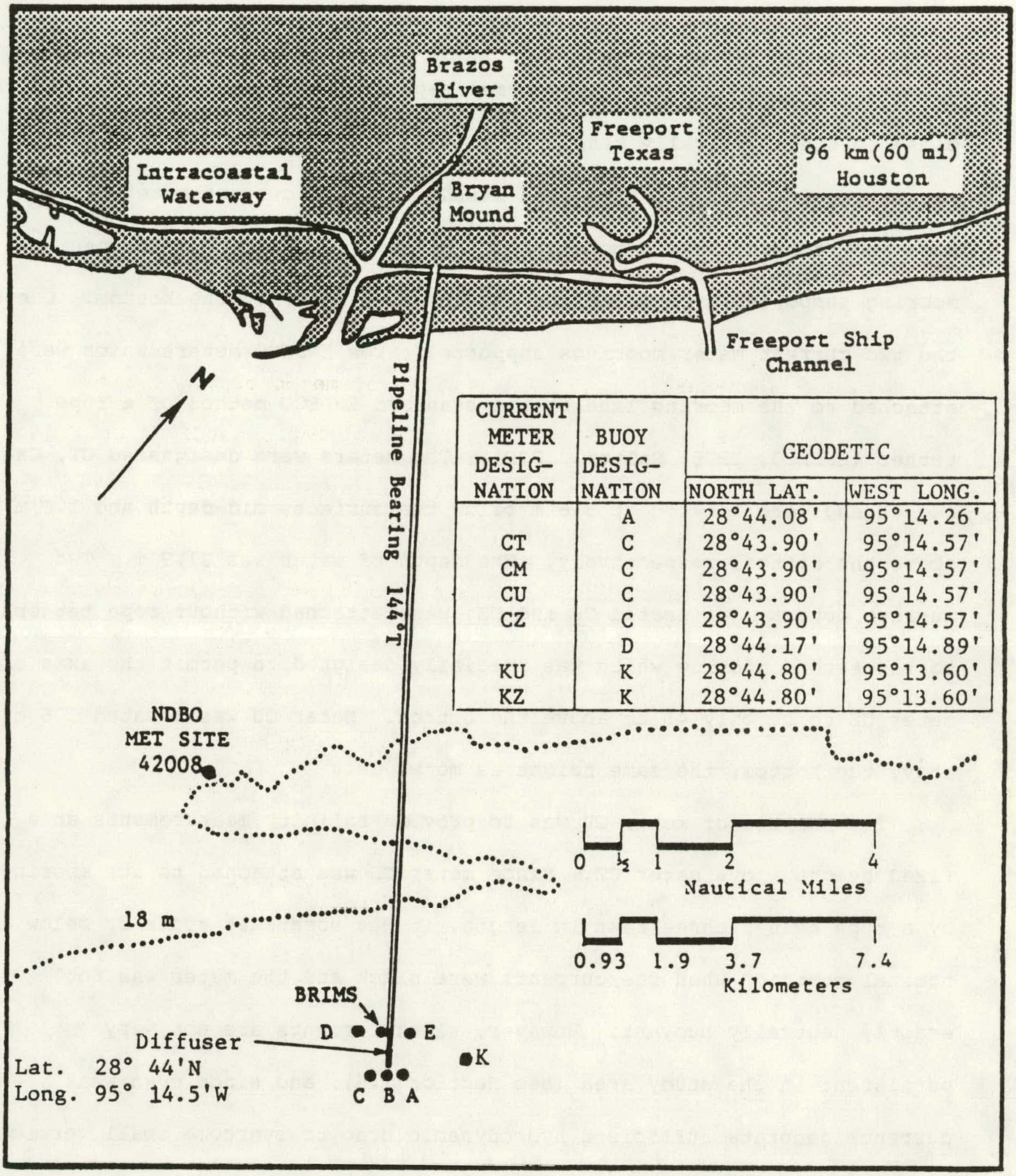
This report is the most recent in a series of reports which have described the results of physical oceanographic studies begun in late 1977 in the region offshore of Freeport, Texas. For the results of the previous studies, the reader is referred to Kelly and Randall (1980) and Kelly et al. (1981, 1982, 1983a). The results of studies at the West Hackberry brine disposal site off Calcasieu Pass, Louisiana and at the planned Big Hill site have been described and compared to those at Bryan Mound in reports by Kelly et al. (1983b, 1984) and Randall and Kelly (1983).

A complete set of vertical sections, monthly statistics, monthly wind and current roses and monthly time series plots of meteorological and oceanographic data have been placed in Appendix A. The appendix also contains other large groups of figures and tables such as spectral density plots, the results of harmonic tidal analyses and expanded plots of near bottom current velocity, salinity, and temperature for the days on which the brine plume was mapped. (Results of brine plume mapping are described in Chapter 2.)

1.2 Instrumentation and Methods

1.2.1 *In situ* Instrumentation

Figure 1-1 shows the location of the diffuser site, various witness buoys which mark the diffuser site, the NDBC meteorological instrument site (42008), and the sites of the oceanographic instrument arrays. Two oceanographic instrument sites, C and K, were operational during the period covered by this report. Site C was located approximately 300 m downcoast (southwest) from the end of the diffuser. Site K was established in June of 1983 about 1.8 km upcoast (northeast) of the diffuser site to serve primarily as a control site to obtain salinity measurements outside the area of strong brine plume influence. It also provided redundancy for measurements of bottom currents. Site K was at



CURRENT METER DESIG-NATION	BUOY DESIG-NATION	GEODETIC	
		NORTH LAT.	WEST LONG.
	A	28°44.08'	95°14.26'
CT	C	28°43.90'	95°14.57'
CM	C	28°43.90'	95°14.57'
CU	C	28°43.90'	95°14.57'
CZ	C	28°43.90'	95°14.57'
	D	28°44.17'	95°14.89'
KU	K	28°44.80'	95°13.60'
KZ	K	28°44.80'	95°13.60'

Figure 1-1. Locations of Bryan Mound, brine disposal pipeline, brine discharge area and in situ instrumentation.

approximately the same location as hydrographic station 34B (see Section 1.2.3).

Figure 1-2 schematically shows the configuration of the instrument moorings at site C. There were three separate instrument moorings located close to the elastically tensioned mooring of the witness buoy. Two of the instrument moorings supported ENDECO Type 174 current meters (which also had temperature and conductivity sensors). The third instrument mooring supported an Applied Microsystem tide meter at the bottom. One of the two current meter moorings supported three ENDECO meters which were attached to the mooring line by the standard ENDECO method of a rope tether (ENDECO, 1978; Salter, 1979). The meters were designated CT, CM and CB and were located at 3.6 m below the surface, mid-depth and 1.6 m above the bottom, respectively. The depth of water was 21.9 m. Two current meters, designated CU and CZ, were attached without rope tethers to the second mooring which was specially designed to permit the axis of meter CZ to be only 46 cm above the obttom. Meter CU was located 1.6 m above the bottom, the same height as meter CB.

The purpose of meter CU was to provide salinity measurements at a fixed height above meter CZ. Since meter CB was attached to its mooring by a rope tether three feet in length, it was sometimes above or below its nominal position when the currents were slack and the meter was not exactly neutrally buoyant. However, slack currents are not very persistent in the study area (see Section 1.5), and since even weak currents generate sufficient hydrodynamic drag to overcome small vertical buoyancy forces on the meter, there appears to be little difference in the salinity data recorded by the two meters. Because of the depth of the meters it also appears that eliminating the rope tether, the purpose of

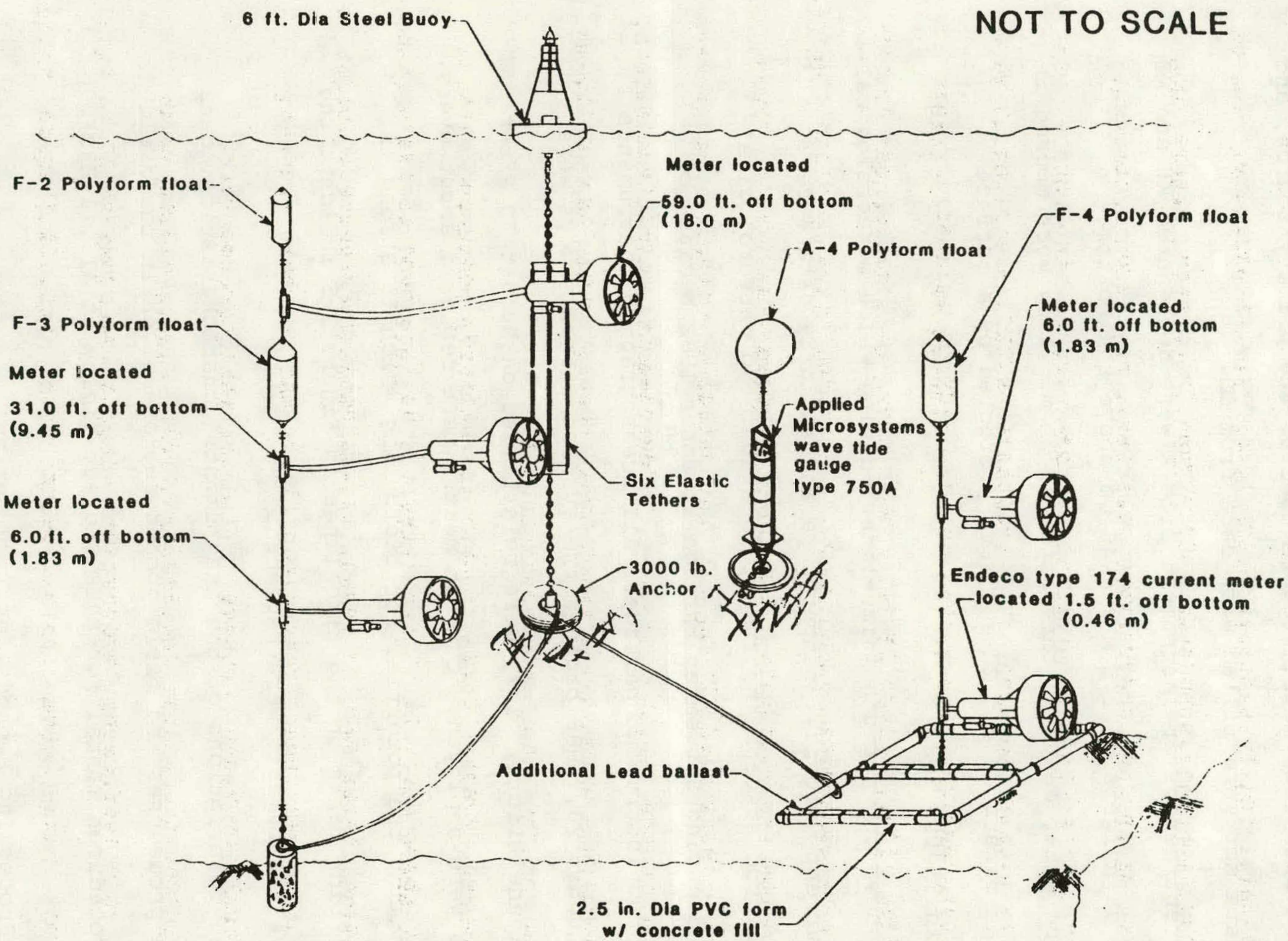


Figure 1-2. Schematic diagram of instrument moorings at site C. The three meters on the left are designated CT, CM and CB (top to bottom) and the two on the right are designated CU and CZ.

which is to reduce the effect of surface gravity waves, did not adversely affect the current measurements. A quantitative comparison of the data from the two meters is being made and will be discussed in a later report. In this report the data from meter CU were used as the primary source, and gaps in the CU data set were filled with data from CB.

The two current meters at instrument site K were designated KU and KZ and were located at heights of 1.6 m and 46 cm above the bottom, respectively. The water depth at this site was 21 m. They were moored in the same manner as meters CU and CZ and were protected by a surface witness buoy as in Figure 1-2.

Figure 1-3 shows the periods (time-lines) during which meteorological parameters and current velocity, temperature and salinity data were successfully collected at each instrument location. No meteorological data were recorded during September through November 1982 because of problems in the NDBC instrument package. All oceanographic instruments were removed on August 23, 1983 because the surface witness buoys were lost during Hurricane Alicia. They were reinstalled on August 30 after new witness buoys were deployed. Current meters were replaced about every four weeks to minimize the potential for biofouling which is strong in this area. Small tick marks on the time lines in Figure 1-3 indicate the dates on which the instruments were replaced.

More detailed descriptions of the instruments' characteristics, data quality assurance procedures and field procedures are given in the field and laboratory procedures manual for this project (Kelly et al., 1983c).

1.2.2 Data Processing Methods for Time Series

The time series of raw data (speed, direction, temperature, and conductivity) for each deployment period were carefully edited to

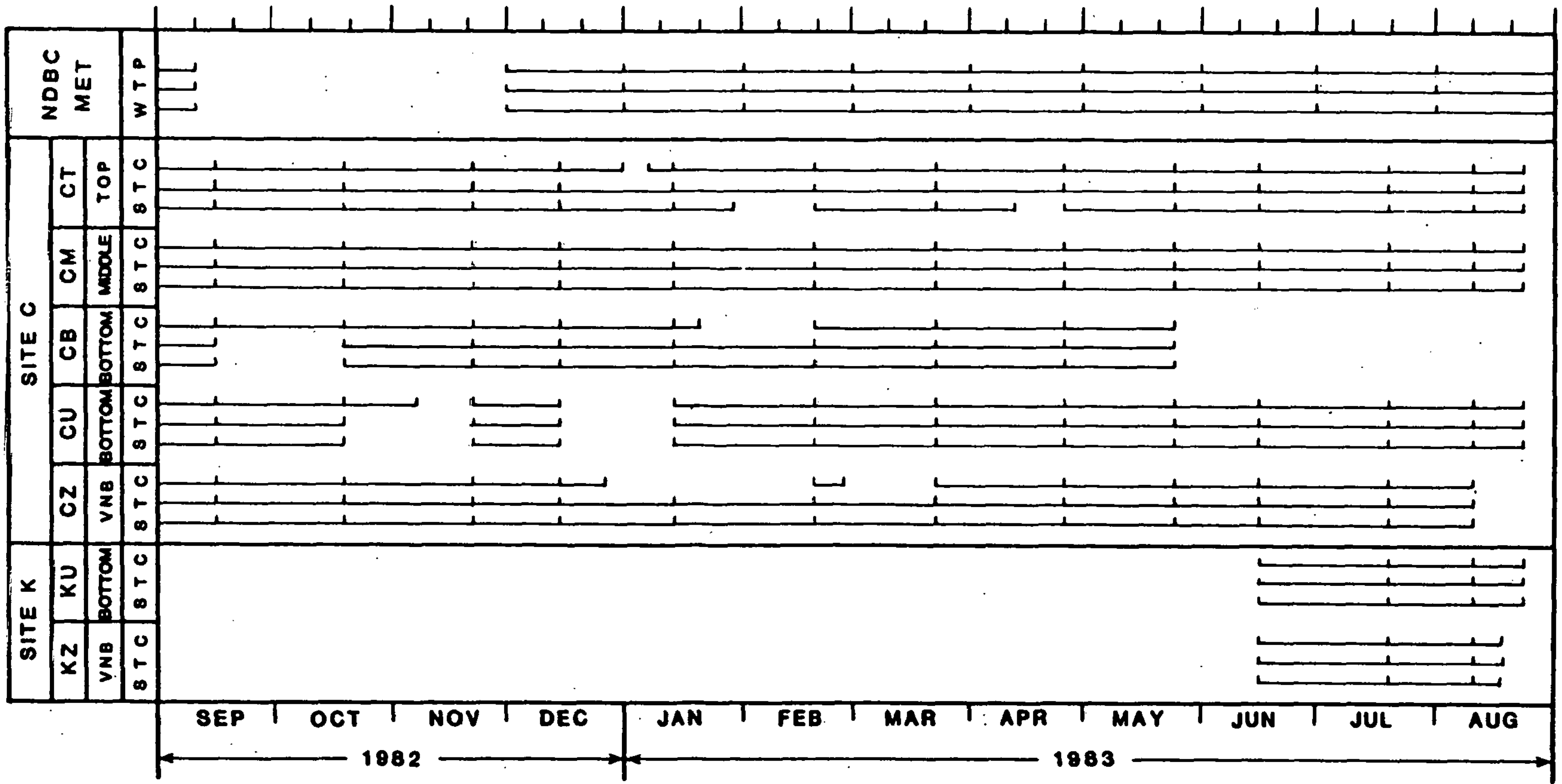


Figure 1-3. Time-lines showing the periods of time during which good data were recorded for the following parameters: current velocity (C), temperature (T), salinity (S), barometric pressure (P), wind velocity (W) and air temperature (T).

eliminate spikes or other obviously bad data points. Current velocity data were then resolved into orthogonal components oriented parallel and perpendicular to the local isobaths. The parallel direction was approximately 055°T to 145°T. Temperature and conductivity data were used to calculate salinity according to the equation of Daniel and Collias (1971), a low order polynomial which is computationally efficient and quite sufficient for the accuracies of the instrument.

A two-hour, low-pass, symmetric Lanczos filter was then applied to each of the time series: alongshelf current, cross-shelf current, temperature and salinity. The raw data were recorded at several different sampling intervals, depending on a meter's location. Meters CT and CM had a 3-minute sample interval; meters CB, CU and KU had a 5-minute interval; and meters CZ and KZ had a 10-minute interval. Two-hour low-pass filters were designed to produce identical responses for each of the different sample intervals. The filters had a -6 db point at two hours and a sharpness which resulted in 1.5 hour being lost from each end of the record. The filtered series were then subsampled at a half-hour interval.

The resulting half-hour series from each deployment period were joined end-to-end to form a single long series for each parameter. Short gaps were filled by linear interpolation. Gaps greater than about one day in duration were not filled and thus determined how long the joining process was carried on before a new series was begun.

Table A-6 lists the dates for each deployment period along with notes about the data quality for each period.

The joined series were filtered with a three-hour low-pass filter and subsampled at hourly intervals; finally they were filtered with a 40-hour, low-pass filter and subsampled at six-hour intervals. Both filters were symmetric Lanczos filters and had sharpnesses which resulted in a loss of eight hours and four days of data, respectively, from each end of the record. The 40-hour, low-pass filter was designed to eliminate all fluctuations of a daily nature such as tides, inertial oscillations, etc. The subsequent analyses to be discussed utilize the three-hour and 40-hour, low-pass filtered time series. The above time-series operations were performed using the FESTSA software package (Brooks, 1976).

The time series were analyzed by a variety of methods. First, basic statistics were computed for monthly intervals for each series, and the results are listed in the tables in section A.2. Next, joint frequency distributions of speed and direction were computed for wind velocity and for current velocity over monthly intervals and rose diagrams were plotted. These results are shown in section A.3. Monthly plots of the meteorological time series (section A.4) and the oceanographic time series (section A.5) were constructed. For vector time series, the monthly plots show both the three-hour and the 40-hour, low-pass filtered series of each orthogonal component and a stick vector series reconstructed at six-hour intervals from the 40-hour, low-passed orthogonal components. For scalar time series, just the three-hour low-passed data are plotted. Harmonic analyses for 29-day intervals were performed for the currents. A modified version of the program by Dennis and Long (1971) was used, and the parameters of the tidal current ellipse were also computed (Doodson and Warburg, 1941). Tables of the results are given in section A.6. Section A.7 shows time series plots of the site C, bottom data for each day on which a plume-mapping cruise was conducted. These plots are provided primarily for reference purposes in the discussion in Chapter 2.

Autospectra, rotary spectra, phase and coherence squared were computed for various individual series and pairs of series of wind and currents. The Fast Fourier Transform (FFT) method was used.

An introduction is provided for each section in Appendix A which gives additional details about the method of analysis used to obtain the results of that particular section and how to interpret the tables or plots. In the discussions in this chapter, selected figures from the Appendix are used along with special summary plots to elucidate the main points of interest.

1.2.3 CTD/DO Hydrographic Surveys

Conductivity, temperature, depth, and dissolved oxygen (CTD/DO) data were collected at the stations listed in Table 1-1 and shown in Figure 1-4. These data were measured at the bottom, 1 m above the bottom, every 3 m, and 1 m below the surface. The hydrographic data were collected on monthly cruises aboard the university research vessel, the R/V EXCELLENCE II, using a Hydrolab 8000 system which measures conductivity, temperature, depth and dissolved oxygen. The accuracy of the conductivity sensor (four electrode type) is ±0.5% of full scale, which is 200 mmho/cm at 25°C; this corresponds to ±1 mmho/cm or ±0.7 o/oo. To improve the salinity accuracy, the probe is calibrated with standard solutions using a Grundy laboratory salinometer. It has an accuracy of ± 0.003 o/oo (Grundy, 1978), and the salinity accuracy after calibration is about ±0.5 o/oo. The temperature, dissolved oxygen, and depth sensors have accuracies of ± 0.2°C, ±0.2 mg/l, and ±1 m, respectively.

The conductivity data were converted to salinity using the equation of Weyl (1964). The salinity data were then corrected as required by the calibration results after each cruise. The temperature data were used as read from the instrument since calibration results have shown the

Table 1-1. Latitude and longitude for conductivity, temperature, depth and dissolved oxygen field measurement stations.

Station	North Latitude	West Longitude
12	28°51.96'	95°19.74'
14	28°49.50'	95°17.99'
16	28°47.33'	95°16.20'
33	28°42.30'	95°17.70'
34	28°44.45'	95°14.67'
34A	28°45.20'	95°12.70'
34B	28°44.70'	95°13.20'
34C	28°43.20'	95°13.90'
34D	28°42.40'	95°13.30'
34E	28°43.00'	95°16.40'
34F	28°43.60'	95°15.50'
34G	28°44.90'	95°15.10'
36	28°41.40'	95°11.45'
39	28°47.00'	95°10.40'

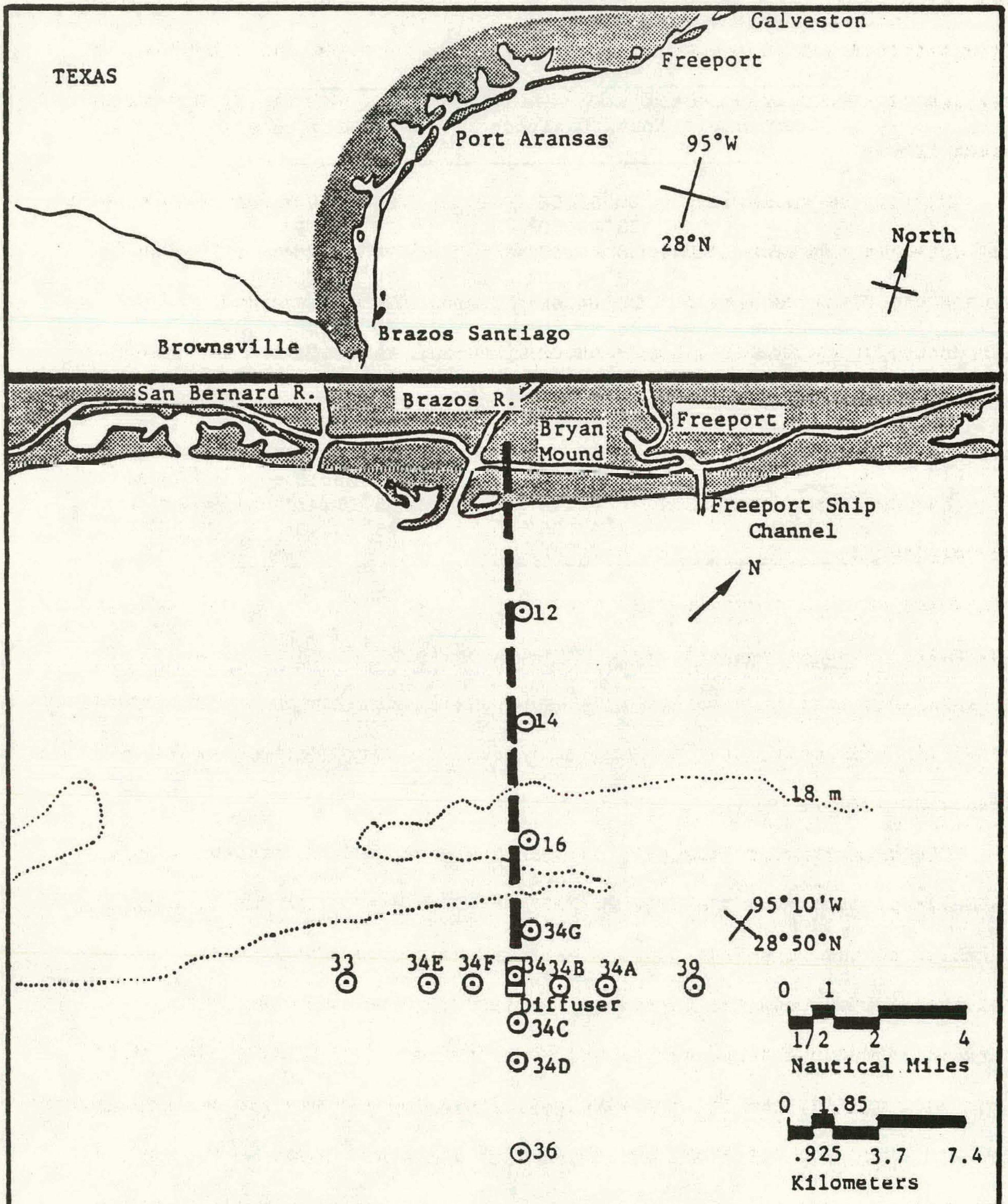


Figure 1-4. Locations of CTD/DO hydrographic survey stations occupied monthly during September 1982 through August 1983.

temperature measurements to be within the manufacturer's accuracy specifications. The depth measurements frequently required a correction. It was determined by a surface (zero depth) measurement and a bottom measurement which was checked with the ship's depth sounder or the marked winch line.

During the collection of the CTD/DO data, selected water samples were collected at the same location as the sensor and were chemically fixed aboard the research vessel. These water samples were returned to the laboratory and analyzed using Winkler titration procedures. The field dissolved oxygen data were corrected for salinity and temperature effects and then further corrected using the results from the Winkler analysis.

The salinity, temperature, and depth data for each station are used to compute the density of the water column. This is presented in the customary oceanographic form of sigma-t. Sigma-t values are computed from salinity, temperature, and depth data using the equation of LaFond (1951). A detailed description of the instrumentation, calibration procedures and field procedures is given in the Field and Laboratory Procedures Manual (Randall, 1983).

The hydrographic data for the period September 1982 through August 1983 are presented in the form of vertical cross-sections for transects parallel to the pipeline (cross-shelf) and normal to the pipeline (alongshelf) through the center of the diffuser (station 34). The stations for the cross-shelf transect are numbers 12, 14, 16, 34G, 34, 34C, 34D, and 36, and for the alongshelf transect the station numbers are 39, 34A, 34B, 34, 34F, 34E, and 33, all of which are shown in Figure 1-4. The vertical sections clearly show the magnitude and extent of the effect of the brine discharge at station 34 on the hydrography of the area and demonstrate the natural short-term and intra-annual variations which result from fresh water runoff along the Texas-Louisiana coast as previously described by Kelly and Randall (1980) and Kelly et al. (1983a). Selected vertical sections are discussed in detail; a complete set of monthly vertical sections is in Appendix A.

1.3 Observations

The data of this report were divided into four seasons of three months each beginning in September 1982. For each season, the temporal variability is described using the continuously recorded data, and then the spatial distributions of the hydrographic variables are described for a single date each month using the results of the hydrographic surveys by ship. The 40-hour, low-passed time series are used for discussion and comparison of the continuously recorded data. Forty-hour, low-passed data are similar to daily averages, i.e. fluctuations with a period of a day or shorter have been removed. Large fluctuations can and do occur within one day, and the figures in Appendix A.5 show detailed monthly plots which include short period fluctuations. A common scale has been used for the seasonal plots of 40-hour, low-passed data to facilitate comparison. This resulted in a few cases in which the range of currents exceeded the range of the plot, but the figures in Appendix A.5 can be referred to for the full range.

The time series of currents are also presented in the form of progressive vector diagrams for each season. They were made from the three-hour, low-passed data. A progressive vector diagram shows the displacement a particle would have if it had the velocity measured at the fixed position of the current meter at all times. For small displacements the progressive vector diagram is an approximation to the particle trajectory and is useful for estimating advective length scales and the relative displacements between different meter locations.

In the discussions of the effect of the brine plume on salinity, it is assumed that the salinity at CU is ambient and that greater values at CZ are a result of the brine. Based on the results of the salinity data from the control site KU, this appears to be a good assumption. The CU meter often recorded short fluctuations of 1 o/oo or less which appear to be brine related, but these disappear when the data are filtered or averaged; the salinities at CU and KU then agree within instrument accuracy.

The principal source of the fresher water observed in the study area is the Mississippi-Atchafalaya river system, although discharge from smaller rivers and/or bays and estuaries may significantly freshen the inner coastal waters for brief periods of time. Figure 1-5 shows the volume flow for 1982 and 1983 of the Mississippi River at Tarbert Landing, the Atchafalaya River at Simmesport, and the sum of the two (U.S. Army Corps of Engineers, personal communication). There was clearly a much greater volume of discharge in 1983 than in 1982, and peak discharge was greater by a factor of almost two. The peak in late May-early June 1983 was partly the cause of the low salinity values in June and July. Another contributing factor was the lack of a persistent reversal to upcoast alongshelf wind and currents (see Section 1.3.4).

The hydrographic data are presented in the form of vertical sections and vertical profiles.

1.3.1 Fall (September, October, November)

Meteorological data were not recorded during this season because of problems in NDBC instrument package. Figures 1-6 and 1-7 summarize the

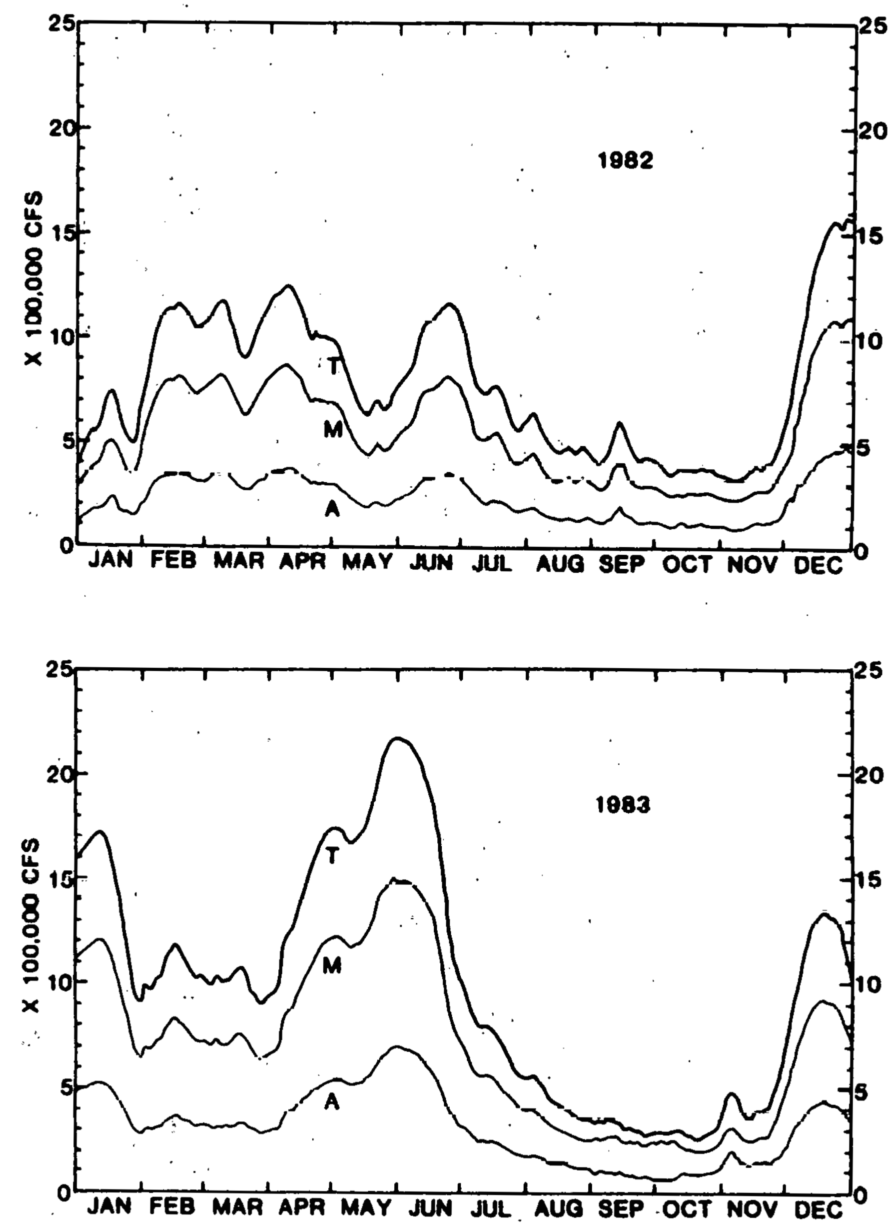


Figure 1-5. Average daily streamflow of the Mississippi River (M) at Tabert Landing, the Atchafalaya (A) at Simmesport and their sum (T) for 1982 and 1983.

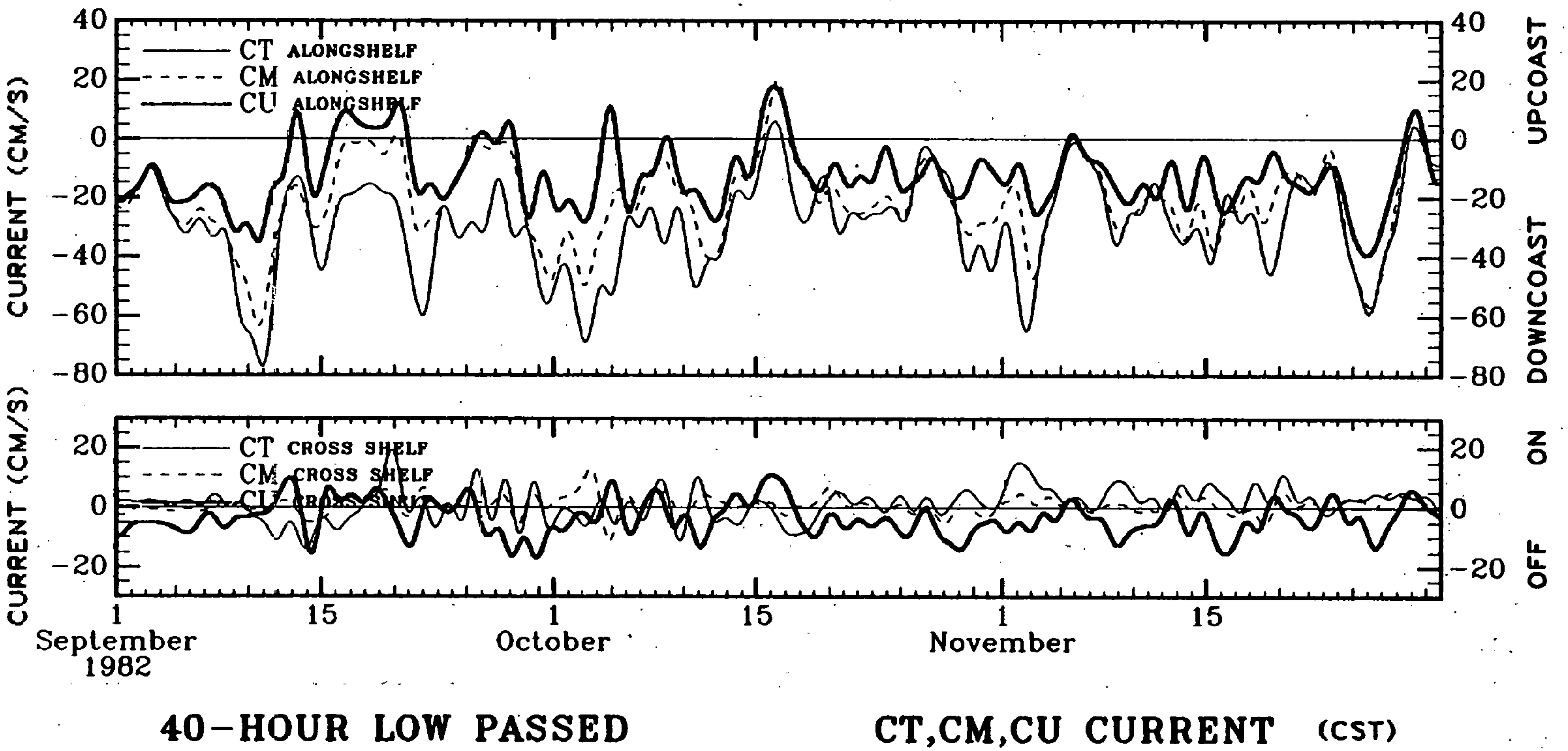
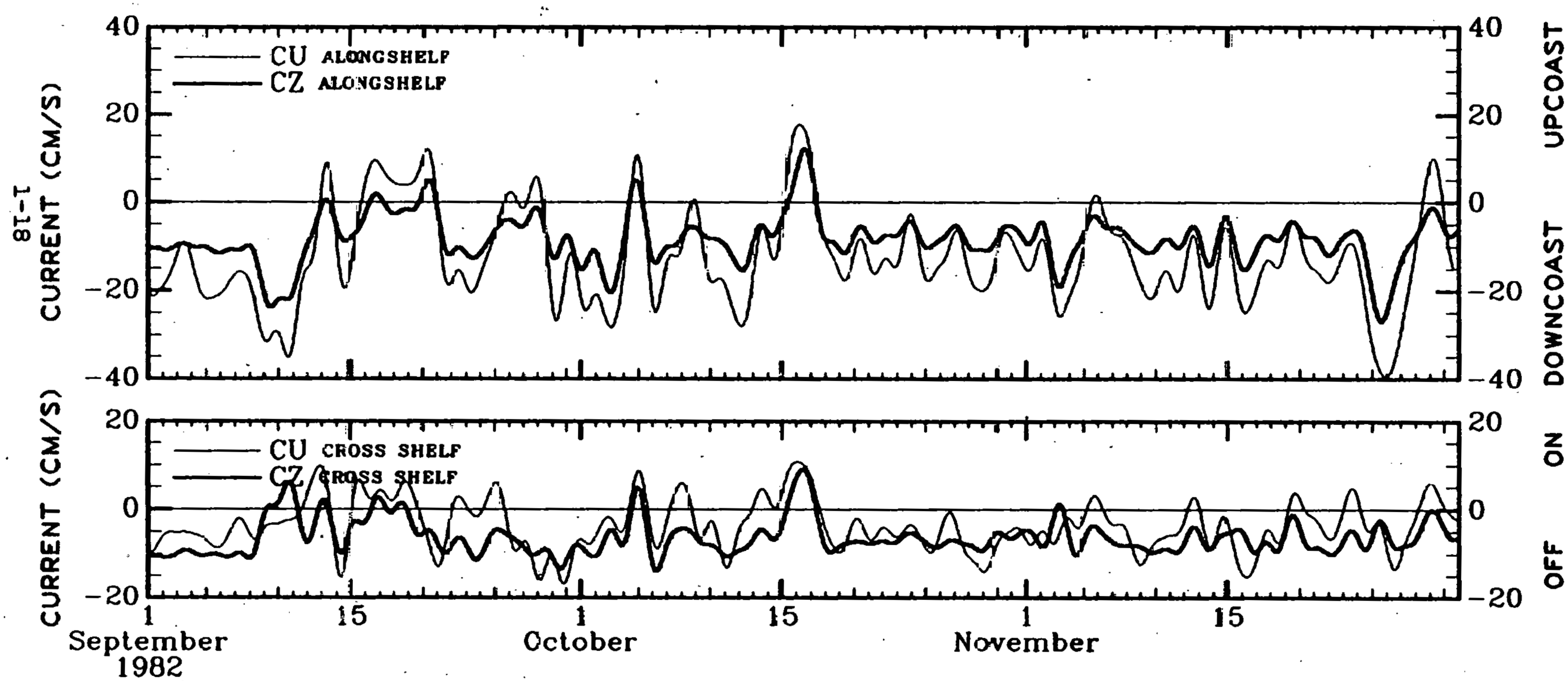


Figure 1-6. Summary of 40-hour, low-passed CT, CM and CU current data for fall 1982.



40–HOUR LOW PASSED WIND AND CU,CZ CURRENT (CST)

Figure 1-7. Summary of 40-hour, low-passed CU and CZ current data for fall 1982.

fall currents. Progressive vector diagrams are shown in Figures 1-8 and 1-9. The temperature and salinity data are summarized in Figures 1-10 and 1-11.

Alongshelf currents were downcoast through most of the fall except for a few short reversals to upcoast. The means for CT decreased from -32 cm/s in September to -26 cm/s in November. At CM, they were similar for the three months at about -21 cm/s. For CU, the alongshelf means were about -11 cm/s for the first two months and then increased to about -15 cm/s in November. Very close to the bottom, at CZ, the alongshelf means were still relatively high at -8 cm/s to -9 cm/s.

Cross-shelf means were almost zero at CT and CM during September and October and then in November were onshore at 4 and 1 cm/s respectively. The bottom meters recorded relatively strong offshore flow. At CU, the means were in the -3 to -4 cm/s range, and at CZ, they were about -6 cm/s. The progressive vector diagrams show that the reason CZ had stronger offshore flow than CU was a countercockwise rotation in the direction of the currents with depth. In terms of magnitude, CZ currents were not much smaller than CU currents.

Current roses for CT (see Appendix A.3) show that the most frequently recorded speed range was 30 to 40 cm/s in all three months while SW was the most frequently recorded direction sector. The predominance of downcoast currents resulted in the vector alongshelf means and the scalar averages of speed having about equal values in each month. At CM, the roses show that SW was also the most frequently recorded direction in all months. Speeds, however, were distributed broadly. Only in October did any speed range exceed about 15%. Scalar mean speeds were again similar to the vector alongshelf means.

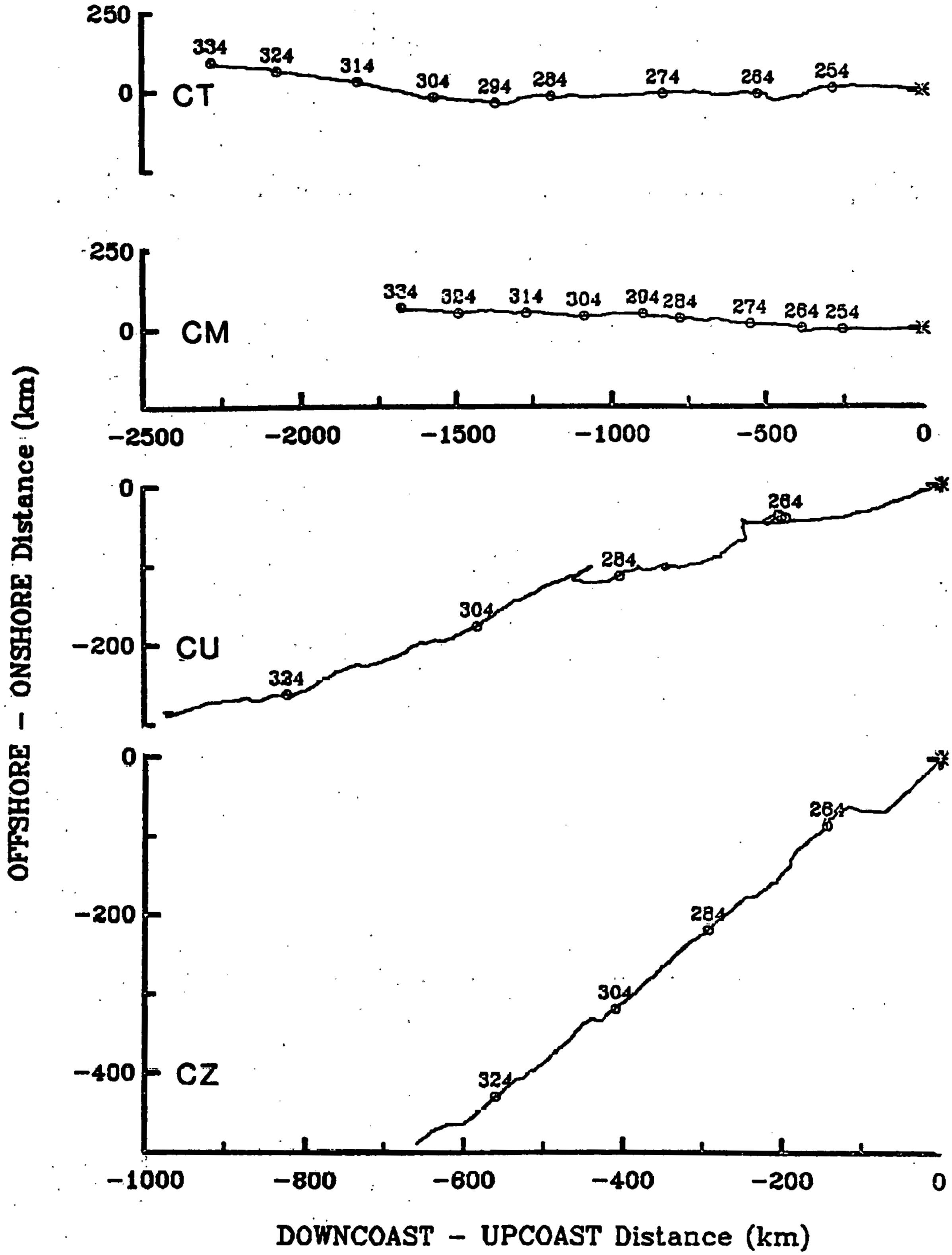


Figure 1-8. Progressive vector diagrams for current observed at meters CT, CM, CU and CZ during September 1, 1982 through November 30, 1982 (calendar days 244 through 334).

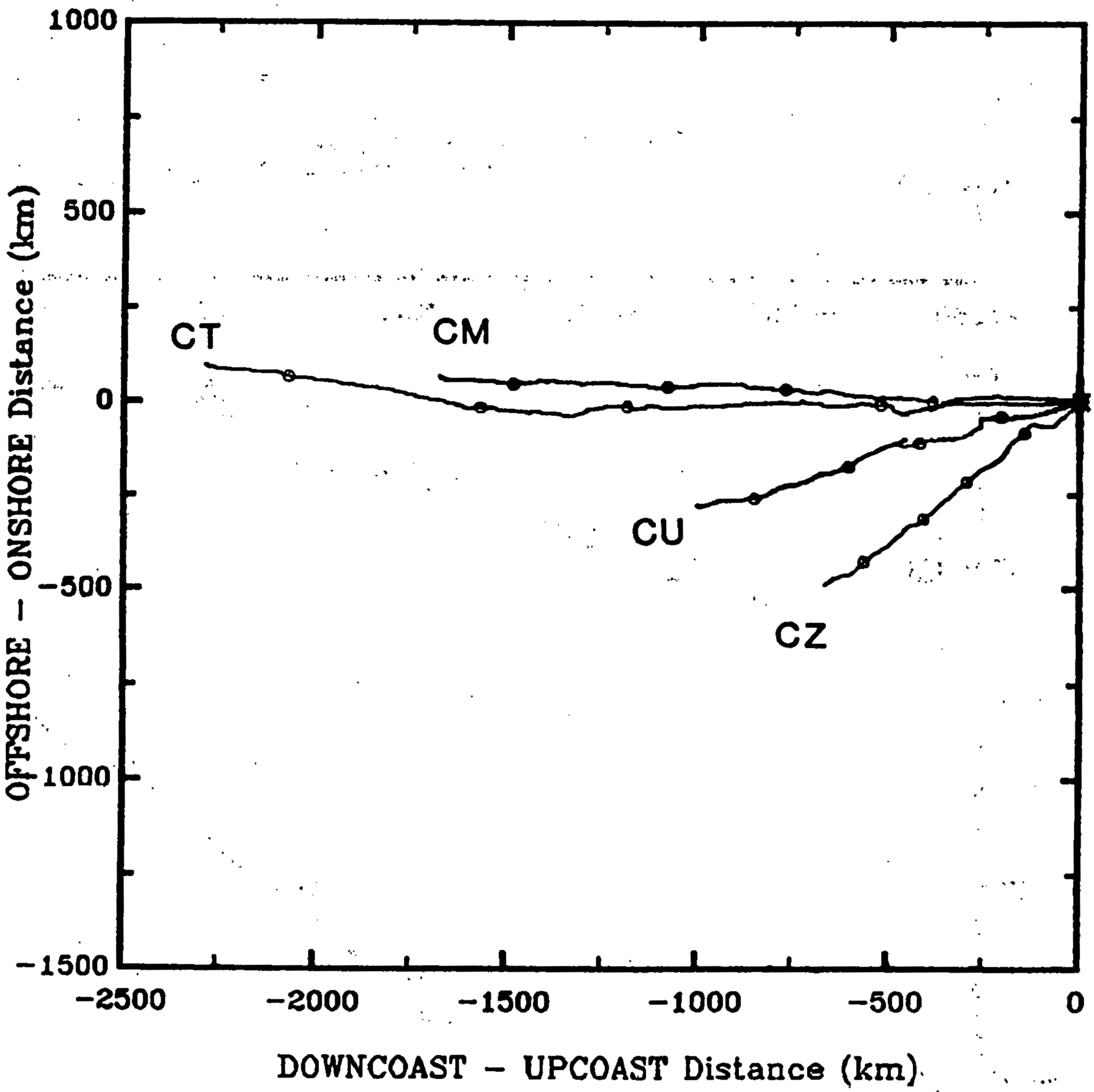
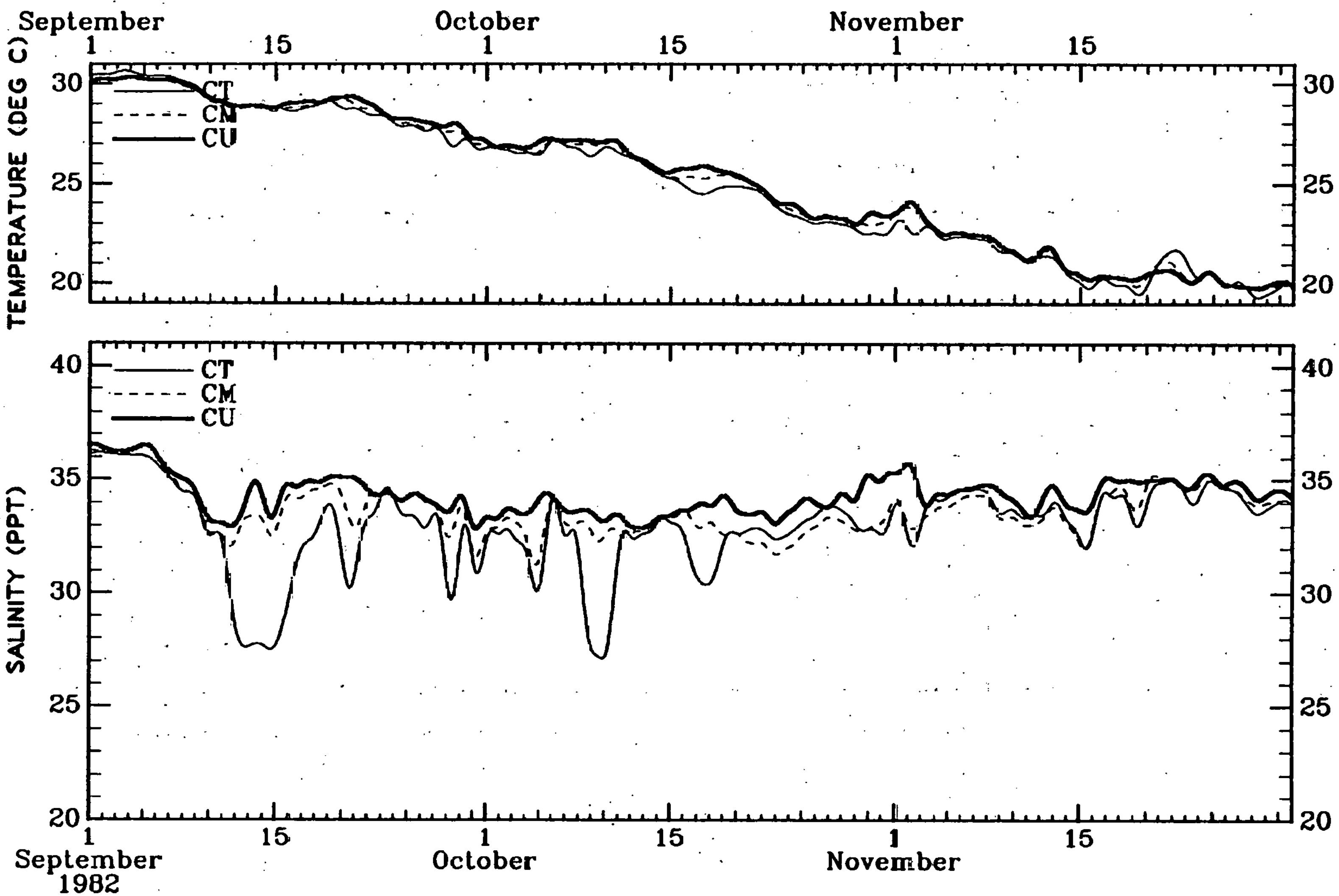


Figure 1-9. Progressive vector diagrams of Figure 1-8 plotted with a common scale and starting point. (Calendar days numbers above the tick marks have been eliminated to avoid overlap.)



40-HOUR LOW PASSED T AND S FOR CT,CM,CU (CST)

Figure 1-10. Summary of 40-hour, low-passed CT, CM and CU temperature and salinity data for fall 1982.

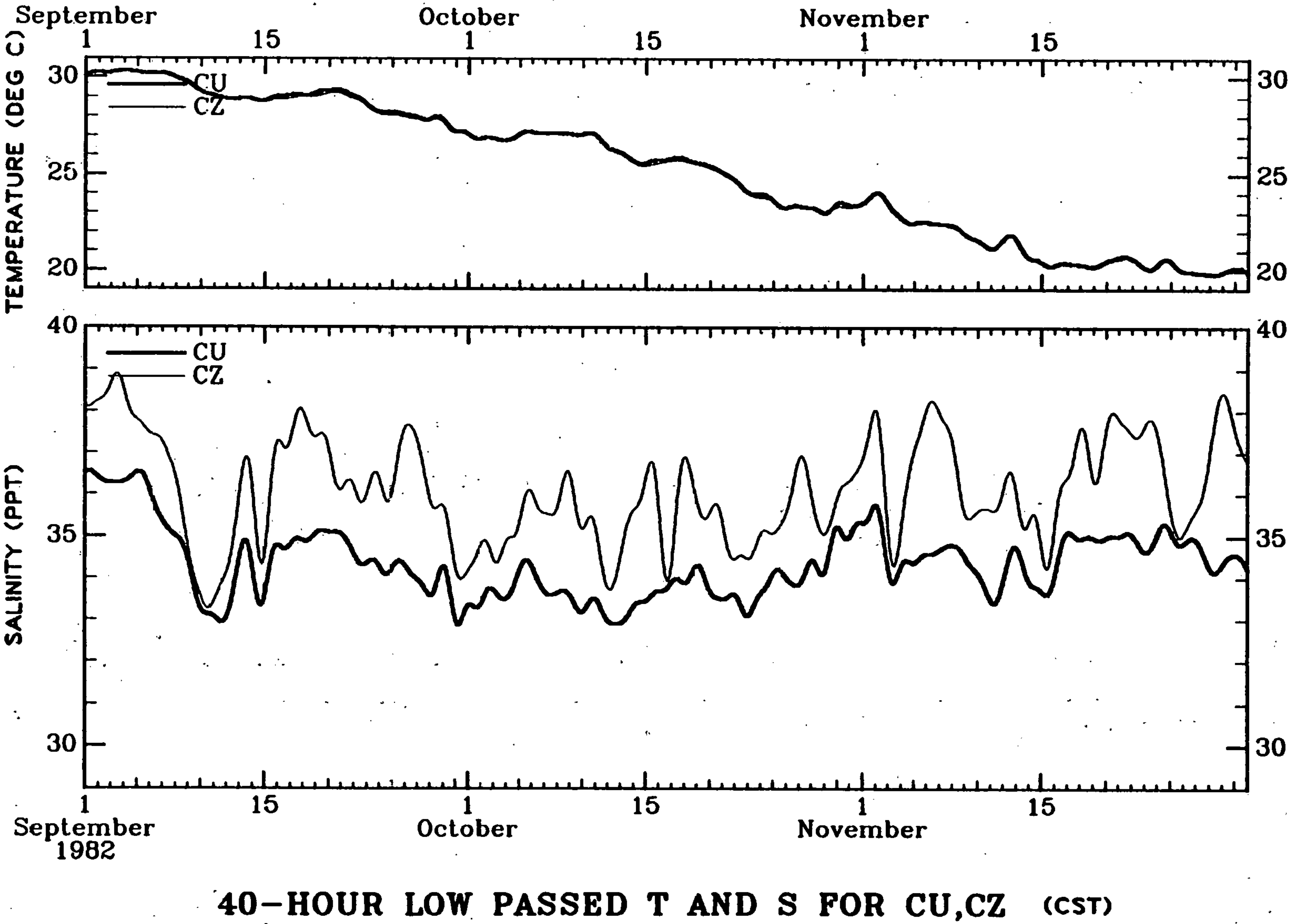


Figure 1-11. Summary of 40-hour, low-passed CU and CZ temperature and salinity data for fall 1982.

The roses for CU indicate that SW was still the most frequent direction sector. The progressive vector diagrams show there was some counterclockwise rotation of CU currents relative to CT and CM currents but not enough to influence the low percentage of observations in the S sector. Speeds were broadly distributed between 5 and 25 cm/s. Scalar mean speeds were about 17 cm/s in each month or several times the vector means. At CZ, the additional counterclockwise rotation in the bottom currents caused S to be the most frequent direction sector. The most frequent speed range was 10 to 15 cm/s in all months. Mean scalar speeds were high at about 12 cm/s.

Temperature (Figures 1-10 and 1-11) decreased from a high of slightly less than 31°C at the beginning of fall to about 20°C at the end. After mid-September, the bottom water was usually warmer than the surface water. Vertical differences were usually less than 1.5°C.

Salinity of the water column between CT and CU was fairly homogeneous from September 1 to September 10, but decreased from about 36 to 33 o/oo. Between September 10 and October 20, a series of pulses of fresher water were recorded. The salinity at CU varied slowly between 33 and 35 o/oo while the salinity at CT dropped to 26 to 27 o/oo during the September 11 through September 19 and October 13 through October 17 periods. At site C, the fresher water was confined mostly to the upper half of the water column. Smaller salinity decreases of about 4 o/oo occurred briefly a number of other times. The one on October 5 penetrated below mid-depth.

Figure 1-11 shows the effect of brine on near bottom salinity. Assuming that the salinity at CU is approximately an ambient measure, the salinity at CZ varied between ambient and about 4 o/oo above ambient. The larger above ambient values occurred with low current conditions such as during the periods September 16 through September 20 and November 5 through November 8. Plume effects vanished during very strong currents on September 11 and November 26 and during periods when the current was moderate but directed so that site C was upstream of the diffuser, such as on October 16. Despite the fact that the average bottom currents were strong, plume effects were quite evident. This may be related to the fact that bottom currents during the fall were directed such that site C lay downstream from the diffuser much of the time.

Spatial distributions of the hydrographic variables were mapped in the fall of 1982 on September 7, October 5 and November 2. The results of the September 7 cruise are shown by the vertical transects in Figures A-2 and A-3. On this date, the brine with a salinity of 252 o/oo and a temperature of 29°C was being discharged at an average rate of 41,189 barrels/hr. Currents were approximately downcoast at about 25 cm/s.

The ambient environment of the region was relatively homogeneous with salinity values near 35 o/oo, temperature values near 29.8°C, sigma-t values near 22, and dissolved oxygen values near 5.6 mg/l. Salinity increased slightly in the offshore and downcoast directions. The brine plume was clearly evident near the bottom of station 34. The 36 o/oo isohaline extended almost to stations 34G and 34C in the cross-shelf direction, or a distance of about 1.6 km from the diffuser. In the alongshelf direction, the plume extended from midway between stations 34 and 34B to midway between stations 34E and 34F; the plume was clearly directed downcoast and reached a distance of about 3 km from the diffuser. The highest bottom salinity was 37.9 o/oo at station 34 or about 2.9 o/oo above the ambient salinity at station 39.

On October 5, there were strong spatial gradients in the ambient environment as Figures 1-12 and 1-13 show. Brine was being discharged at an average rate of 40,850 barrels/hr with a salinity of 254 o/oo and a temperature of 29°C. Currents were strongly sheared in the vertical (Figures A-57, A-69, A-81, and A-93) and variable during the time of this cruise. Near surface currents were downcoast and varied between 25 cm/s and 65 cm/s while bottom currents varied between 20 cm/s upcoast and onshore and 25 cm/s downcoast and offshore.

Water temperature was near 27°C, and it increased slightly from bottom to top and in an offshore direction. The plume did not change the ambient temperatures near station 34.

A wedge of fresher water with a double frontal structure lay inshore of station 34D. Salinity values in this wedge ranged from 27 o/oo to 34 o/oo. Inshore of station 14, the water column was vertically homogeneous but horizontally stratified because of a vertical front between stations 12 and 14. A stronger inclined front extended from inshore of station 18 to offshore of station 34G. The alongshelf transect through station 34 shows that the mass of fresher surface water was deeper downcoast from station 34. However, this may be an artifact since the currents were quite variable during the time of this cruise. The density distribution is almost identical to the salinity distribution.

The presence of the brine plume is clearly shown by the closely spaced convex isohalines extending to three meters above the bottom near station 34. The ambient bottom salinity at station 39 was 34.8 o/oo, so the 35 o/oo isohaline represents a 0.2 o/oo above ambient contour line. The 35 o/oo isohaline extended from 34G to 34C in the cross-shelf direction and from 34F to 34B in the alongshelf direction. The span of the 35 o/oo contour was 3.7 km in both the alongshelf and cross-shelf

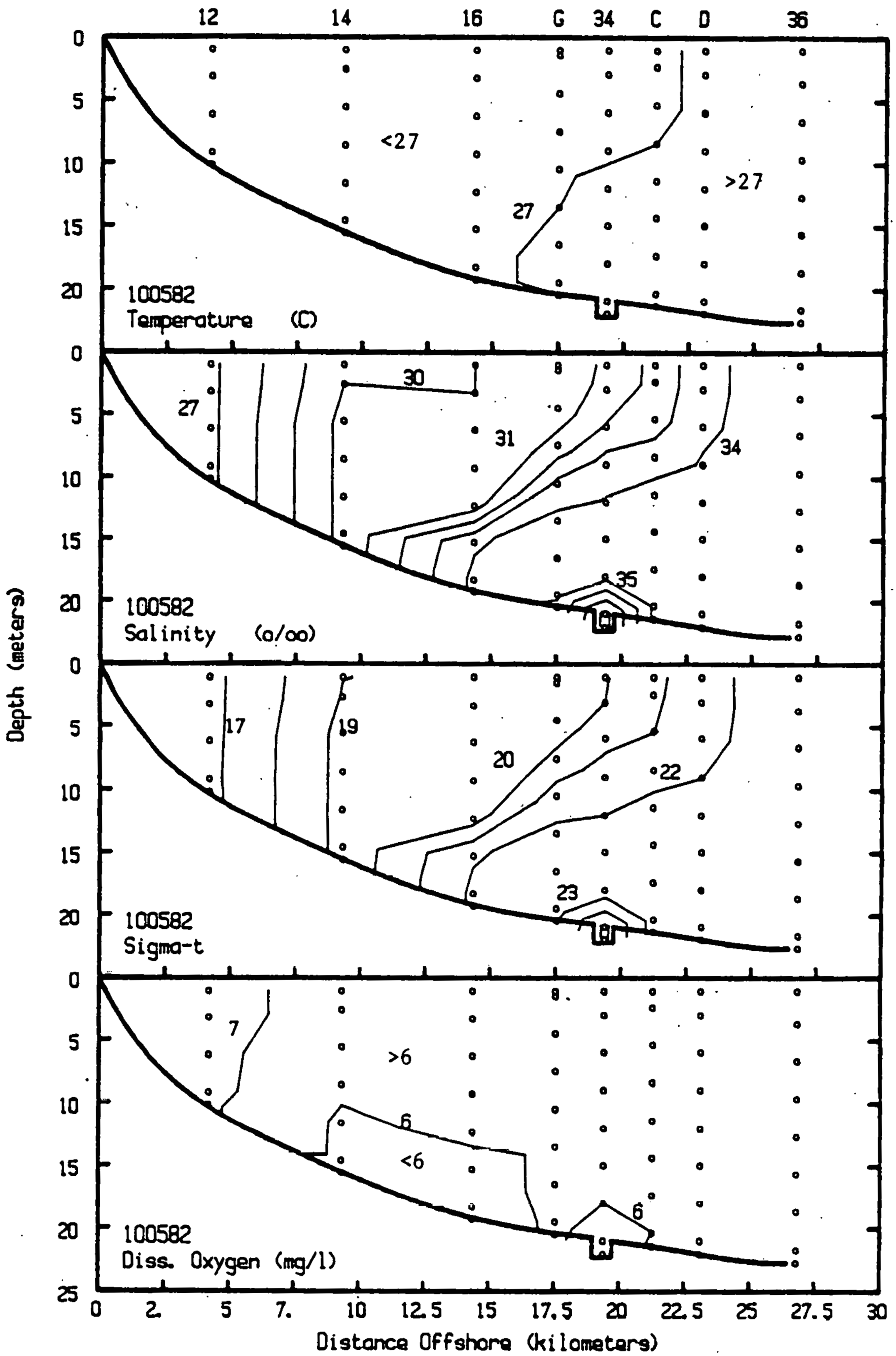


Figure 1-12. Hydrography for the cross-shelf transect offshore Freeport, Texas on October 5, 1982.

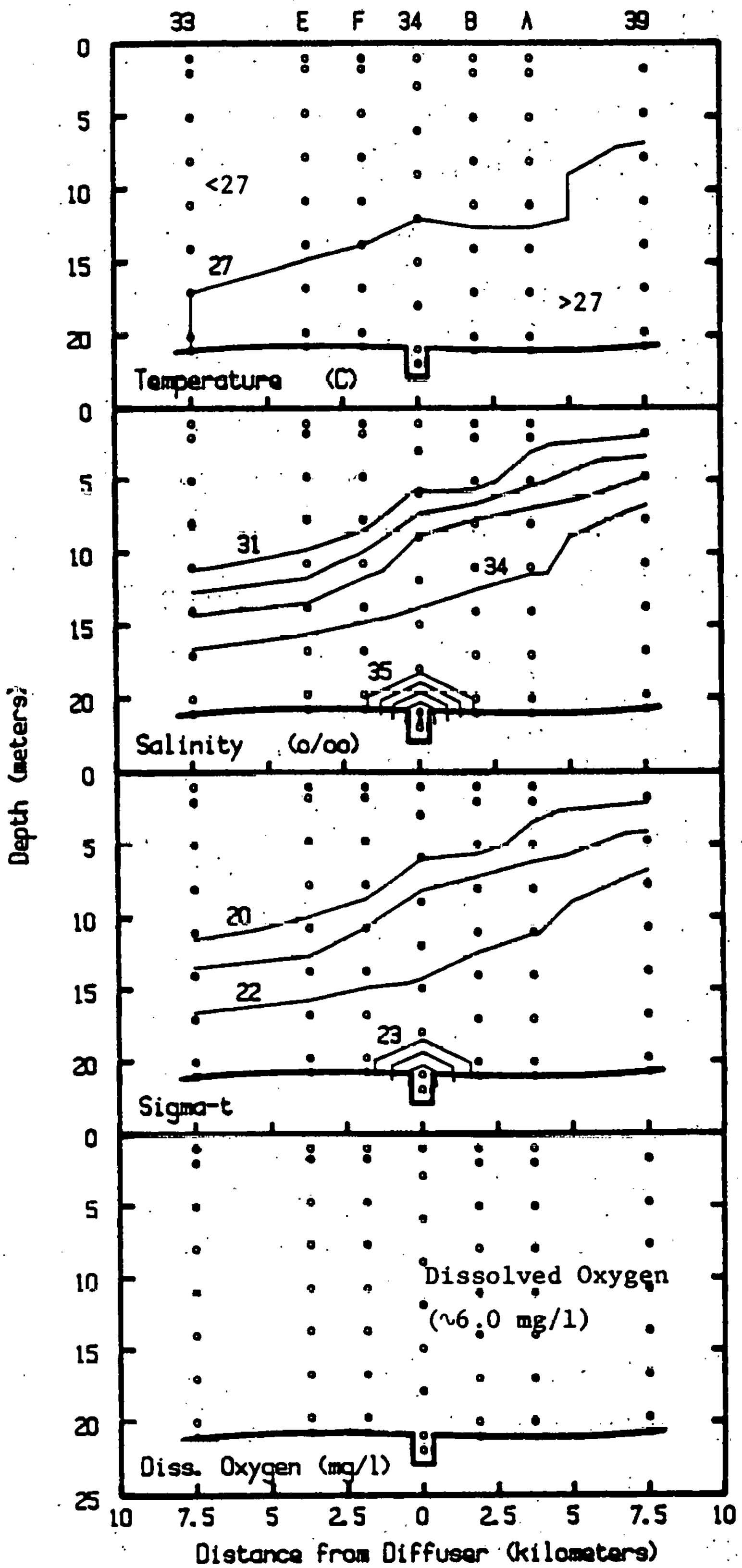


Figure 1-13. Hydrography for the alongshore transect offshore Freeport, Texas on October 5, 1982.

directions. The highest salinity values measured at station 34 were 38.3 o/oo during the cross-shelf transect and 39.2 o/oo during the alongshelf transect.

The dissolved oxygen data indicate the water column was near 7 mg/l at station 12 and near 6 mg/l in the remainder of the water column in both the cross-shelf and alongshelf directions. There was a slight decrease in oxygen content from the surface to the bottom. For example, at station 34, it decreased from 6.6 mg/l at the surface to 5.7 mg/l at the bottom.

Data from the November 2, 1982 cruise are shown in Figures A-6 and A-7. On this date, the brine was being discharged at an average rate of 38,147 barrels/hr, and the average brine salinity and temperature were 257 o/oo and 31°C, respectively. Currents were variable and vertically sheared during the day of this cruise but were directed downcoast at all depths. Near surface currents varied between 45 cm/s and 75 cm/s and near bottom currents varied between about 10 cm/s and 25 cm/s (see Appendix A).

The temperature increased with distance offshore from slightly less than 22°C at station 12 to slightly greater than 24°C at station 36. A slight temperature increase with depth was observed in the alongshelf direction with values slightly less than 23°C near the surface and near 24°C at the bottom.

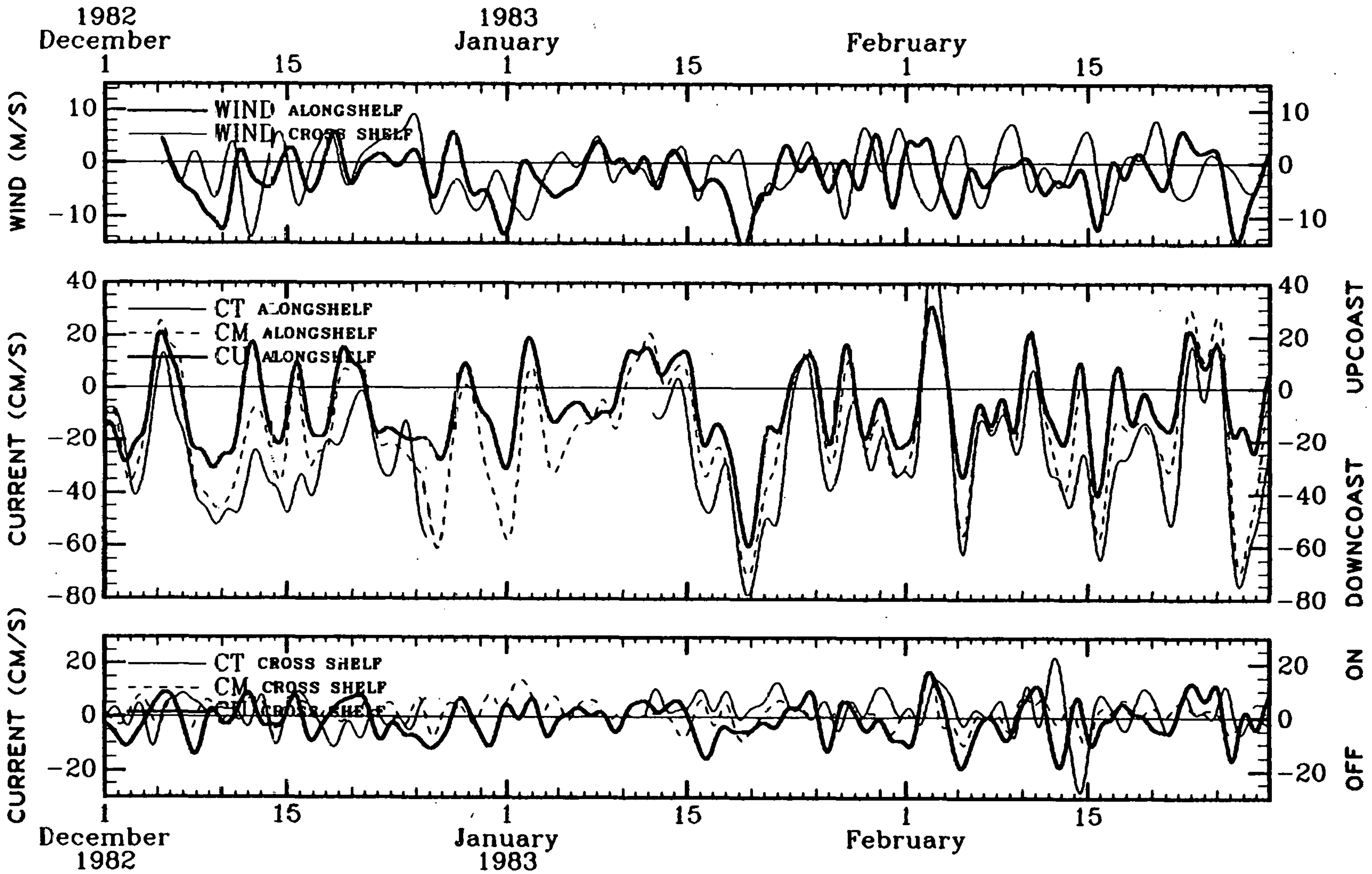
The salinity and density data in November generally increased from surface to bottom, from inshore to offshore and from northeast to southwest. The salinity ranged from 29 o/oo nearshore to 34 o/oo offshore. The brine plume is indicated by the convex isohalines of 35 and 36 o/oo near the bottom in the vicinity of station 34 in both the cross-shelf and alongshelf transects. The 35 o/oo isohaline spanned a distance of about 8 km in the cross-shelf direction and 6 km in the alongshelf direction. The bottom salinity at station 39 was 34.6 o/oo so the 35 o/oo isohaline was approximately 0.4 o/oo above ambient. The highest measured salinities were 37.7 and 37.8 o/oo at the bottom of station 34 (diffuser location) during the alongshelf and cross-shelf transects, respectively.

Dissolved oxygen decreased with depth; values slightly greater than 7 mg/l were observed in the upper part of the water column and less than 7 mg/l in the lower part. At the diffuser site the dissolved oxygen decreased from 7.9 mg/l at the surface to 6.8 mg/l at the bottom. The data show no indication of a brine effect on the dissolved oxygen in the bottom waters.

1.3.2 Winter (December, January, February)

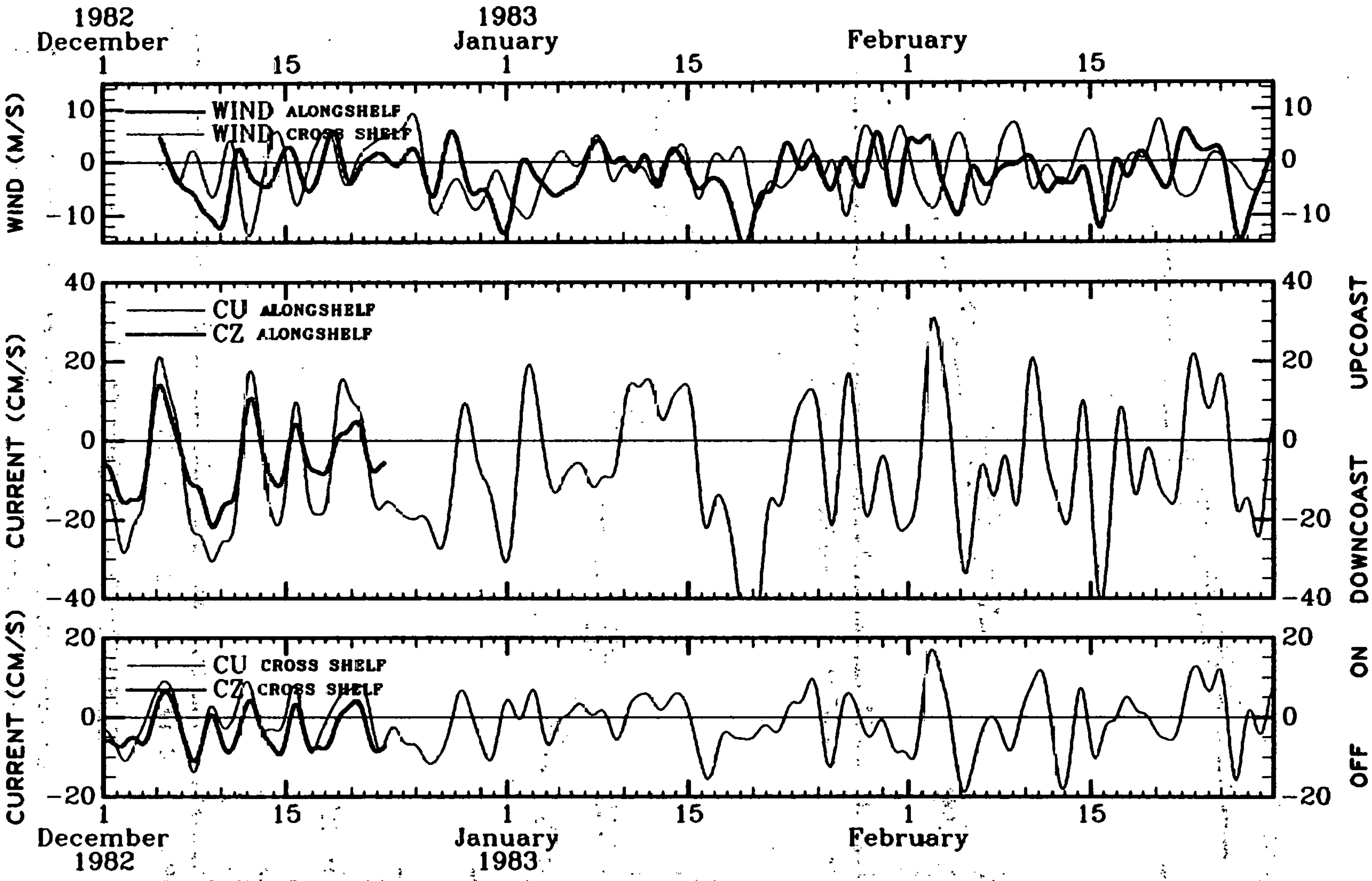
There are no currents from the CZ location from December 26, 1982 to March 22, 1983, and no currents from the CT location from December 30, 1982 to January 7, 1983. (The gaps in the 40-hour, low-pass filtered data are longer because of the filtering operation). Figures 1-14 and 1-15 summarize the wind and currents from the winter season. Figures 1-16 and 1-17 show the progressive vector diagrams. The gap in CT currents was filled with data from CM in order to plot the CT progressive vector line. The CZ line is only for a short 26-day period. There were no gaps in the temperature data during the winter, but salinity at CT had a gap from January 29 to February 19, 1983. Figures 1-18 and 1-19 show the 40-hour, low-passed temperature and salinity data.

The monthly mean wind components were downcoast and offshore in all three months (see Appendix A.3). The means increased in strength from December to January. The most frequent direction sector was S in all three months. The second most frequent sector changed from NW in December



40−HOUR LOW PASSED WIND AND CT,CM,CU CURRENT (CST)

Figure 1-14. Summary of 40-hour low-passed wind and CT, CM and CU current data for winter 1982-1983.



40−HOUR LOW PASSED WIND AND CU,CZ CURRENT (CST)

Figure 1-15. Summary of 40-hour low-passed wind and CU and CZ current data for winter 1982-1983.

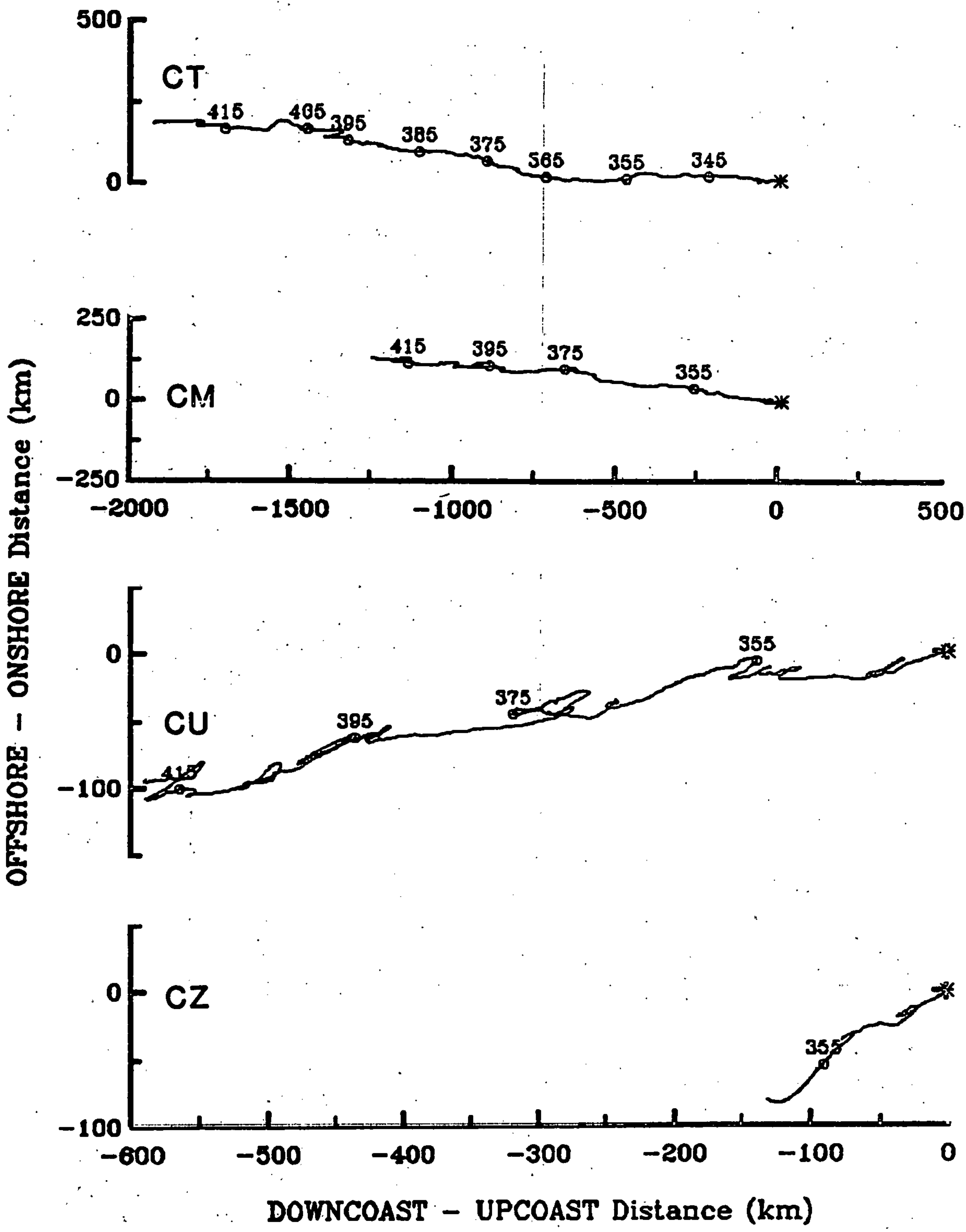


Figure 1-16. Progressive vector diagrams for currents observed at CT, CM, CU, and CZ during December 1, 1982 through February 28, 1983 (Calendar days 335 through 424).

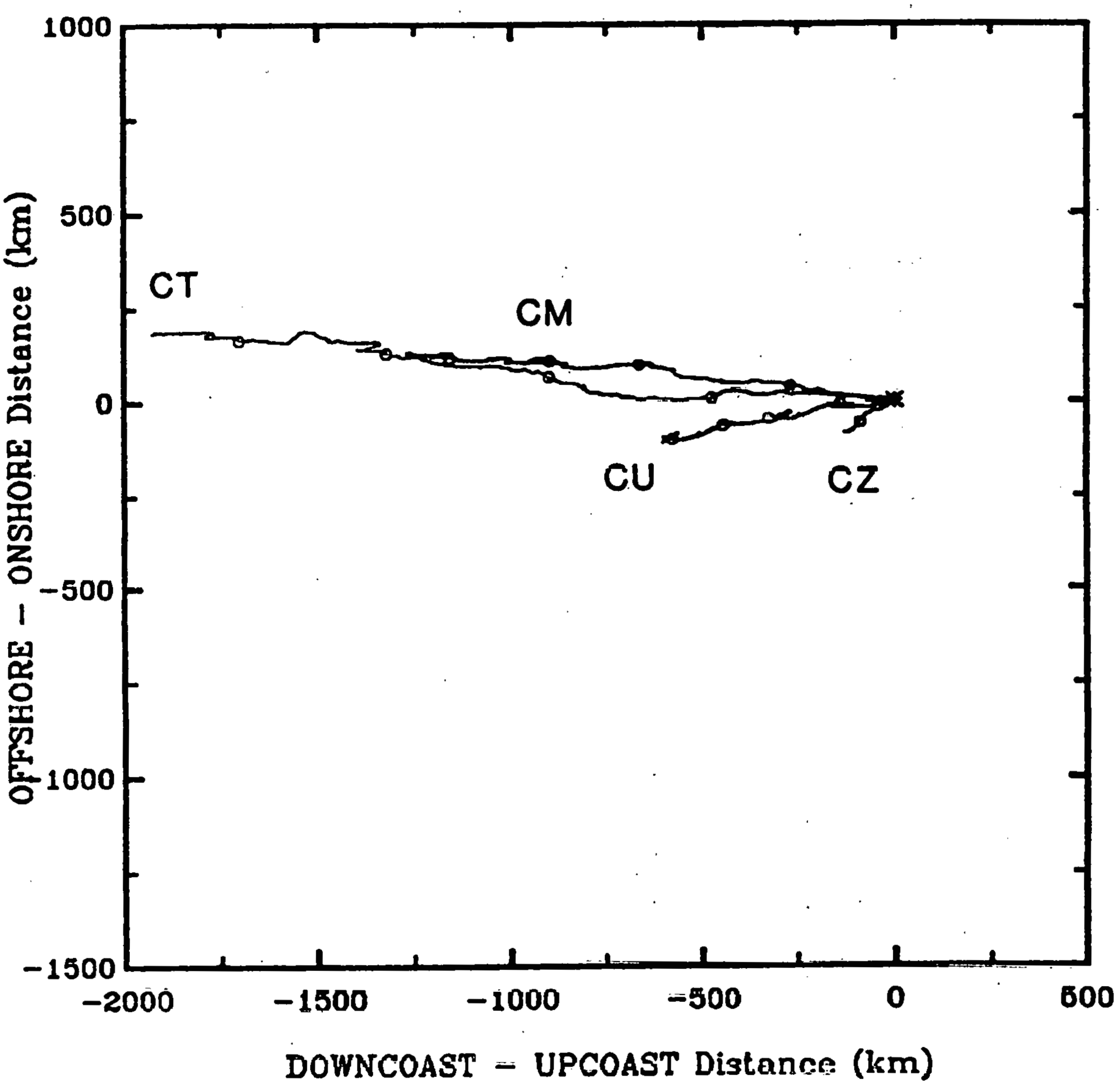
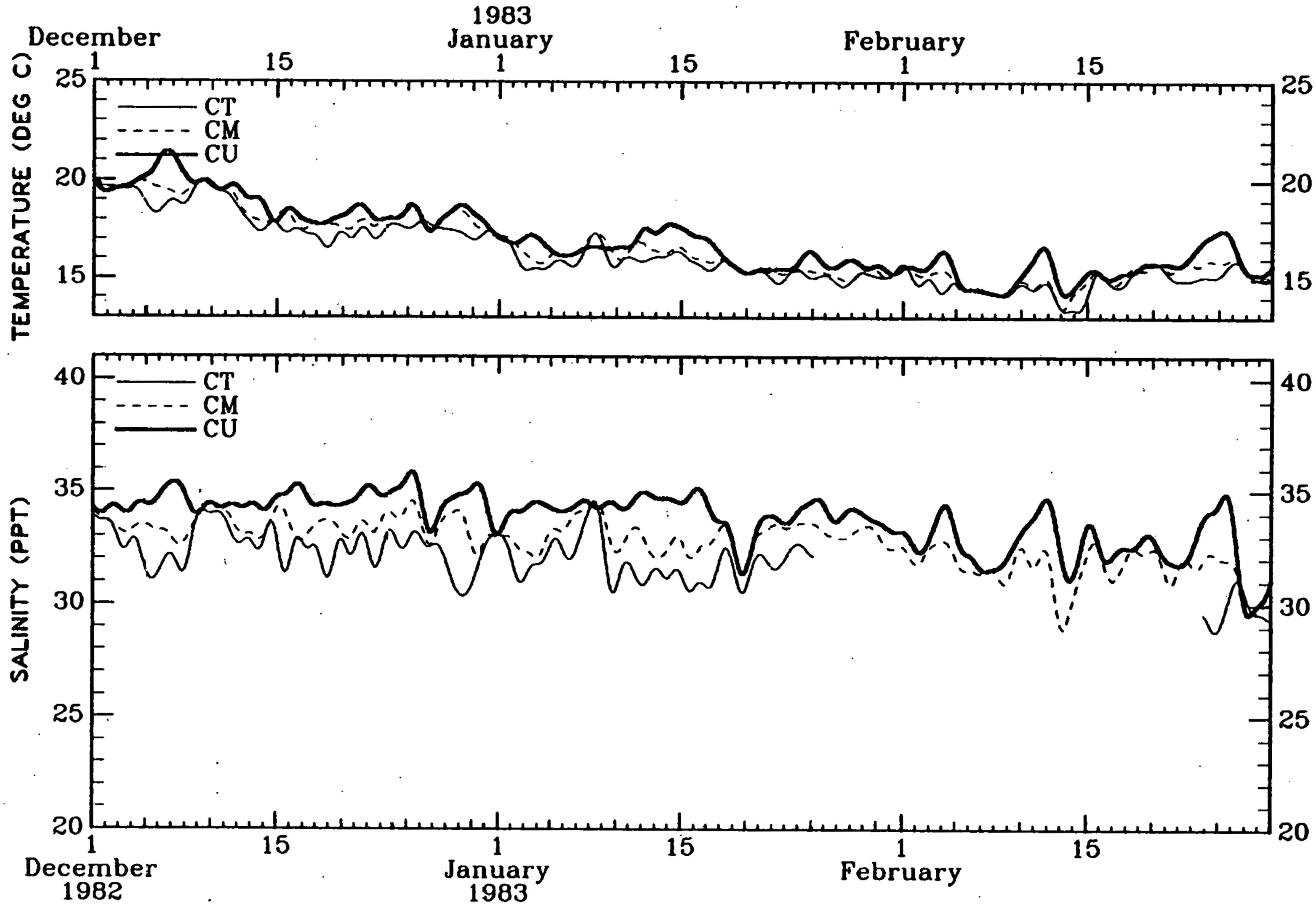
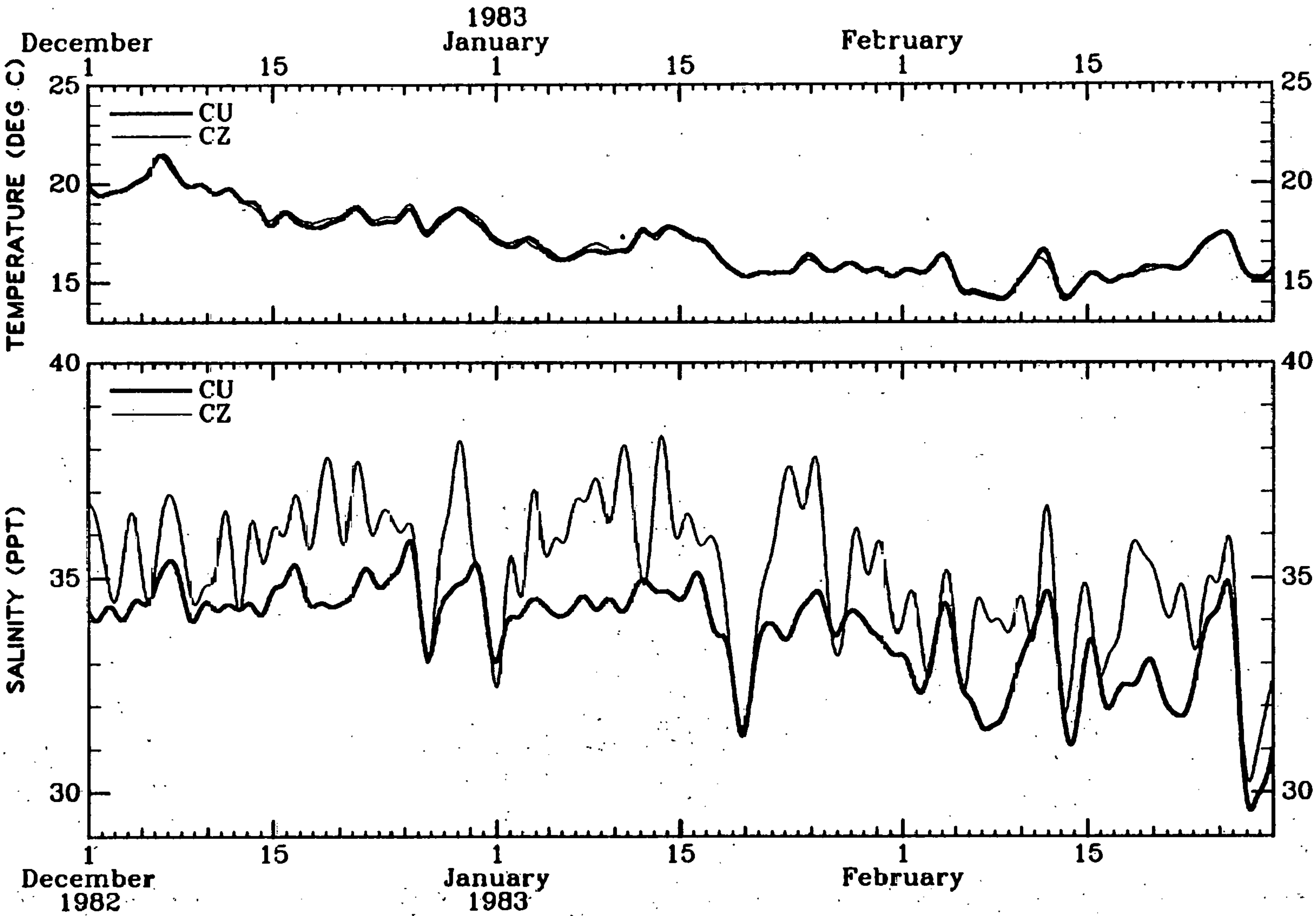


Figure 1-17. Progressive vector diagrams of Figure 1-16 plotted with a common scale and starting point. (Calendar day numbers above tick marks have been eliminated to avoid overlap.)



40-HOUR LOW PASSED T AND S FOR CT,CM,CU (CST)

Figure 1-18. Summary of 40-hour, low-pased CT, CM and CU temperature and salinity data for winter 1982-1983.



40-HOUR LOW PASSED T AND S FOR CU,CZ (CST)

Figure 1-19. Summary of the 40-hour, low-passed CU and CZ temperature and salinity data for winter 1982-1983.

to SW in January and February reflecting the increasing effects of winds from the northeast associated with winter storm fronts (see Figures A-48 through A-50). The most frequent speed range was 4 to 6 m/s in the winter, but there were significant percentages of observations in the higher ranges.

The currents had a much greater number of occurrences of upcoast flow in the winter than in the fall (Figure 1-14). The periods with upcoast flow are associated, in most instances, with alongshelf wind in the upcoast direction. The peaks in upcoast current lag the corresponding wind peaks by three-fourths of a day. There are also some periods when the currents appear to be unrelated to the wind as on December 17 and February 2.

Monthly mean alongshelf currents decreased from December to February. At CT, they went from -30 to -23 cm/s; at CM from -20 to -13 cm/s; and at CU from -10 to -5 cm/s. It is interesting that little change in mean vertical shear was observed. Mean cross-shelf currents were onshore in the upper part of the water column and offshore at CU.

During the first month of the winter period, the most frequent speed range at CT and at CM was 30 to 40 cm/s. During the second and third months, the CT speeds were somewhat bi-modal in distribution, but the most frequent speed range was 50 cm/s and up. At CM, however, the speeds fell most frequently in the 5 to 25 cm/s range. Speeds at CU also fell mainly in the 5 to 25 cm/s range with the upper side preferred in December, the lower side in January. The most frequent direction sector during winter at CT, CM, and CU was SW. Data were only collected during December at CZ. Its current rose shows a high percentage of currents fell in the 10 to 15 cm/s range, and the currents were rotated more toward offshore resulting in S being the most frequent direction sector.

Water temperature dropped during the winter from values near 20°C to a minimum of 13°C to 14°C in mid-February (Figure 1-18). The water column at site C alternated between being isothermal and being thermally stratified with top to bottom differences of 2°C to 3°C. A comparison of Figures 1-14 and 1-18 shows that in most cases, thermal stratification increased when there was upcoast flow and vice versa. The upcoast currents were usually associated with onshore bottom currents which advected warmer, more saline offshore bottom water to site C.

Salinity was less variable than in the fall (Figure 1-18). Surface values fluctuated between about 29 and 35 o/oo at CT and CM and between about 30 and 36 o/oo at CU. There was a decreasing trend, particularly in February. The surface salinity fluctuations were apparently related to cross-shelf frontal movement. The hydrographic data (Appendix A.1) show that a mass of fresher water lay inshore of site C on the days of the hydrographic surveys. Decreases in surface salinity during the winter were associated with upcoast and offshore currents which moved the salinity front across site C.

Figure 1-19 shows the plume effects on salinity. Above ambient values, CZ minus CU, are typically 2 to 4 o/oo. The rises in CU salinity on February 12 could be misinterpreted as due to a large plume with sufficient thickness to affect the CU meter at 1.8 m above the bottom, and therefore, the salinity at CU would not be a measure of ambient conditions. However, the salinity increase at CU was associated with onshore current and warmer temperature, and it appears that the rise in salinity at CU was due to the shoreward movement of warmer, more saline shelf bottom water, a natural process.

The spatial distributions of the hydrographic variables were measured during the winter season on December 1, 1982 and January 4 and February 3, 1983. During the cruise on December 1, 1982, the brine was being discharged at an average rate of 41,613 barrels/hr with a salinity of 262 o/oo and a temperature of 25°C. Currents on this day were weak and had been weak and variable for the preceding two days (see monthly time series plots in Appendix A). The alongshelf component of current at the surface and mid-depth decreased from about 25 cm/s to 0 cm/s during the day of this cruise; at CU, it fluctuated about 15 cm/s, and at CZ, it was fairly steady at 5 cm/s to 10 cm/s. The cross-shelf component was slightly onshore at the surface and steadily offshore at the bottom at 5 cm/s.

The December salinity and sigma-t data show the salinity and density increase with distance offshore and depth. The surface salinity increased from near 29 o/oo at station 12 to slightly more than 34 o/oo at station 36. Sigma-t units increased from 21 to 24. The alongshelf transect indicates surface salinity increased in the downcoast direction from near 31 o/oo at station 39 to 34 o/oo at station 34. Salinity was nearly constant at slightly greater than 34 o/oo in the lower half of the water column except at station 34. The presence of the brine plume was clearly evident at the bottom in the vicinity of station 34. The 35 o/oo isohaline represents a 0.7 o/oo above ambient condition based upon the 34.3 o/oo bottom salinity at station 39. The plume covered a distance of 8 km from between stations 34G and 34 to station 36 in the cross-shelf direction and 4.5 km from near station 34B to between 34E and 34F in the alongshelf direction. The plume was elongated in the offshore direction because the cross-shelf component of bottom current was offshore. The highest salinity was measured as 37.5 o/oo at the bottom of station 34 on the cross-shelf transect, which was 3.2 o/oo above the ambient salinity.

The dissolved oxygen content decreased with depth from near 8 mg/l at the surface the slightly less than 6 mg/l at the bottom. Again, there was no evidence of a brine discharge effect on the dissolved oxygen in the water column.

On January 4, 1983 brine was being discharged at a daily average rate of 42,250 barrels/hr, with a salinity of 254 o/oo and a temperature of 19°C. The cross-sections of hydrographic data collected on this date are illustrated in Figures 1-20 and 1-21. In the upper part of the water column, the current varied between 15 cm/s and 40 cm/s and was directed downward and onshore, while near the bottom it varied between 5 cm/s and 20 cm/s and was directed downcoast and offshore. On this day cooler fresher water was found from the coast to about station 34C. The warmer and saltier offshore water extended along the bottom to about station 16. The transition from 14°C, 29 o/oo water at station 12 to 16°C, 35 o/oo water near station 34C was gradual. In the alongshelf transect water cooler than 15°C was present in the upper layers in two pockets which straddled station 34, while near the bottom a pocket of 17°C water lay upcoast of station 34. The alonghself transect also shows that the water upcoast of station 34A was slightly fresher than that downcoast of it.

The isopycnals followed the same patterns as the isohalines with values of 22 nearshore and 26 offshore. The brine plume is clearly evident in the convex shape of the isohalines near the bottom in the vicinity of the diffuser. The 36 o/oo isohaline started near station 34G and rose to a height of 3 m above the bottom at station 34. Its height then started to decrease, but rose again as a result of higher ambient salinity water offshore betwen stations 34D and 36. The 37 o/oo isohaline

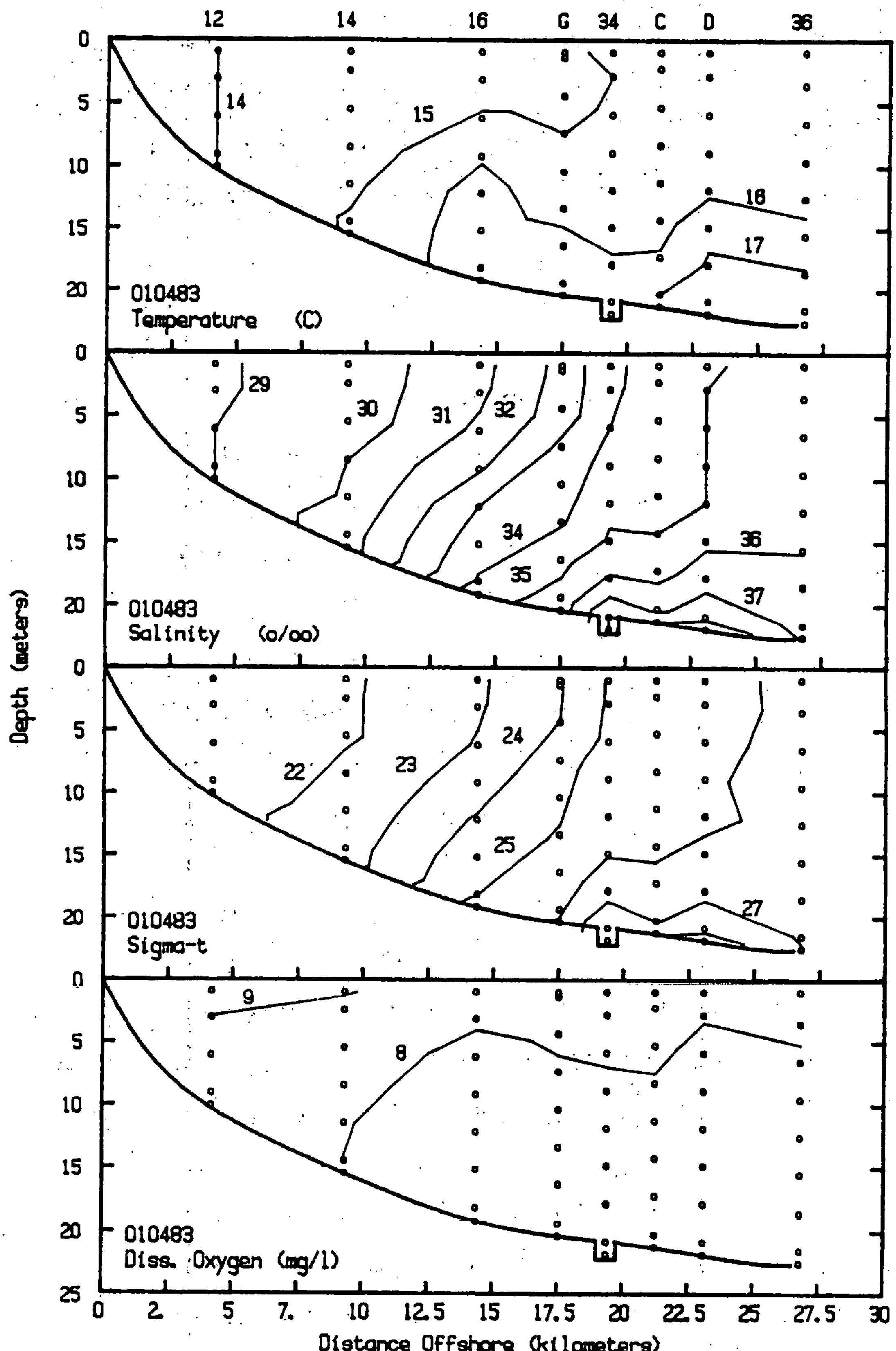


Figure 1-20. Hydrography for the cross-shelf transect offshore Freeport, Texas on January 4, 1983.

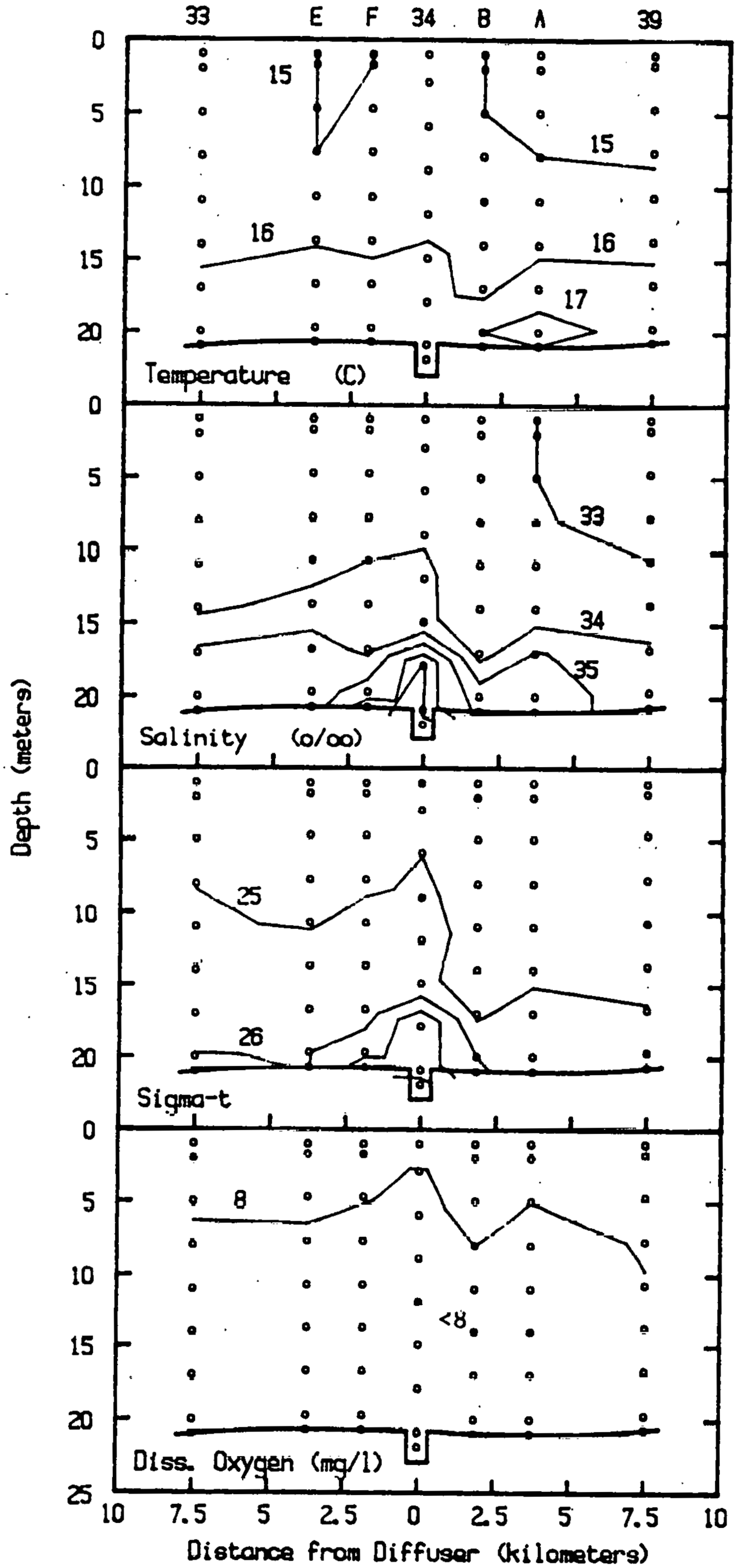


Figure 1-21. Hydrography for the alongshore transect offshore Freeport, Texas on January 4, 1983.

extended to station 36, so the brine plume apparently was approximately 8.5 km wide in the cross-shelf direction. In the alongshelf direction, the 36 o/oo isohaline extended 5 km between station 34E and 34B and reached a vertical height of 4.5 m above station 34. The highest salinity at station 34 was 38.6 o/oo which was 3.8 o/oo above the ambient salinity measured at station 39.

The dissolved oxygen decreased with depth and distance offshore. The highest isopleth of dissolved oxygen (9 mg/l) was observed near the surface between stations 12 and 14. The 8 mg/l isopleth started at the bottom of station 14 and rose to the 5-meter depth at station 16 and remained between the 5 and 10 m depth out to station 36. In the alongshelf transect the 8 mg/l isopleth was generally horizontal between the 5 and 10 m depth over the entire transect. No variation was observed near the diffuser.

On February 3, 1983, the hydrographic data were measured when brine was being discharged at an average of 41,919 barrels/hr, a salinity of 246 o/oo, and a temperature of 19°C. The currents were directed upcoast and onshore at all depths. Early in the day speeds were near 50 cms in the upper layers and 25 cm/s in the lower layer, but they had decreased to half these values by the end of the day.

A mass of water with characteristics of 16°C and 34 to 35 o/oo lay just below mid-depth and extended from offshore to just inshore of station 34. Water with salinity in the 32 to 34 o/oo range lay inshore and above it. There was a sharp halocline at mid-depth beginning just inshore of station 34 and extending past station 36. Dissolved oxygen was slightly less than 6 mg/l in the warmer, saltier water mass and slightly greater in the water surrounding it.

The brine plume was weak and of small extent on this day, probably because of the vertical salinity stratification above station 34 and the strong currents. There was no indication of any plume effect in the temperature and oxygen data.

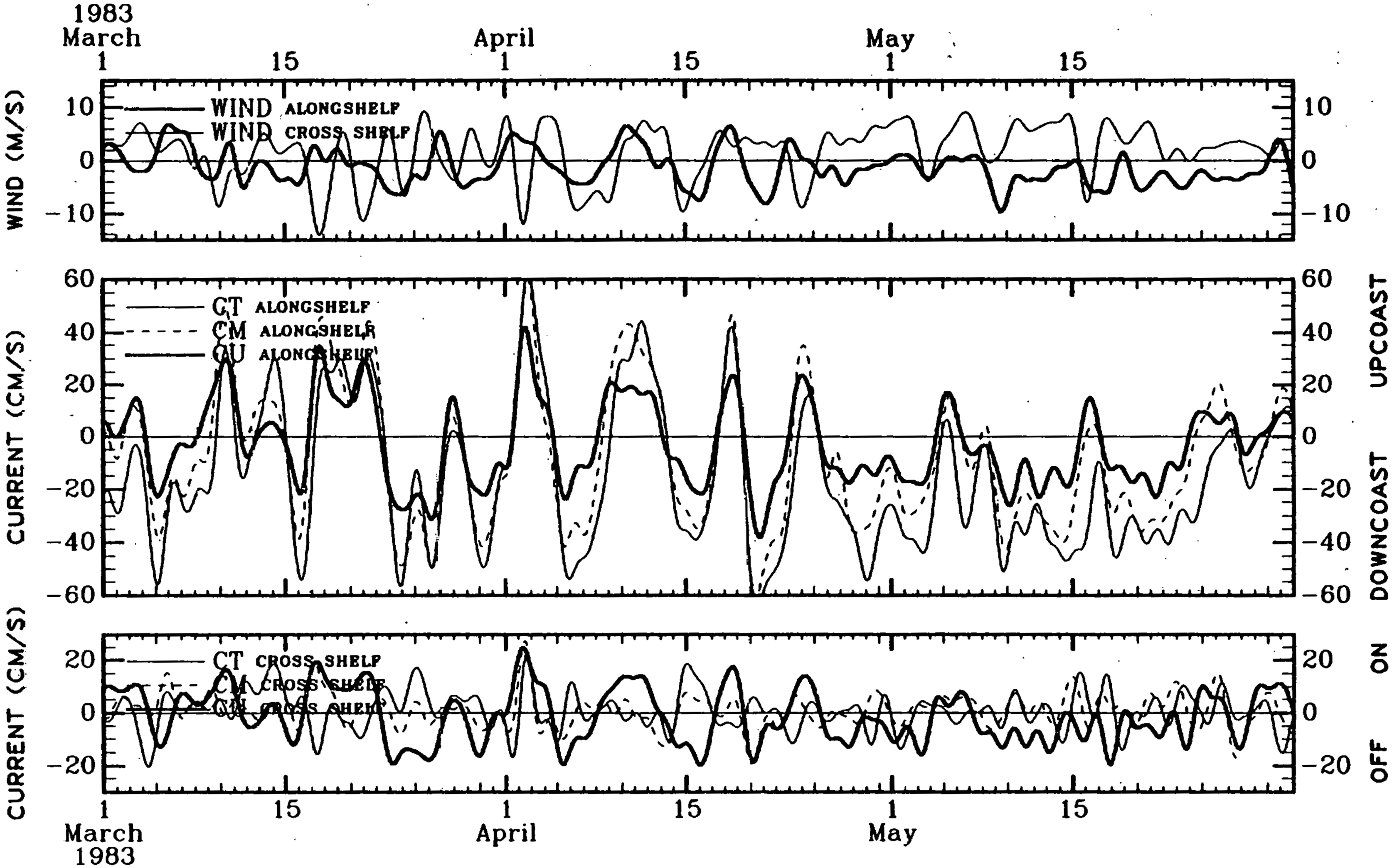
1.3.3 Spring (March, April, May)

The wind and currents during March through May 1983 are summarized in Figures 1-22 and 1-23. Progressive vector diagrams for the CT, CM, and CU currents are shown by Figures 1-24 and 1-25. The hiatus in CZ currents ended on March 22; a progressive vector line is not shown for CZ. Figures 1-26 and 1-27 summarize the spring temperature and salinity data. There is a gap in salinity data from April 12 to April 25.

Monthly means of the wind components dropped significantly in magnitude in March and April and were directed weakly downcoast and onshore. In May, they became strongly downcoast and onshore. The wind roses, however, indicate that the wind speeds were not small in the spring. The most frequent speed ranges were 4 to 6 m/s in March and 6 to 8 m/s in April and May. Scalar average speeds were 6 to 7 m/s. Figure 1-23 shows that during March and April the winds were not weak, but they alternated between periods of approximately equal magnitude but oppositely directed flow thus yielding small vector means. The large standard deviations about the means in Table A-1 reflect this process.

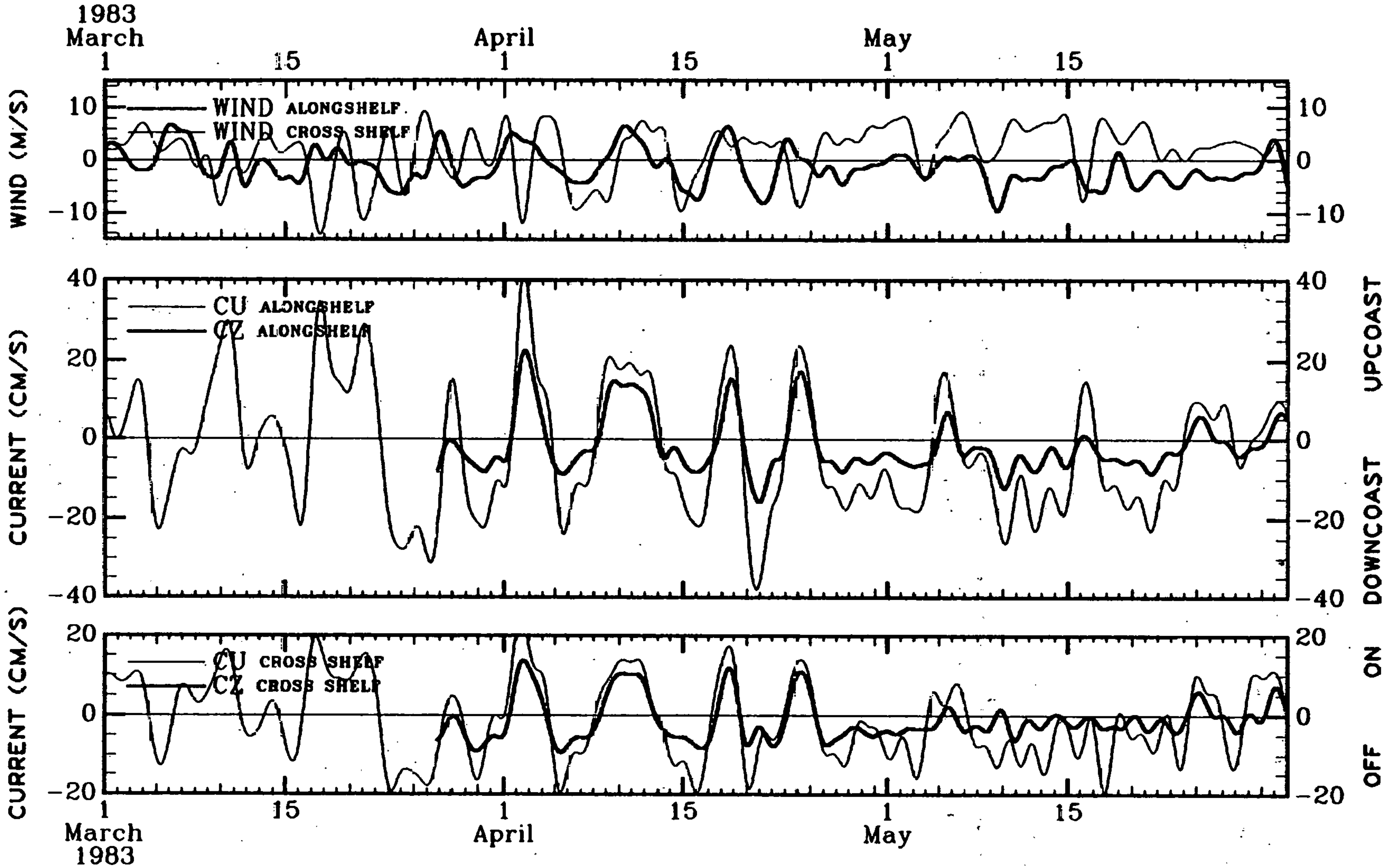
The dominant wind direction was about equally distributed in the W and NW sectors in March, while in April and May, the NW sector became increasingly dominant.

The monthly mean alongshelf currents reflected the weak mean alongshelf winds in March and April and the increase in alongshelf wind strength in May. Mean alongshelf currents were weakly downcoast in March



40-HOUR LOW PASSED WIND AND CT,CM,CU CURRENT (CST)

Figure 1-22. Summary of 40-hour low-passed wind and CT, CM and CU current data for spring 1983.



40–HOUR LOW PASSED WIND AND CU,CZ CURRENT (CST)

Figure 1-23. Summary of 40-hour low-passed wind and CU and CZ current data for spring 1983.

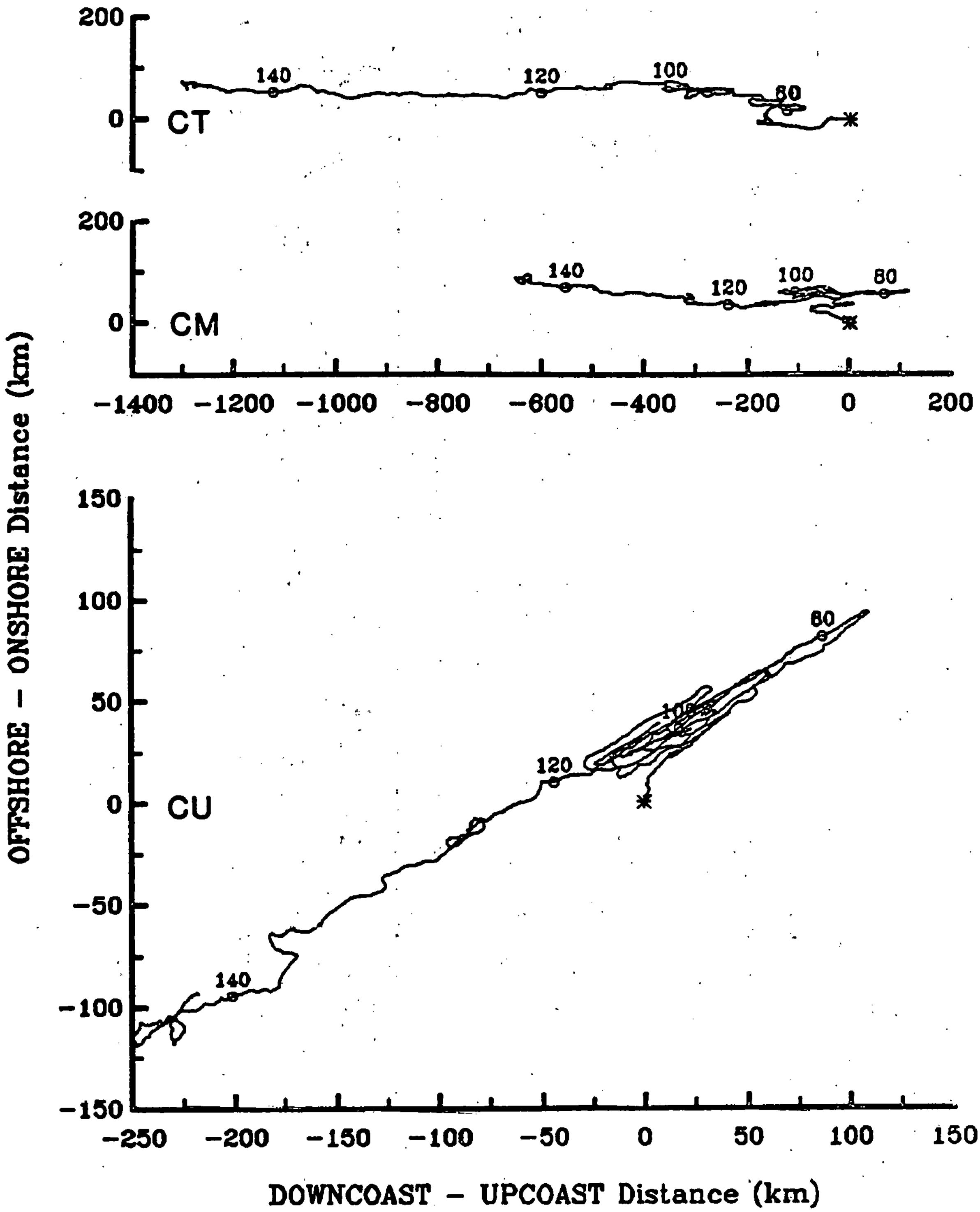


Figure 1-24. Progressive vector diagrams for current observed at meters CT, CM and CU (no CZ data) during March 1, 1983 through May 31, 1983 (calender days 80 through 151).

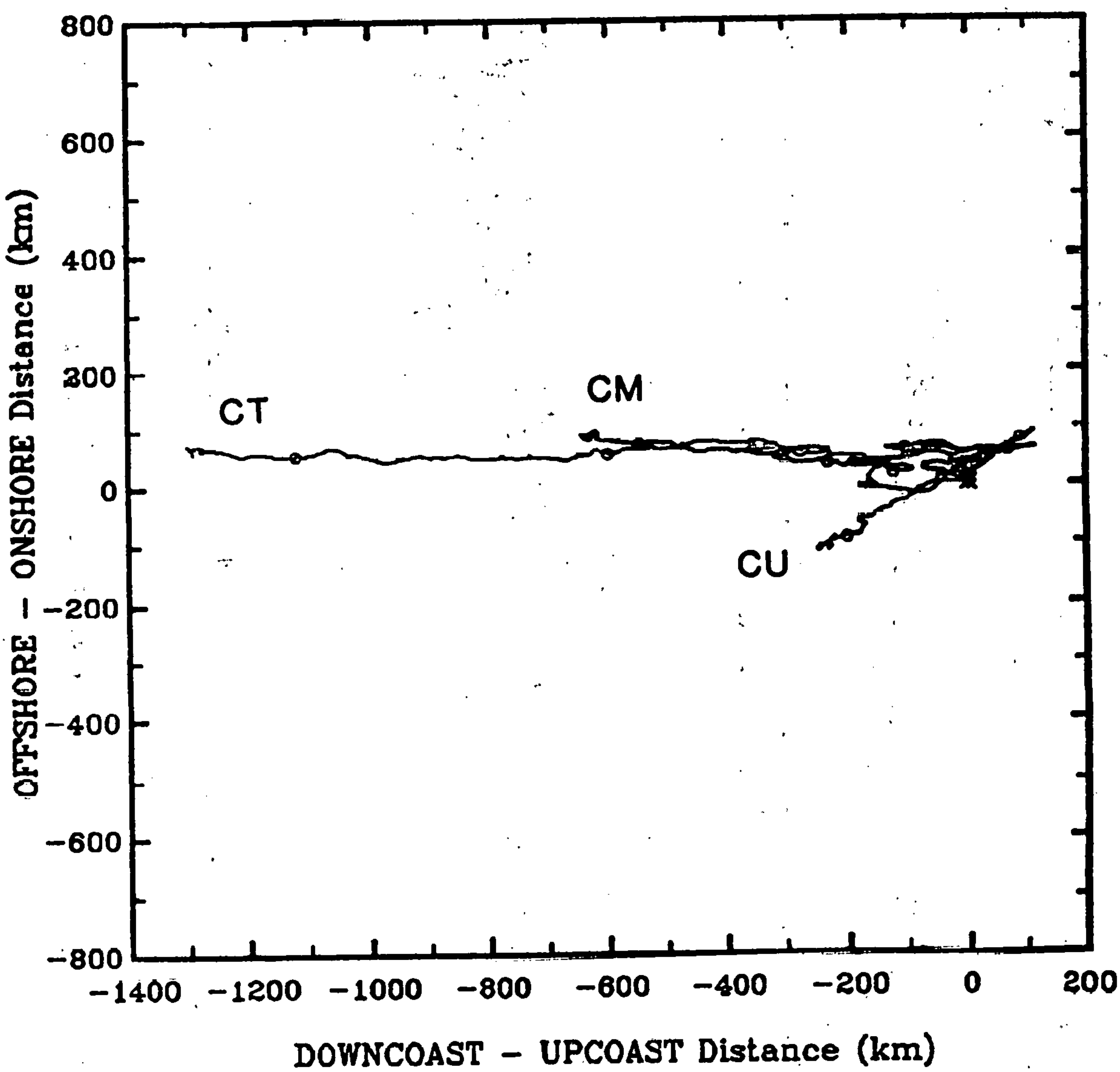
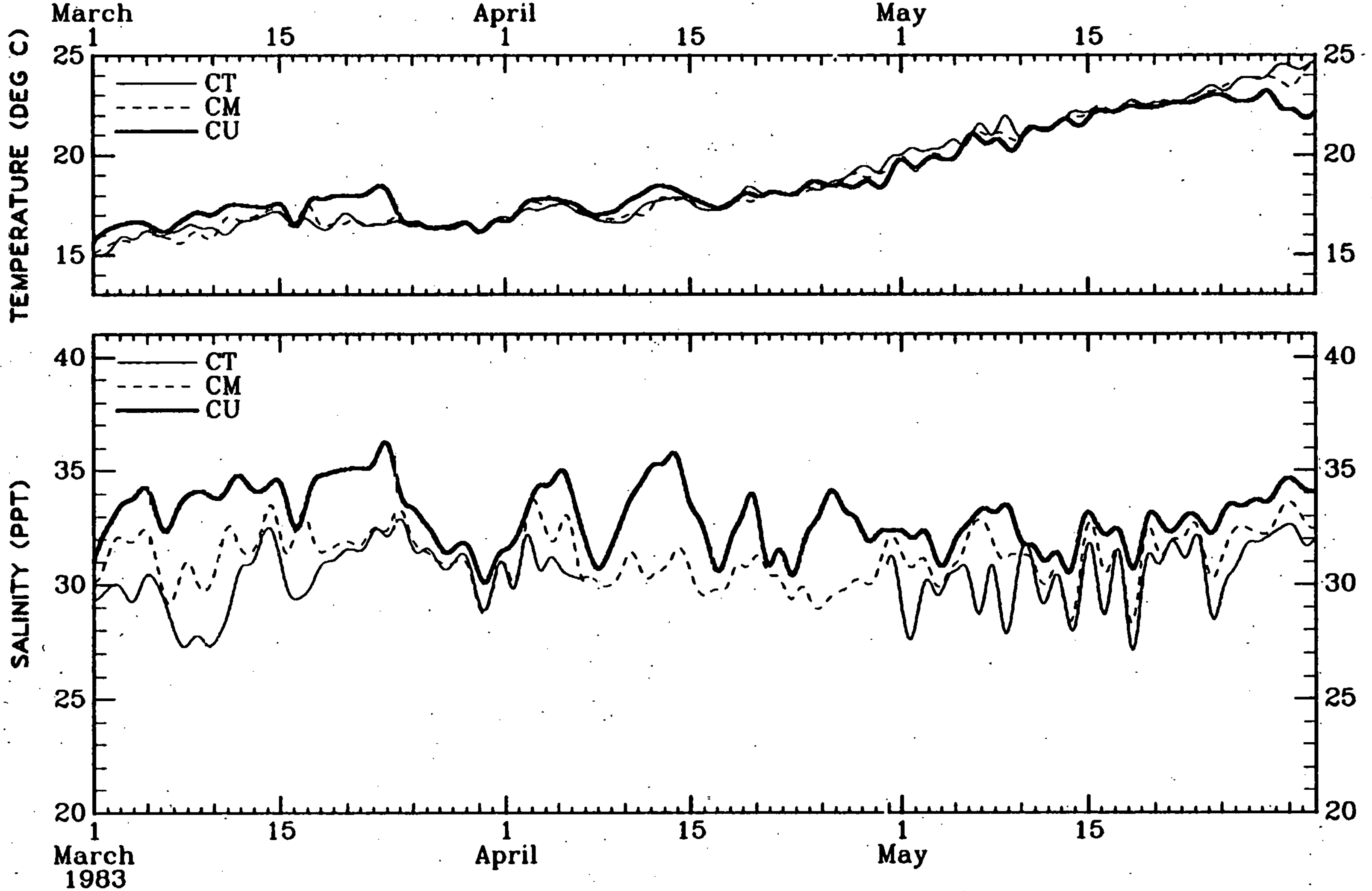
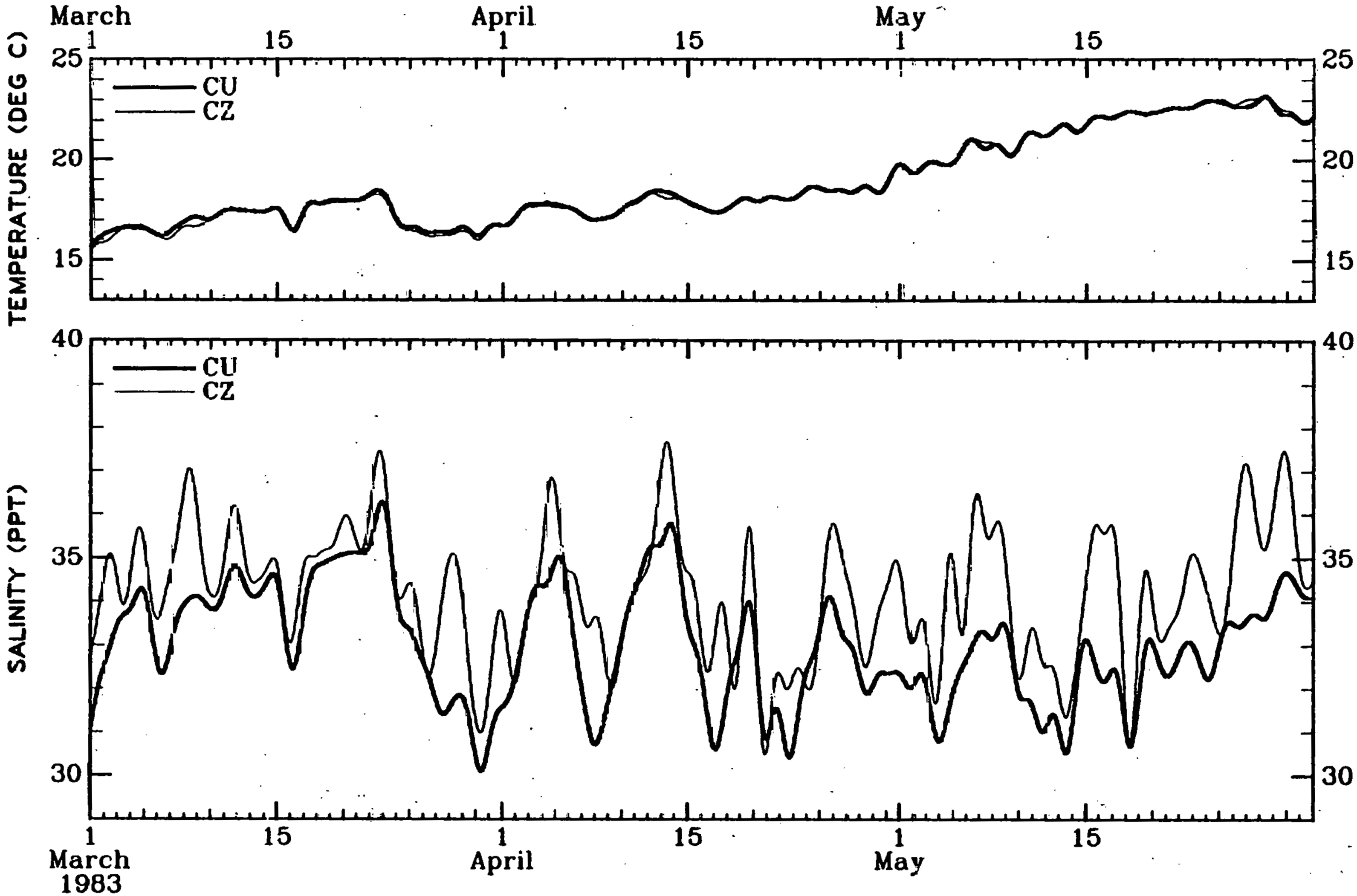


Figure 1-25. Progressive vector diagrams of Figure 1-24 plotted with a common scale and starting point (calendar day numbers above tick marks have been eliminated to avoid overlap).



40–HOUR LOW PASSED T AND S FOR CT,CM,CU (CST)

Figure 1-26. Summary of 40-hour, low-passed CT, CM and CU temperature and salinity data for spring 1983.



40-HOUR LOW PASSED T AND S FOR CU,CZ (CST)

Figure 1-27. Summary of 40-hour, low-passed CU and CZ temperature and salinity data for spring 1983.

and April and increased in downcoast strength at all depths in May. Mean cross-shelf currents, however, did not have a consistent pattern. Like the winds, the currents exhibited large variability about their means (Figure 1-23 and Table A-2). The current roses show that at CT and CM, the most frequent speed range was 30 to 40 cm/s during spring and average scalar speeds were generally in the 25 to 35 cm/s range. While SW was the most frequent direction sector for CT and CM in March and April, the second most frequent was NE, reflecting the alternating nature of the currents. In May, the currents became more persistently downcoast and onshore (SW and W direction sectors).

Currents at CU were broadly distributed among the S, SW, N, and NE sectors in March and April and then became more persistently downcoast and offshore in May (SW and S sectors). Speeds at CU were also broadly distributed in magnitude in March and April and then became more concentrated around the 10 to 15 cm/s range in May.

At CZ, currents were mostly in the S sector and the 5 to 10 cm/s speed range in April and May.

Water temperature warmed during the spring from about 15 to 16°C to 23 to 24°C. Bottom water was warmer than the surface water until the latter half of April when the relationship reversed. In May, a thermocline with a 3°C temperature difference developed as the surface water continued to warm, but the bottom water decreased in temperature slightly.

Salinity was more variable in the spring than in the preceding season. The variability was as great near the bottom as at the surface, apparently because of cross-shelf movement of salinity fronts. The spring values of salinity at CT ranged from 25.4 to 33.3 o/oo, and at CU from

29.6 to 36.7 o/oo. The greater variability of the bottom can be seen by comparing Figure 1-27 with the corresponding figures for fall and winter. Plume effects in the spring were somewhat reduced in terms of persistence.

The first hydrographic data collected during the spring months of 1983 were measured on March 10, 1983 when the average brine discharge rate was 40,750 barrels/hr, the salinity was 231 o/oo, and the temperature was 19°C. Currents were relatively strong but variable on this day. The alongshelf component was upcoast at all depths and varied between about 15 and 60 cm/s in upper layers and between 15 and 40 cm/s in the lower layers. The cross-shelf component was onshore at the bottom with speeds between 10 and 20 cm/s, but in the upper half of the water column it oscillated between onshore at 20 cm/s and offshore at 20 cm/s.

The hydrographic data are illustrated in Figures A-14 and A-15. The temperature data in the alongshelf transect shows there was a 16°C isotherm near the 10 m depth, and a 17°C isotherm southwest of the diffuser. In the cross-shelf direction, the 17°C isotherm was present offshore of station 34G at the 15-meter depth. Thus, a weak positive temperature gradient was present, and again no thermal effect as a result of the brine discharge was observed.

The salinity and sigma-t data show that fresher, lighter water was located in the upper half of the water column, and a strong halocline and pycnocline were present in the lower half of the water column. The movement of saltier water along the bottom in a shoreward direction and the separation of the fresher water from the coast were caused by the upwelling condition of the currents. In the cross-shelf direction, the 29 through 32 o/oo isohalines were nearly horizontal from stations 14 to 34D. The 33 o/oo isohaline begins near the bottom at station 33, and the 34 o/oo isohaline begins near 34G. The brine plume, shown by the 35 o/oo isohaline, was small in the immediate vicinity of station 34. In the alongshelf transect the 28 through 33 o/oo isohalines and 21 through 24 isopycnals were horizontal and located between the 8 and 15-meter depths. The brine plume is indicated by the 34 o/oo isohaline and the 25 isopycnal around the diffuser station. The highest salinities at station 34 were 36.0 and 34.9 o/oo for the cross-shelf and alongshelf transects, respectively. The low above ambient conditions and small brine plume are mainly attributed to the combination of unusually low brine salinity of 231 o/oo, vertical salinity stratification and strong currents.

Dissolved oxygen decreased with depth except near the bottom at stations 33, 34E, 34F and 34 in the alongshelf transect. The 8 mg/l isopleth was present in the lower half of the water column from station 12 to 36 except for station 34C in the cross-shelf transect. It was present in the alongshelf transect near mid-depth and again near the bottom except for stations 34A and 39. These data again show no evidence of the brine discharge affecting the dissolved oxygen content.

The spring of the year usually experiences a large freshwater runoff from the Mississippi/Atchafalaya River system which causes strong salinity and density stratification in the diffuser area, as well as along the entire Texas and Louisiana Gulf coast (Kelly and Randall, 1980; Kelly et al., 1982 and 1983a). The hydrographic data collected on April 11, 1983 is another good example of the beginning effects of the spring runoff on the hydrography of the coastal waters where the Bryan Mound diffuser is located. On this date, the brine was being discharged at an average rate of 41,560 barrels/hr, the average salinity was 254 o/oo, and the average brine temperature was 23°C. Currents were again favorable to upwelling.

In the upper layer they were upcoast and weakly offshore at 35 to 50 cm/s and at the bottom they were upcoast and strongly onshore at 15 to 25 cm/s. The vertical cross-sections of the hydrographic data are shown in Figures 1-28 and 1-29.

The cross-shelf temperature data showed almost isothermal water of about 17°C inshore of station 34G. A tongue of slightly cooler water (≤17°C) near mid-depth and warmer water near 18°C in the bottom waters existed offshore of station 34G. The alongshelf data also showed essentially isothermal conditions. The bottom temperature data for both transects showed no effect of the brine discharge.

The effect of the spring runoff is clearly evident in the salinity and sigma-t data. In the cross-shelf direction (Figure 1-28) the isohalines and isopycnals were nearly horizontal or parallel to the seafloor inshore of station 34G; offshore of station 34G, they sloped slightly upward toward the surface. At station 34 the salinity and density increased slightly to a depth of 12 m. Between 12 and 15 m a halocline and pycnocline were present with isohalines increasing from 31 to 34 o/oo in that depth range. These isohalines were nearly horizontal in the alongshelf direction. The brine plume was indicated in the cross-shelf transect by the convex 35 and 36 o/oo isohalines, but was unexplainably absent in the alongshelf transect. The bottom salinity at station 34 was 36.9 o/oo during the cross-shelf transect which was 2.7 o/oo above the bottom salinity at station 39. The lower above ambient salinity is attributed to the stratification and strong current experienced on this date.

The dissolved oxygen values varied generally from 9 to 7 mg/l in both the cross-shelf and alongshelf transects. The dissolved oxygen decreased

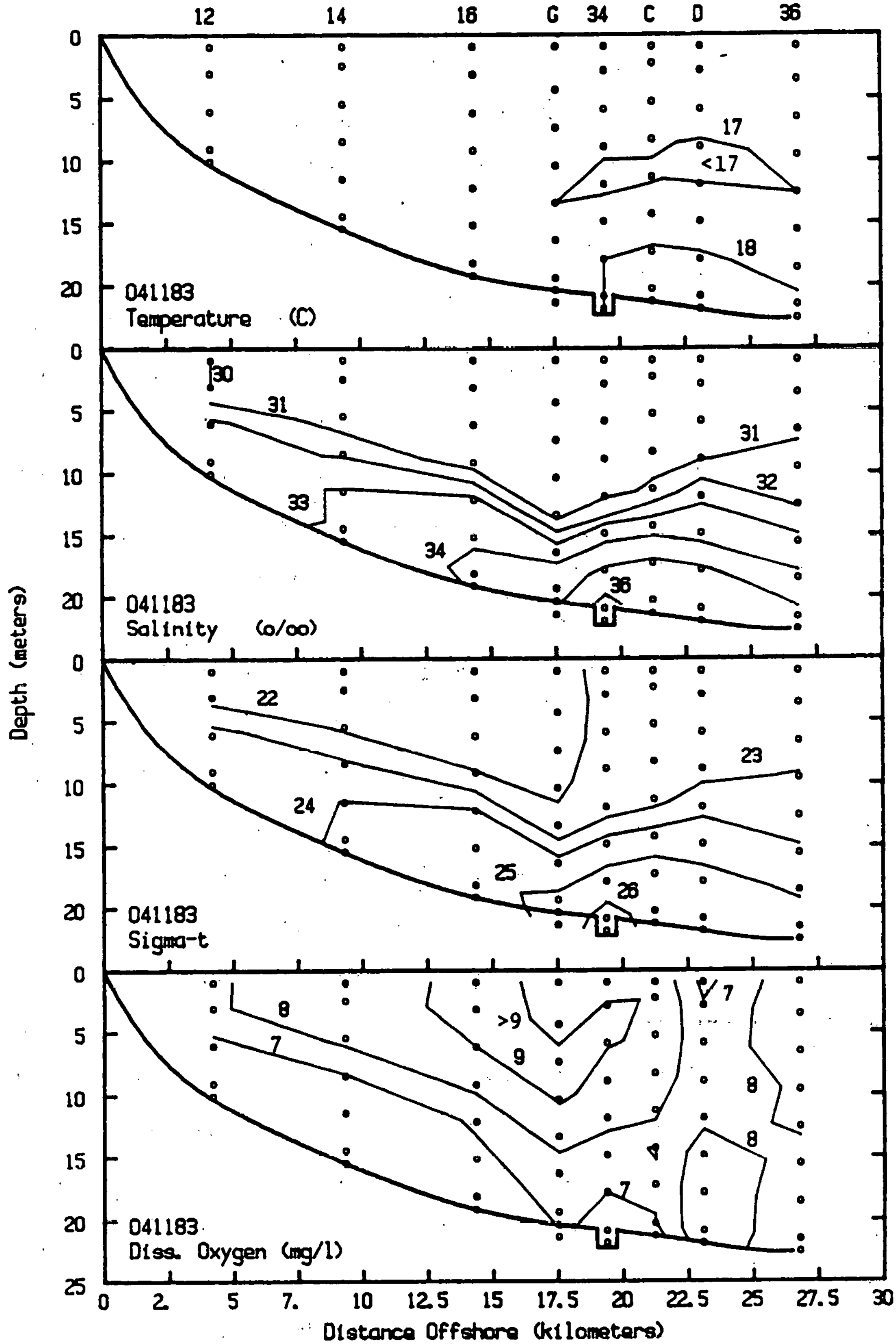


Figure 1-28. Hydrography for the cross-shelf transect offshore Freeport, Texas on April 11, 1983.

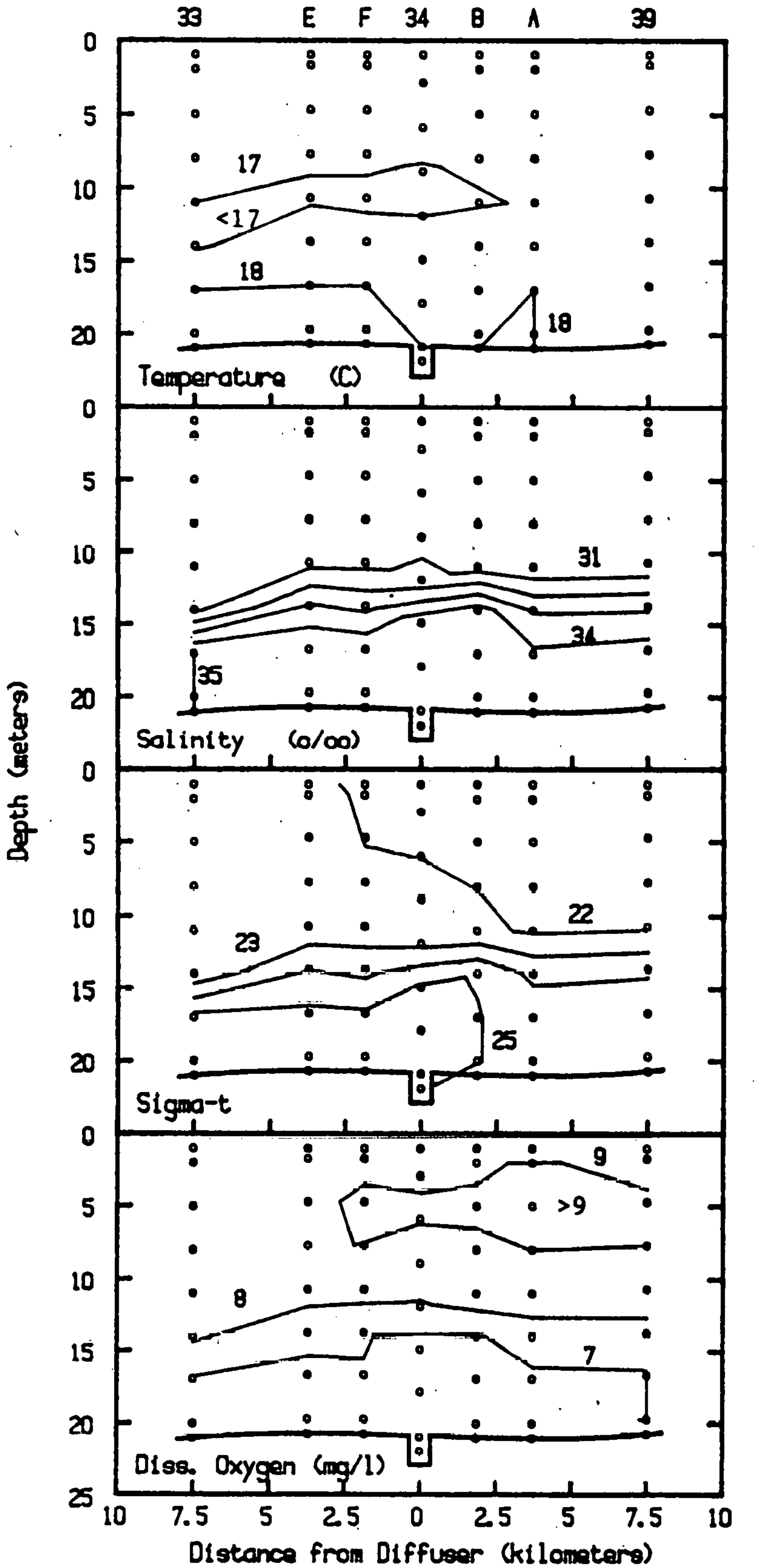


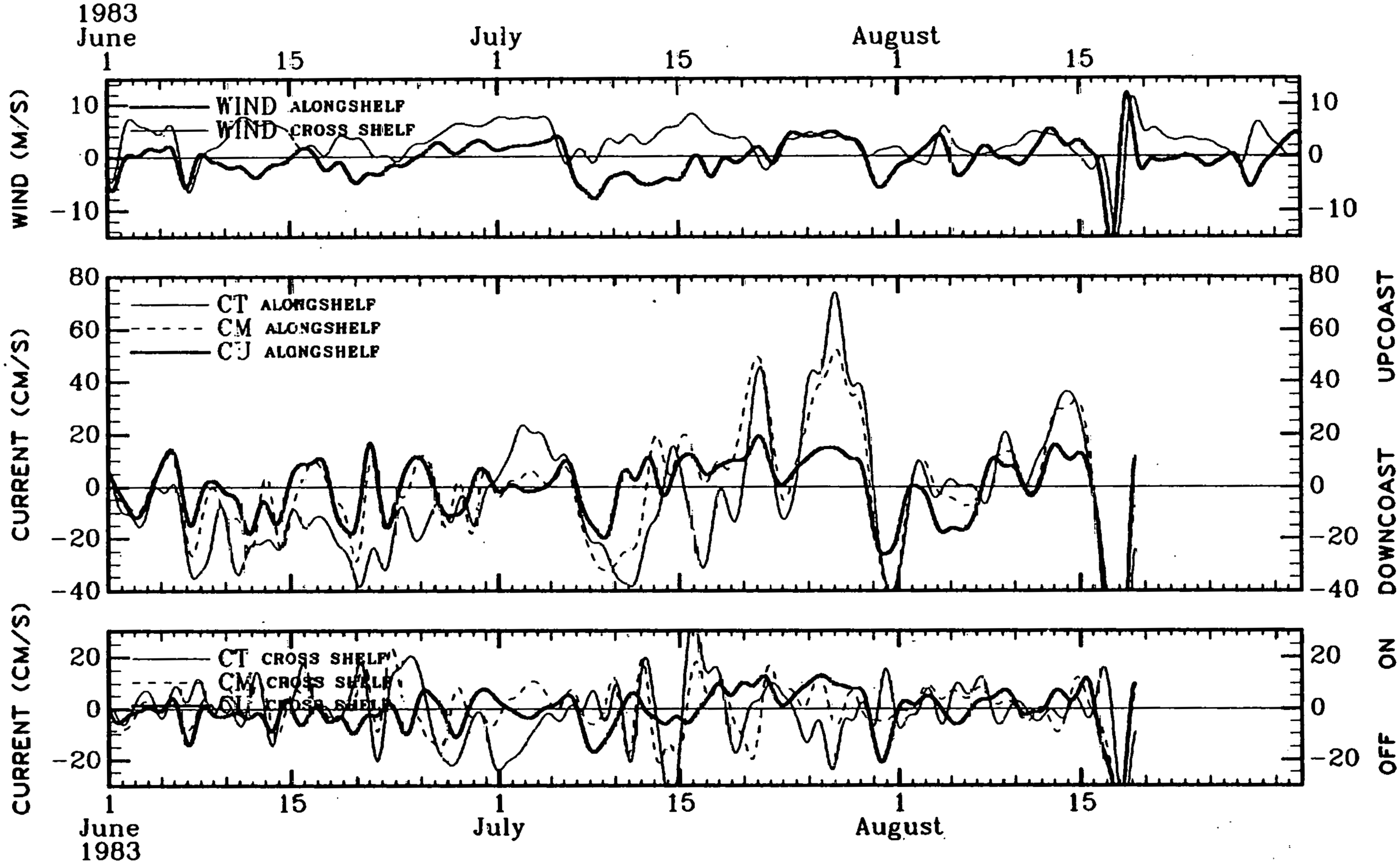
Figure 1-29. Hydrography for the alongshore transect offshore Freeport, Texas on April 11, 1983.

with depth except for a tongue of slightly greater than 9 mg/l values between stations 16 and 34 in the cross-shelf transect and between stations 34F and 39 in the alongshelf transect. In the vicinity of the brine plume as defined in the salinity data, no apparent effects of the brine discharge were detected in the dissolved oxygen data.

The May 5, 1983 hydrographic data were collected when the brine was being discharged at an average rate of 42,175 barrels/hr, an average salinity of 256 o/oo, and an average temperature of 25°C. Surface currents were weakly upcoast with speeds less than 10 cm/s. At mid-depth and below the currents were stronger, 10 to 20 cm/s and upcoast. Bottom currents were weakly onshore. The results of the hydrographic data are illustrated in Figures A-18 and A-19. Temperatures less than 22°C were found between stations 12 and 14 near the surface. Offshore, the temperature was near 21°C and decreased slightly with depth. A relatively strong salinity front separated the inshore and offshore waters. The isohalines and isopycnals were inclined to the surface and sloped upward from the bottom inshore to the surface offshore. The salinity increased from 26 o/oo near station 12 to 32 o/oo near station 34. The brine plume was defined by the near bottom isohalines ranging from 33 to 34 o/oo in the vicinity of station 34. The dissolved oxygen data show values generally decreased with depth from slightly greater than 7 mg/l to near 6 mg/l at the bottom inshore of station 34 and to near 7 mg/l offshore of station 34 in the cross-shelf transect.

1.3.4 Summer (June, July and August)

Figures 1-30 and 1-31 summarize the summer wind and currents. Progressive vector diagrams are shown for currents in Figures 1-32 and 1-33; temperature and salinity are summarized in Figures 1-34 and 1-35.



40−HOUR LOW PASSED WIND AND CT,CM,CU CURRENT (CST)

Figure 1-30. Summary of the 40-hour low-passed wind and CT, CM and CU current data for summer 1983.

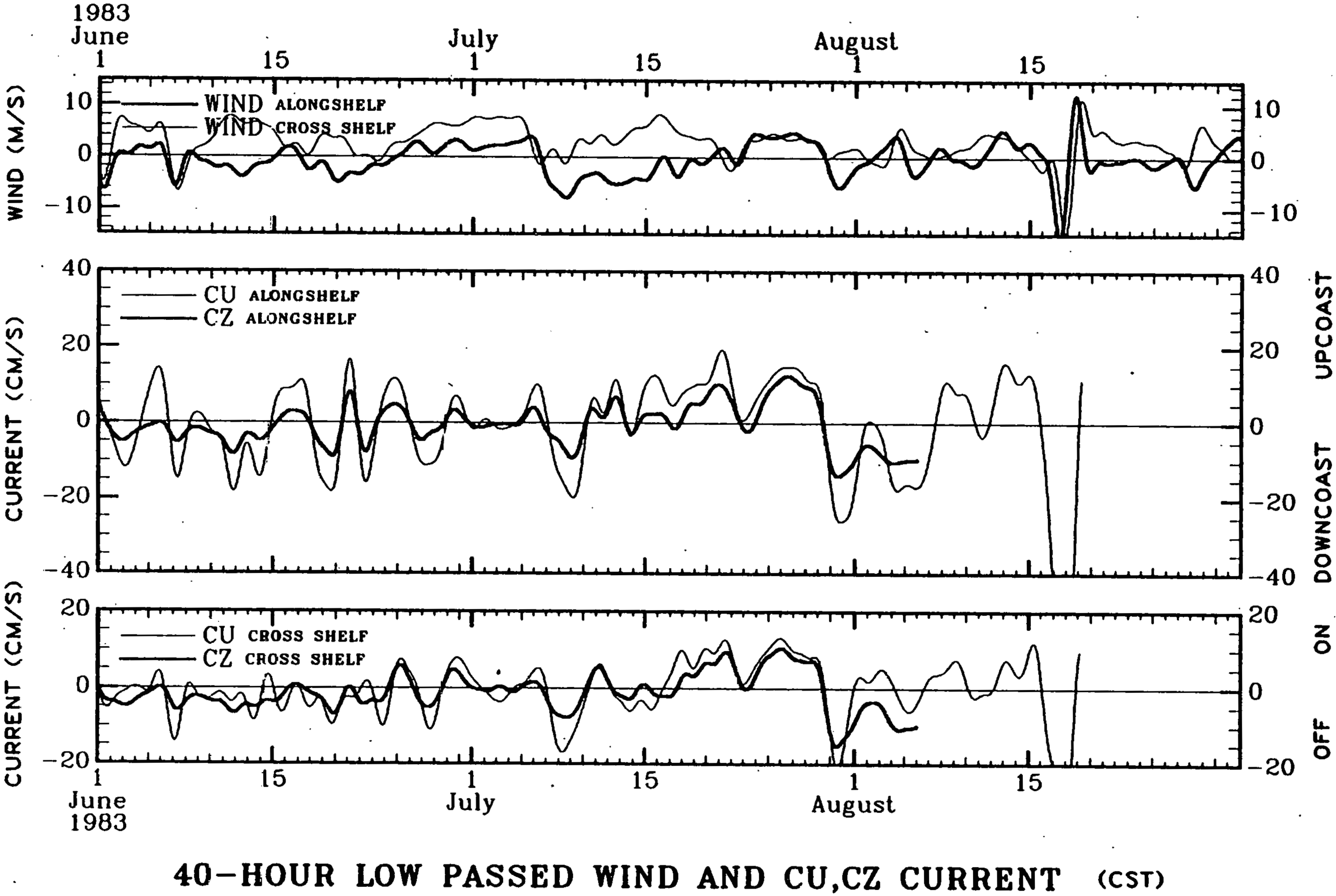


Figure 1-31. Summary of the 40-hour low-passed wind and CU and CZ current data for summer 1983.

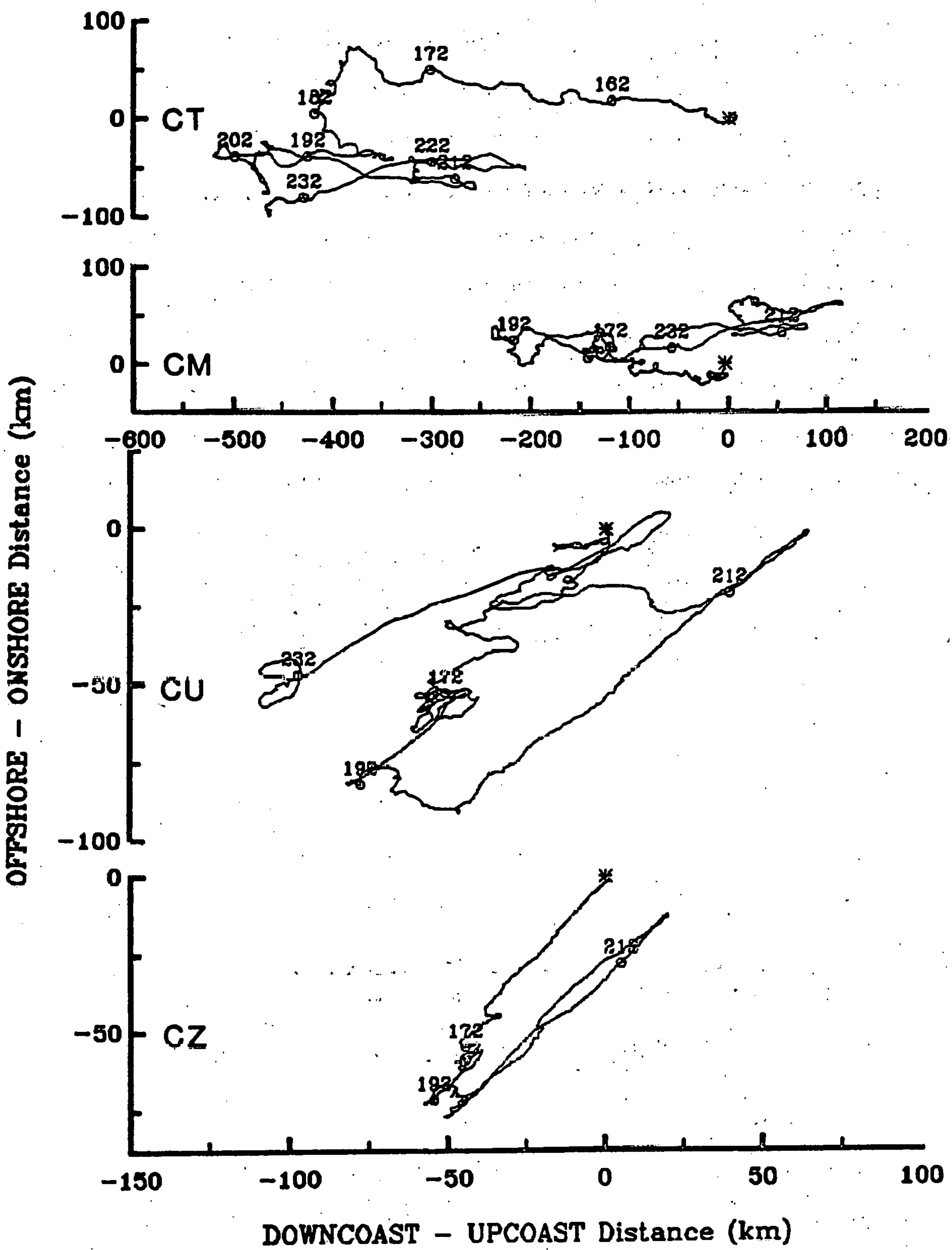


Figure 1-32. Progressive vector diagrams for current observed at meters CT, CM, CU and CZ during June 1, 1983 through August 31, 1983 (calendar days 152 through 243).

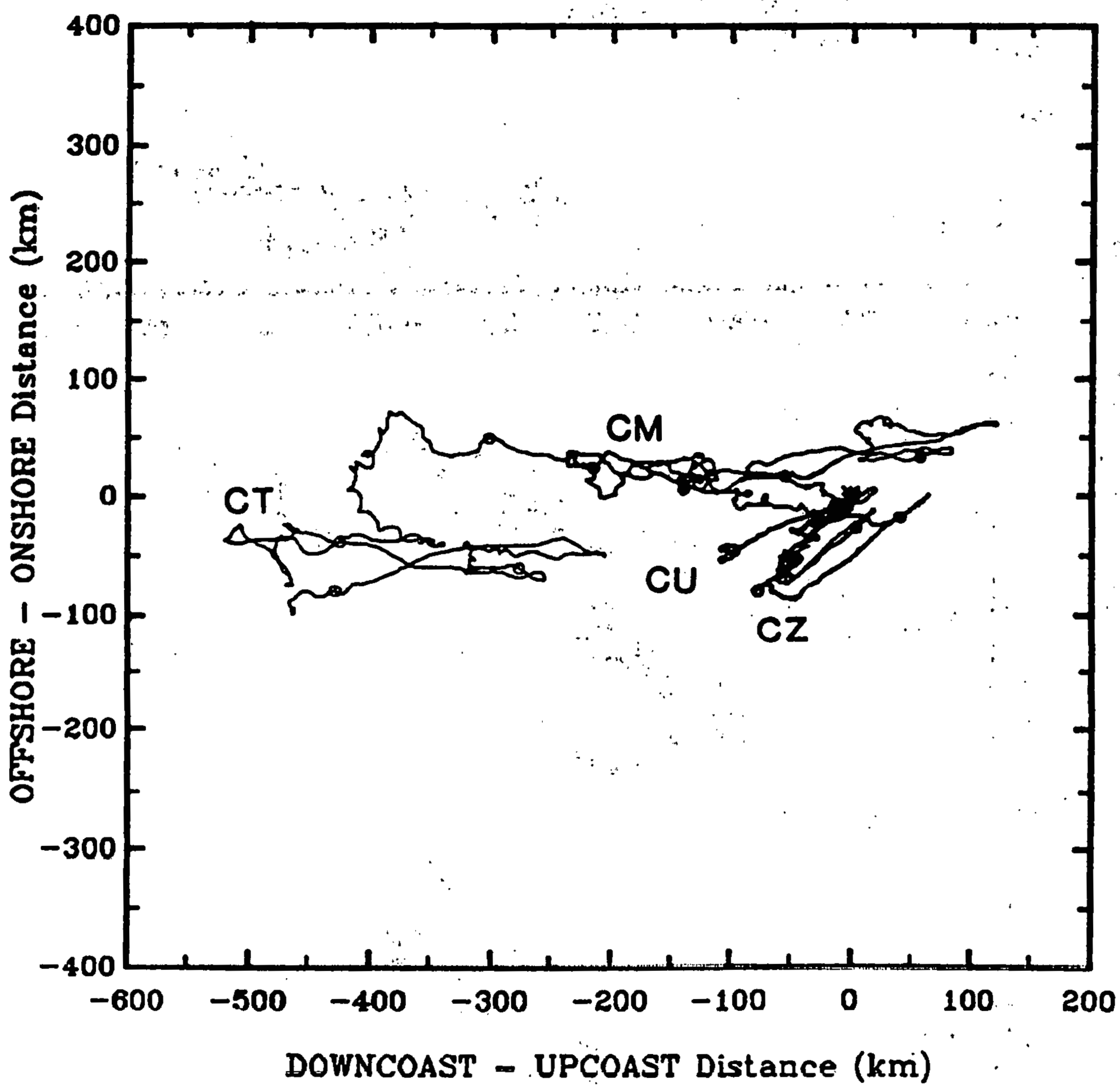
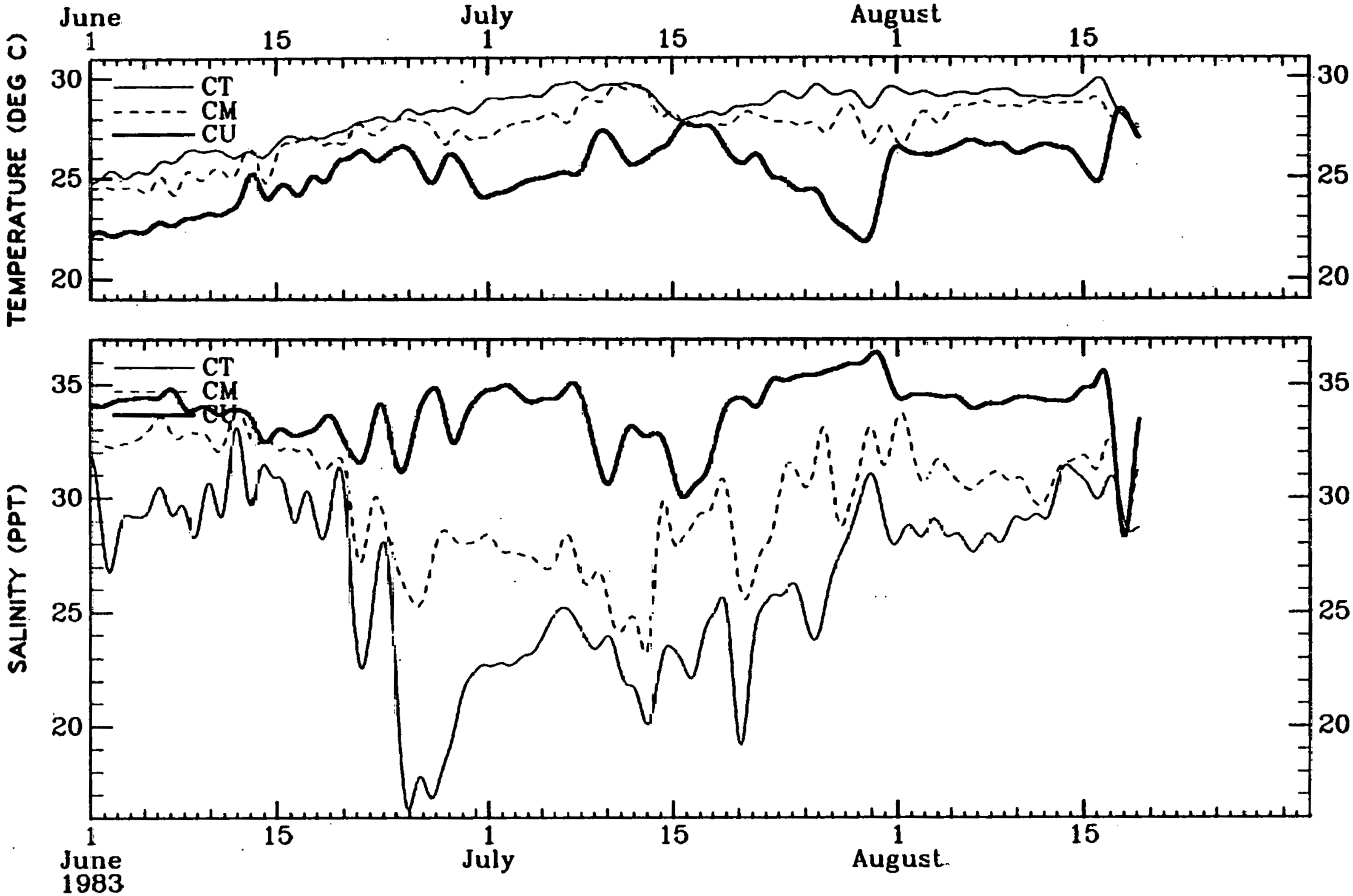
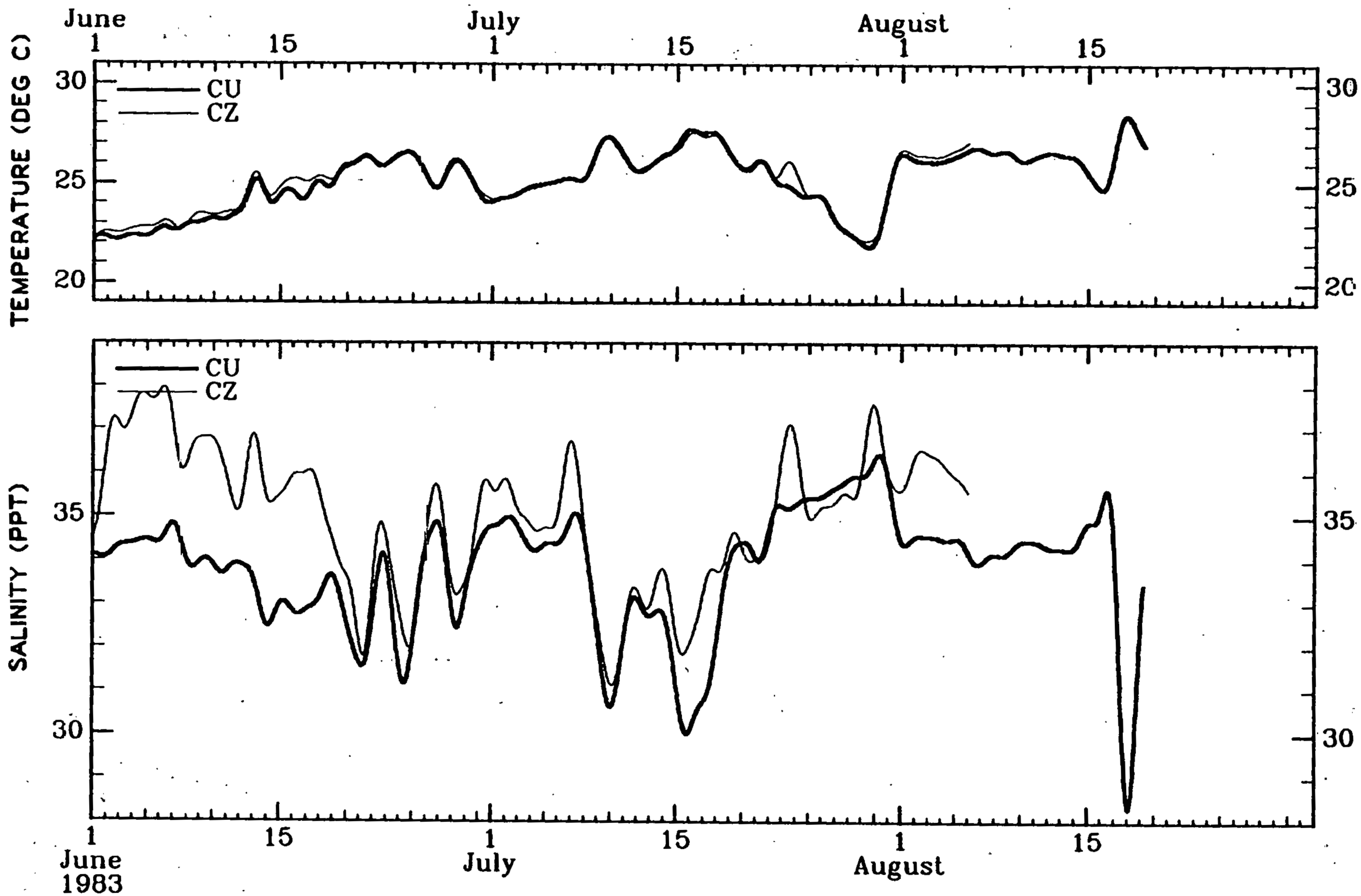


Figure 1-33. Progressive vector diagrams of Figure 1-32 plotted with a common scale and starting point. (Calendar day numbers above tick marks have been eliminated to avoid overlap.)



40-HOUR LOW PASSED T AND S FOR CT,CM,CU (CST)

Figure 1-34. Summary of the 40-hour, low-passed CT, CM and CU temperature and salinity data for summer 1983.



40–HOUR LOW PASSED T AND S FOR CU,CZ (CST)

Figure 1-35. Summary of the 40-hour, low-passed CU and CZ temperature and salinity data for summer 1983.

Mean alongshelf winds were weakly downcoast in June, weakly upcoast in July, and about zero in August. Mean cross-shelf winds were strongly onshore. The most frequent speed ranges were 4 to 6 m/s and 6 to 8 m/s in both June and July; they dropped to 2 to 4 m/s and 4 to 6 m/s in August. The most frequent direction sectors went from NW in June to N in July and then to both NW and N in August. Scalar average speeds were about 5 m/s.

The winds and currents during Hurricane Alicia can be seen in Figures 1-30 and 1-31. The peaks are off of the scale in these figures. The monthly time series plots in Appendix A show the full details. The hurricane made landfall at the south end of Galveston Island about 0100 hours CST on August 18. It first reached hurricane strength at 1600 hours CST August 16, when it was located about 275 km southwest of the study area. The maximum sustained wind speed recorded by Buoy 42008 was 29.9 m/s (66.9 mph), and the maximum gust speed was 40.2 m/s (90.4 mph). These values are somewhat lower than one might have expected for several reasons: the winds were measured only for two minutes each hour; the sustained values were vector averaged over this period; and the eye passed to the east of the area, which put it on the weaker side.

Mean currents were weak in the summer. At CT and CM, they were downcoast-onshore in June and August and upcoast-offshore in July. At CU, they were upcoast in both June and July, but at CZ only in July. Figure 1-30 shows that most of the upcoast flow occurred in the latter half of July. Currents were broadly distributed in direction and speed at all depths but CZ which is consistent with the low vector mean values. Scalar average speeds, however, were in the 20 to 30 cm/s range at CT and CM.

The effects of Hurricane Alicia on the currents in the study area were strong but short-lived. Figures A-67, A-79 and A-91 show that peak currents were strongly downcoast and offshore at all depths. The peak alongshelf components were 160 cm/s at CT, 125 cm/s at CM and 100 cm/s at CU. The peak currents occurred between 1800 hours and 2400 hours (CST) on August 17 when the eye passed just east of site C. Current speeds dropped to less than 25 cm/s at all depths by the end of August 18 and became quite weak for several days. The strong currents probably caused substantial scour, resuspension and redistribution of the bottom sediments.

Water temperature continued to warm during the summer. The summer thermocline is clearly evident in Figure 1-34. The temperature difference between CT and CM was often smaller than that between CM and CU. Largest vertical temperature differences, up to 7°C, occurred when the bottom temperatures decreased during upwelling events such as on July 1 and July 29.

Strong vertical salinity differences, up to 18 o/oo occurred between June 20 and July 30 as relatively fresh water, from a late spring runoff (Figure 1-5), was advected through the area. The lowest salinity, 15.7 o/oo at the surface, was recorded on June 24. The summer ranges were 15.7 to 33.4 o/oo at CT, 19.8 to 34.5 o/oo at CM and 38.4 to 36.6 o/oo at CU. Plume effects were much weaker during the period of strong salinity stratification (Figure 1-35).

Prior to Hurricane Alicia, on August 16, the water at site C was strongly stratified. A thick layer of fresher, warmer water (30 to 32 o/oo and 29 to 30°C) overlay a thinner bottom layer of saltier, cooler water (35 o/oo and 25°C). The 40-hour, low-passed filtered time series in Figure 1-34 suggest that the water column became homogeneous during the hurricane. The three-hour, low-passed filtered records in Figures A-67, A-79 and A-91 provide additional details, however, which show that the changes during the hurricane were very transient and suggest that advection and the movement of fronts separating water masses may have been partly responsible for the rapidity of the observed changes. At CT the salinity decreased from about 30 o/oo on August 16 to about 28 o/oo on August 22 except for a transient 4 o/oo rise early on August 17 which was preceded by a strong onshore pulse of current. At CM and CU the salinities dropped rapidly on August 17 to values of about 28 o/oo and rose even more rapidly on August 18 to close to pre-hurricane values. Thus on August 19 salinity stratification had returned and the difference between CT and CU was greater than 5 o/oo. The data are consistent with advection along the coast, caused by the strong downcoast flow, of a mass of fresher water, the offshore edge of which was at times offshore and at times inshore of site C. The relative importance of mixing versus water mass movement in explaining the observed changes is not known, but it is clear that large scale homogenization of the coastal waters did not occur.

The June 9, 1983 hydrographic data are illustrated in Figure A-20 to show the cross-shelf variation and in Figure A-21 to show the alongshelf variation. This example of early summer conditions shows the existence of strong vertical gradients of temperature, salinity, density, and dissolved oxygen. On this date, the brine discharge was continuing at an average rate of 33,384 barrels/hr, a salinity of 251 o/oo, and a temperature of 27°C. Currents were weak on this day. Surface currents were downcoast at less than 20 cm/s while the deeper currents oscillated between upcoast and downcoast flow with speeds less than 15 cm/s.

The cross-shelf isotherms were nearly horizontal and decreased from 27 to 24°C between the depths of 3 and 15 m. This same negative temperature gradient without the 27°C isotherm was present in the alongshelf transect and the isotherms were also nearly horizontal in this transect. The negative temperature gradient is expected for the summer. There is no apparent affect of the brine discharge on the temperature distribution.

The salinity and sigma-t data show the isohalines and isopycnals sloped upward from inshore near the bottom toward the surface offshore. The salinity values increased with depth and distance offshore. For example, the isohalines and isopycnals ranged from 24 o/oo and 14 sigma-t units inshore to 34 o/oo and 24 sigma-t units offshore. Evidence of the brine plume is given by the 35, 36, 37 and 38 o/oo isohalines in the cross-shelf transect. The bottom salinity at station 34 was 38.9 o/oo which was 4.9 o/oo above the ambient bottom salinity at station 39.

A strong negative dissolved oxygen gradient was present. An 8 mg/l isopleth was present between the 5 and 10 m depth from stations 12 to 34G where it sloped upward to the surface at station 34C. In the lower half of the water colummn isopleths of 7 through 3 mg/l were present inshore of station 34, and offshore, all but the 3 mg/l isopleths were present. A pocket of less than 2 mg/l isopleth was detected at the bottom of station 14. In the alongshelf transect, only the surface value at station 34 indicated a value greater than 8 mg/l, and the isopleths of 7 through 3 mg/l were present in the lower half of the water column.

The July 22, 1983 hydrographic data are illustrated in Figures 1-36 and 1-37 for the cross-shelf and alongshelf transects, respectively. The brine was being discharged at an average rate of 44,264 barrels/hr, salinity of 244 o/oo and temperature of 28°C. This was one of the highest discharge rates during the study period. Currents were weak on

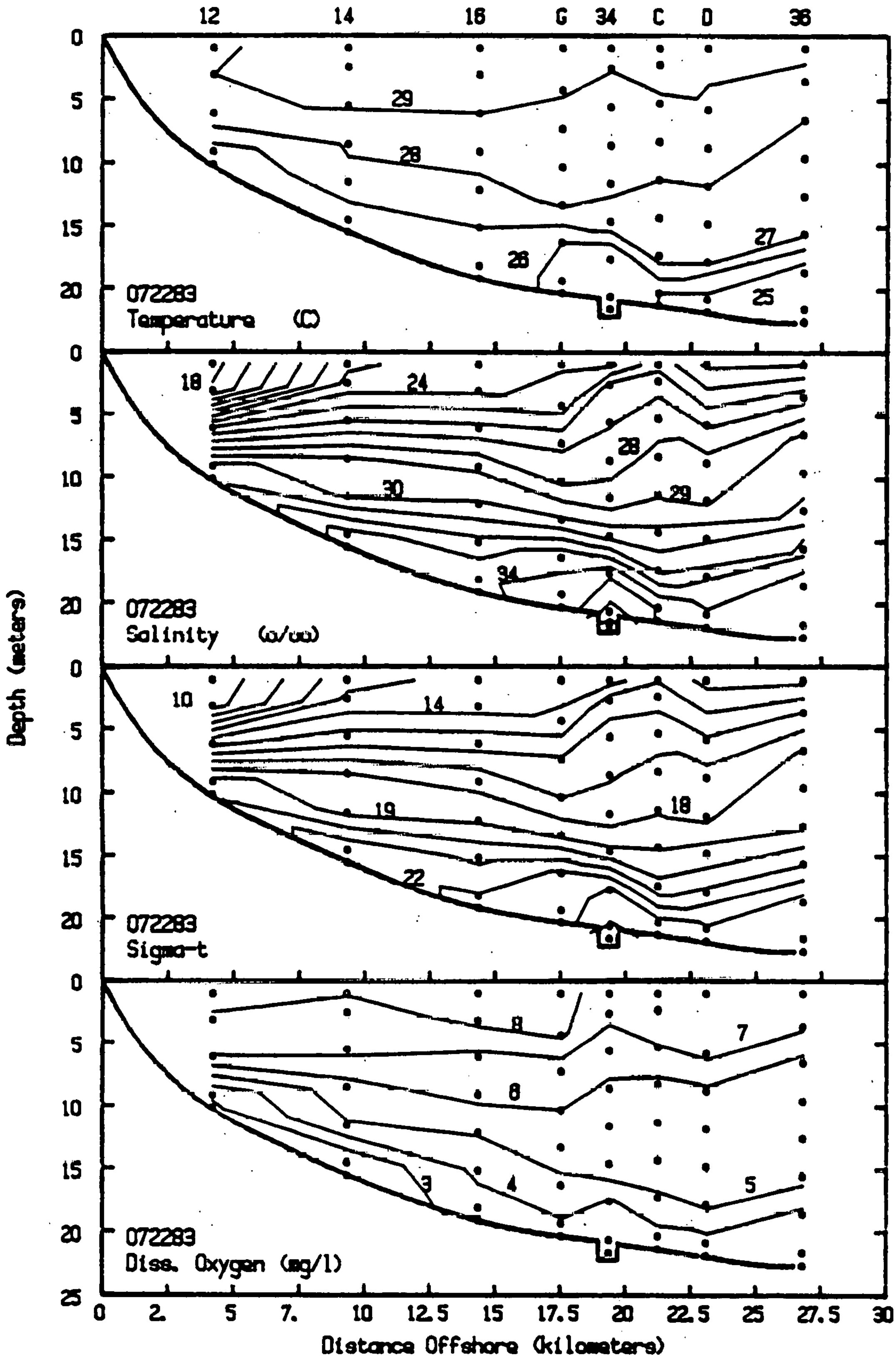


Figure 1-36. Hydrography for the cross-shelf transect offshore Freeport, Texas on July 22, 1983.

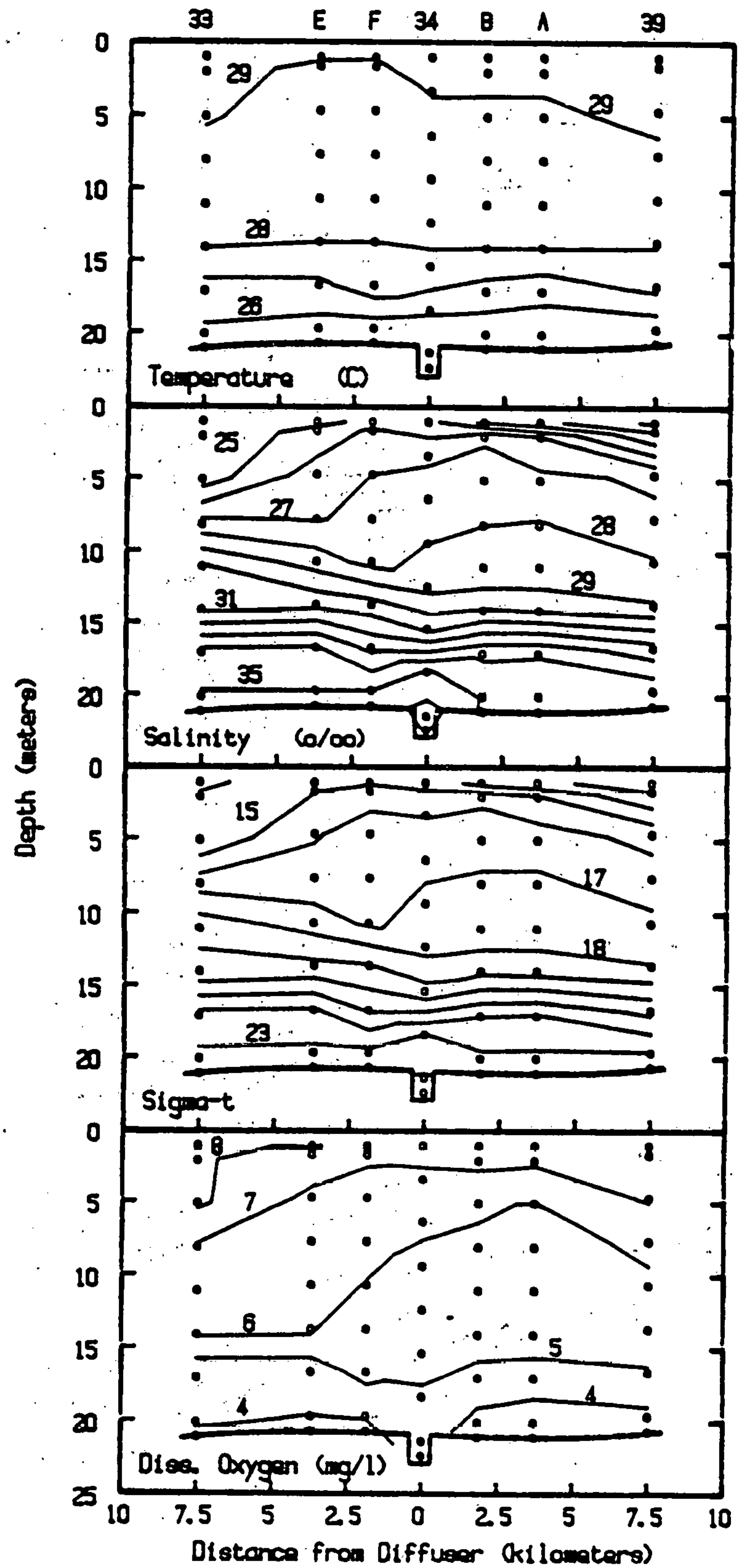


Figure 1-37. Hydrography for the alongshore transect offshore Freeport, Texas on July 22, 1983.

this day. Surface currents were less than 15 cm/s and changed from upcoast to downcoast during the day while bottom currents were less than 5 cm/s. Strong upwelling currents had occurred, however, during the preceding two days.

The cross-shelf temperature data indicate the presence of a 29°C isotherm near the 5-meter depth; the 28 and 27°C isotherms were generally located in the lower half of the water column over the entire transect. Temperatures of 25 to 26°C were found in the bottom waters just inshore and offshore of station 34, respectively. The alongshelf data indicate horizontal isotherms with the 29°C isotherm near the surface and the 28, 27 and 26°C isotherms in the lower half of the water column.

The salinity and sigma-t data illustrate the intense stratification over the entire water column, which was probably caused by the upwelling currents during the preceding two days. Isohalines between 18 and 24 o/oo were located near the surface from stations 12 to 34. Isohalines between 25 and 31 o/oo covered the entire transect. At station 34 the isohalines ranged from 24 to 37 o/oo. The brine plume was defined by the 35 to 37 o/oo isohalines which were located between stations 34G and 34C. Isohalines from 25 to 36 o/oo were present in the alongshelf transect. The presence of the brine plume is indicated by the 35 to 37 o/oo isohalines. However, larger above ambient salinity conditions were expected under the low current conditions. The smaller above ambient salinity conditions are attributed to the higher exit velocities which produce better dilution, to the salinity gradient in the receiving waters providing fresher water for dilution than the surrounding bottom water and to the lower brine salinity. The brine jets are predicted to reach the 14-meter depth for the discharge conditions present during the hydrographic cruise.

A large dissolved oxygen gradient was found in both transects. The 8 mg/l isopleth was near the surface between stations 12 and 24 in the cross-shelf direction and between 33 and 34E in the alongshelf direction. The 7 through 4 mg/l isopleths were present over the entire transect in both the alongshelf and cross-shelf directions. A 3 mg/l isopleth was present in the cross-shelf transect near the bottom between stations 12 and 16. In the alongshelf transect the 4 mg/l dissolved oxygen isopleth is discontinuous at station 34. This is attributed to the brine discharge which brings higher oxygenated water to the bottom as the brine sinks to the bottom.

The August 12, 1983 hydrographic data were collected when the brine was being discharged at a daily average rate 31,558 barrels/hr, a salinity of 246 o/oo and a temperature of 29°C. Currents were upwelling favorably on this day. Surface currents were upcoast and offshore between 20 and 35 cm/s while bottom currents were upcoast and onshore between 10 and 25 cm/s. The results are graphically presented in Figures A-24 and A-25.

The temperature data show the temperature gradient had weakened. Isotherms of 29, 28 and 27°C were present in both transects with the 29°C isotherm near mid-depth followed by the other two in deeper water.

The salinity and density data also show the stratification had weakened. In the cross-shelf transect, the isohalines of 30 through 34 o/oo were nearly horizontal over the entire transect. The 36 o/oo isohaline indicated the presence of the brine plume and extended from station 34G to between stations 34D and 36 (8 km) in the cross-shelf direction. In the alongshelf direction it reached from station 34F to 34A (5.5 km). The bottom salinity at station 34 was 39.5 on the cross-shelf transect which was the highest measured salinity during the hydrographic cruises and 4.9 o/oo above the bottom salinity at station 39. The sigma-t data show the isopycnals ranged from 17 to 25 in the cross-shelf data and 19 to 24 in the alongshore data.

The dissolved oxygen data indicate surface values were 6 to 7 mg/l while the bottom waters were hypoxic with values less than 2 mg/l. The 2 mg/l isopleth covered the entire cross-shelf transect and all but the area in the immediate vicinity of the diffuser was hypoxic at the bottom. The break in the 2 mg/l isopleth is attributed to the brine jets entraining higher oxygenated water during the jet mixing process. A similar hypoxic event was observed in June of 1982 (Kelly et al., 1983a). Hypoxic conditions of the bottom water at Bryan Mound were reported also during the summer of 1979 prior to brine disposal by Harper and McKinney (1980) and Slowey (1980). Similar hypoxic conditions occur on a near annual frequency at the West Hackberry site as discussed by Kelly et al. (1983b). Thus, there is considerable evidence that the brine disposal is not causing the hypoxic conditions.

1.4 Spectral Analyses

1.4.1 Wind and Currents

Autospectra, rotary spectra, phase and coherence squared were computed for the wind and current time series. The Fast Fourier Transform method was used. The mean and linear trend were removed as a first step. A 10% cosine taper was then applied to the time series. The spectrum was smoothed by repeated passes with a Hanning filter. The resulting degrees of freedom are stated in each plot and confidence limits are indicated for the spectra. The algorithms used follow a formula given by Bendat and Piersol (1971). Rotary spectra were computed from the standard spectral quantities of two time series as described by Gonella (1972).

The three-hour, low-passed series of alongshelf and cross-shelf wind and currents were used (see Section 1.2). They were divided into periods of 90 days to correspond to each season. There were no wind data in the fall and no CZ currents in the winter. The figures from these analyses have been grouped together in Appendix A.8. Figures A-122 through A-125 show the component autospectra of wind and currents and Figures A-126 through A-129 show the rotary spectra. The spectral densities have units of $(m/s)^2/cpd$ for wind and $(cm/s)^2/cpd$ for currents, and therefore, are proportional to kinetic energy density. The autospectra and rotary spectra are provided for reference and are not discussed. The coherence between the cross-shelf wind and currents was found to be low in previous studies of this area and was not computed for this report. The phase and coherence squared between the alongshelf component of wind and each of the current components are shown in Figure A-130 through A-132. These show that low frequency current fluctuations up to about 0.2 cpd were strongly coherent with the alongshelf component of wind at all depths; cross-shelf currents were coherent with the alongshelf wind at these frequencies only near the bottom.

1.4.2 Harmonic Tidal Analyses of Currents

Records of half-hourly current velocity for periods of 29 days each were analyzed using a modified version of the harmonic tidal analyses program of Dennis and Long (1971). It is a computerized version of the method described by Schureman (1940) which determines the amplitude and local epoch for each of five major tidal constituents (K_1, O_1, M_2, S_2, N_2), harmonics (M_4, M_6, M_8, S_4, S_6) and about 14 smaller tidal constituents. In addition, the parameters of the tidal current ellipse are determined (Doodson and Warburg, 1941) including the amplitudes of the semi-major and semi-minor axes, the orientation of the axes in degrees in a clockwise direction from north, the sense of rotation, and the eccentricity of the ellipse (distance between the foci divided by the length of the major axis). The results are shown in Appendix A.6. Only the results for the K_1, O_1, M_2, N_2 and S_2 constituents are shown.

1.5 Persistence Analysis of Bottom Currents

The persistence of currents less than various levels of speed was studied for the CU record from August 20, 1982 through August 23, 1983. This type of analysis is of interest because the size, shape, and "strength" of the brine plume are strongly affected by the near bottom currents. Model studies (Randall and Kelly, 1982) have assumed a current of at least 3 cm/s and have shown that periods with currents less than about 6 cm/s result in large plumes.

The results of the last section indicate that currents during this study were not less than 3 cm/s for any appreciable length of time because of the magnitude of the tidal/inertial components of the current. For example, monthly vector mean speeds were larger than 2 cm/s in all months but March and April; the current roses for CU (Appendix A.3) show that the average scalar speeds were large and the most frequent speed range was at least 5 to 10 cm/s; speeds in the 2 to 5 cm/s range were recorded less than 8% of the time, and thus, speeds of 6 cm/s occurred frequently. The following analysis quantifies the persistence of the currents.

Current speed was computed from the three-hour, low-pass filtered orthogonal components of current velocity recorded at meter CU. The persistence of the speed records were then studied in a straightforward manner. For each given threshold, the record was searched for periods of time when the speed fell below the threshold. (Such a period is called a "run".) The start time and duration of each run were recorded and then the statistics of the ensemble of runs for each threshold were studied.

Table 1-2 shows the distribution of the run durations for each threshold. The entries in the table are the number of runs which had a duration between the given limits, i.e., for the 12 cm/s threshold in Table 1-2, there were 8 runs with a duration between 24 and 32 hours. Summing over adjacent "duration bands" can broaden the duration limits, i.e., for the 12 cm/s threshold there were 33 runs with a duration between 16 and 40 hours. Table 1-3 shows the basic statistics for each threshold, i.e., the number of runs, the maximum duration, the mean duration, and the standard deviation about the mean. The statistics of run duration (Table 1-3) show that during the 368 days of the record, there were 101 runs with speed less than or equal to 3 cm/s but none exceeded 13 hours in duration. The mean duration was only 2.4 hours. Thus, the model assumption (Randall and Kelly, 1982) of speeds of at least 3 cm/s seems valid. For the 6 cm/s threshold, the maximum duration was 27 hours and the mean duration was 3.6 hours. It is concluded that stagnation of the bottom waters does not occur and that the persistence of speeds less than 6 cm/s, a condition which results in an increase in plume size, is typically only a few hours and less than two days at most.

1.6 Discussion

An overview of the results can be gained from the monthly mean values of wind and currents listed in Appendix A.2 and plotted in Figure 1-38. For comparison, the results from the last annual period are reproduced in Figure 1-39 (Kelly et al., 1983a). As found previously, the mean alongshelf component of wind was well correlated with alongshelf and

Table 1-2. Distribution of the number of occurrences of runs of current speed with a duration between the indicated lengths of time. Results are based on a time series of 8818 hourly values of current speed computed from the three-hour, low-passed filtered orthogonal components of current velocity from meter CU for the period August 20, 1982 through August 23, 1983.

SITE C, METER CU (08/20/82-08/23/83)

DURATION (HR)	0	8	16	24	32	40	48	56	64	72	TOTAL
SPD. THRESHOLD											
3 CM/S	101	4	0	0	0	0	0	0	0		105
6 CM/S	213	17	1	1	0	0	0	0	0		232
9 CM/S	270	48	9	1	1	1	0	0	0		330
12 CM/S	250	83	24	8	1	3	0	2	0		371
15 CM/S	237	70	42	15	8	6	3	3	4		388

Table 1-3. Basic statistics for the duration of runs from Table 1-2.

SITE C, METER CU (08/20/82-08/23/83)

SPEED	MAXIMUM DURATION (HR)	MEAN DURATION (HR)	STD.DEV. ABOUT MEAN (HR)	TOTAL OCCURRENCES
3 CM/S	13.0	2.4	2.3	105
6 CM/S	27.0	3.6	3.3	232
9 CM/S	42.0	5.6	5.1	330
12 CM/S	63.0	8.1	8.0	371
15 CM/S	77.0	11.0	12.3	388

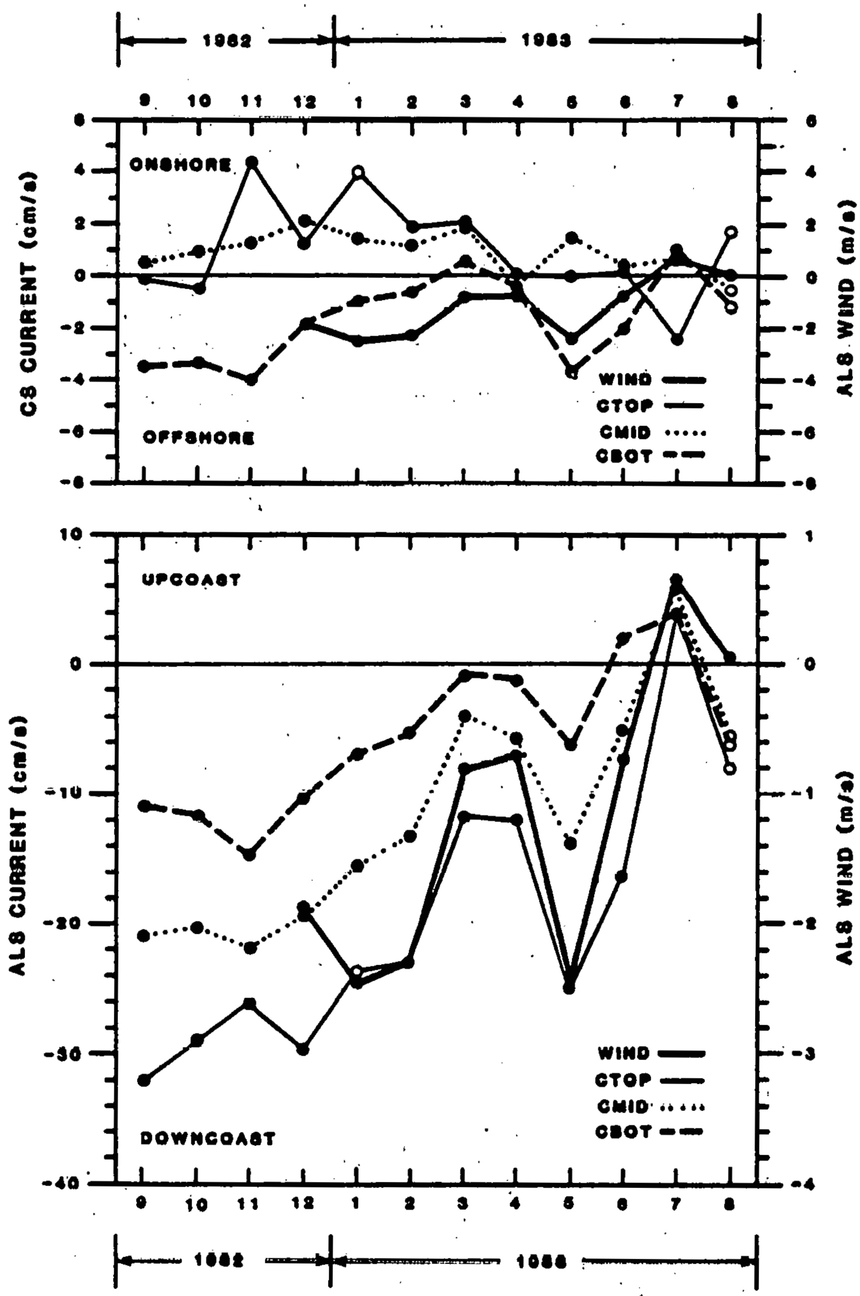


Figure 1-38. Monthly mean cross-shelf and alongshelf components of currents for the top, middle and bottom current meters at site C together with the monthly mean alongshelf component of wind for the present sampling period. An open circle indicates a month with more than 10% data missing.

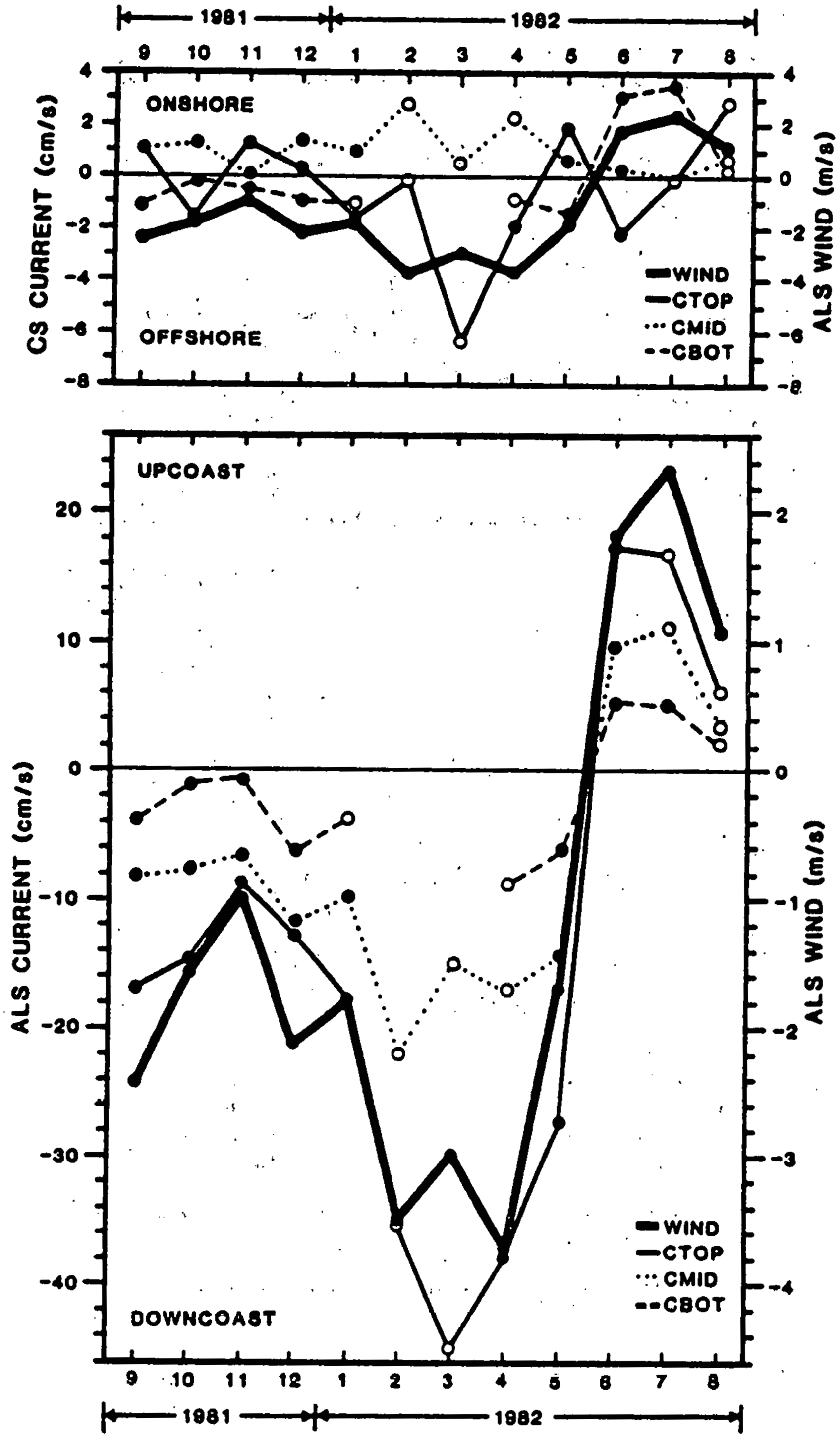


Figure 1-39. Monthly mean cross-shelf and alongshelf components of currents for the top, middle and bottom current meters at site C together with the monthly mean alongshelf component of wind for September 1981 through August 1982. An open circle indicates a month with more than 10% data missing.

cross-shelf components of mean current. When the mean alongshelf wind was downcoast the alongshelf currents were downcoast at all depths. Cross-shelf currents were onshore at CT and CM and offshore at CU. When the wind switched to upcoast in July the alongshelf currents followed suit while the cross-shelf currents reversed their vertical relation. The present annual period was significantly different from the previous one, however, in several respects. During the fall of this period the currents were substantially stronger than during the previous fall. Also, from December through April of this annual period the currents decreased in strength, but during the previous annual period previously they had increased from December through April. Thus, seasonal changes in the currents followed the alongshelf component of wind, as in previous years, but the pattern was significantly different compared to previous years.

A major step in understanding the circulation on the Texas-Louisiana Shelf, has been achieved in finding that the circulation indicated by monthly mean geopotentials (integrated along the bottom to a common reference pressure) fits together, at least qualitatively, the known facts about the circulation. (The flow parallel to the coast is nearly geostrophic flow, that is, flow in which there is a balance between pressure gradient and Coriolis force.) The theoretical basis for using geopotentials is provided by Csanady (1979). In months other than June, July and August, an elongated region of low geopotential dominates the shelf, as Figure 1-40 illustrates. At that time, downcoast flow prevails on the inner shelf in agreement with the downcoast wind component along much of the coast and there is a counterflow (eastward or northeastward) along the shelf break. During the summer months, as Figure 1-41 illustrates, there is upcoast flow along much of the inner shelf up to

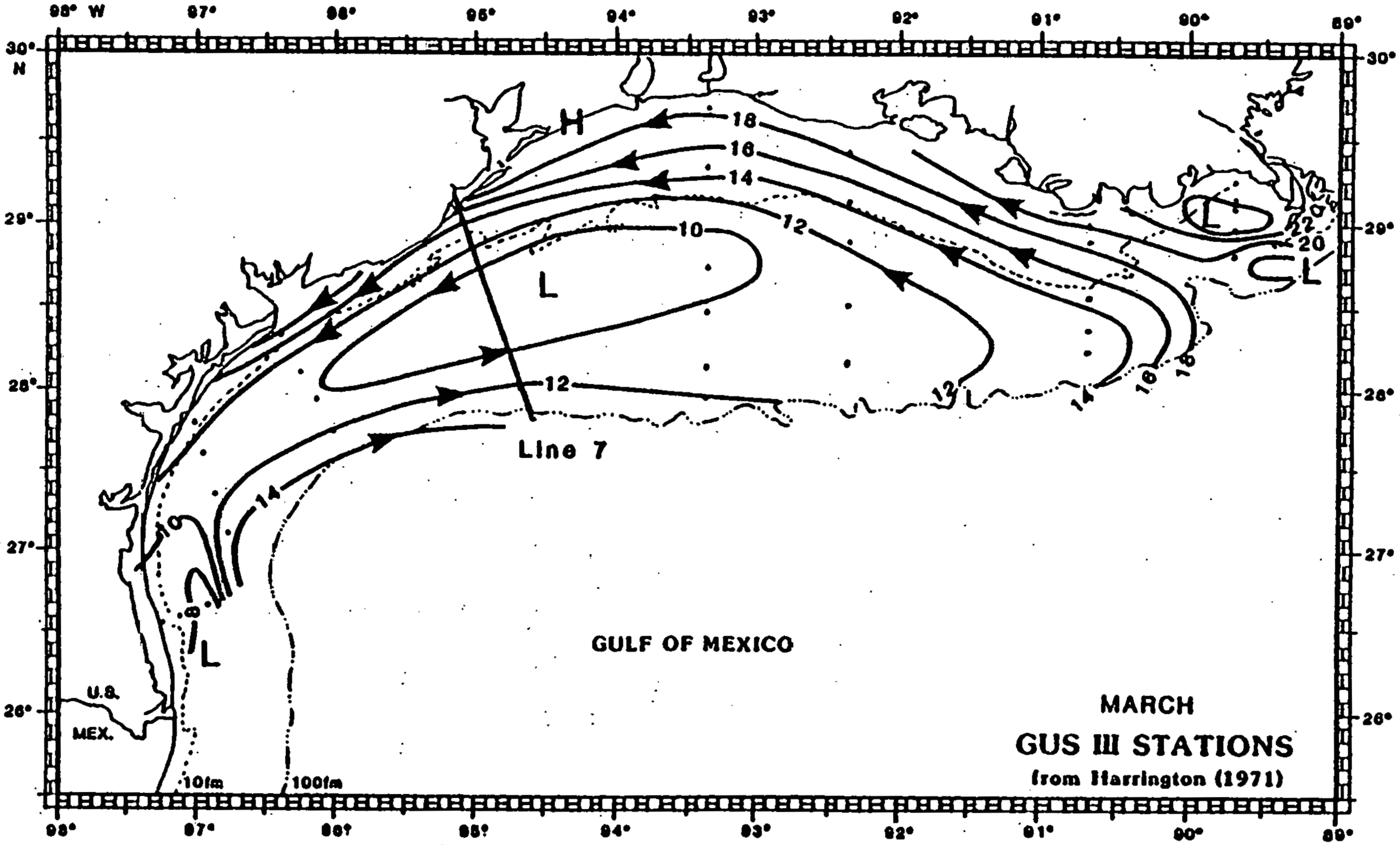


Figure 1-40. Mean geopotential anomaly (dyn.cm) of the sea surface relative to 70 db based on GUS III data for March.

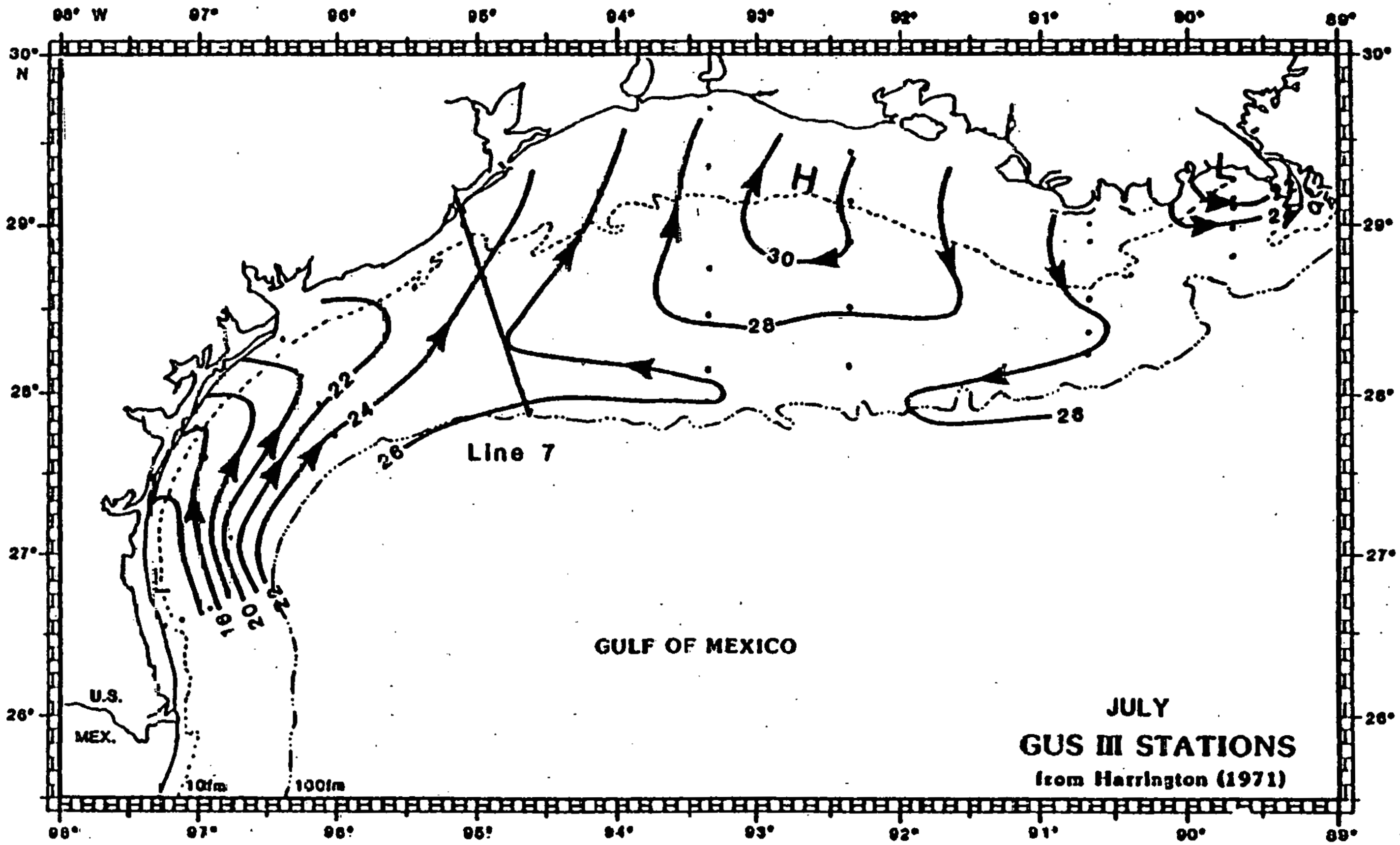


Figure 1-41. Mean geopotential anomaly (dyn.cm) of the sea surface relative to 70 db based on GUS III data for July.

about 92.5°W while a high in geopotential lies off the Louisiana coast; although there is a suggestion of eastward or northeastward flow along the shelf break, it is quite weak, very different from the situation during the rest of the year when there is a distinct "low" in geopotential over the outer shelf. The upcoast flow agrees with the prevalence at that time of an upcoast wind component along the coast. The situation is described in detail in the annual report for September 1981 through August 1982 (Kelly et al., 1983a).

The inshore currents implied by the geopotential explain the sea-surface salinity encountered in the GUS III cruises. The patterns result largely from Mississippi River discharge being advected downcoast and diffusing. The geopotentials also are in agreement with the direct measurements of current in the Bryan Mound and West Hackberry brine disposal regions, and to the extent allowed by brief periods of measurement or observation with the current measurements reported by Smith (1975, 1978, 1979, 1980) and drifter observations.

The low or cyclonic circulation in Figure 1-40 has a limited downcoast extent. According to the geopotential, the coastal currents weaken and outer portions of the flow turn offshore off the Texas coast near 97°W. This is in agreement with a convergence along the coast implied by the alongshore components of the prevailing wind. Sea-surface salinity patterns observed from GUS III and by Smith (1979) indicate such offshore turning.

The geopotential indicates that the cyclonic turn away from the coast continues and that on the outer shelf, or over the inner continental slope, it meets a current approximately along the isobaths there flowing counter to the coastal current. Independent evidence of that flow has been rather tenuous: the low surface salinity observed in some GUS III cruises was its only confirmation. During the past year, however, current measurements on the Flower Garden Bank and on Bakers Bank were brought to our attention by Dr. David McGrail of Texas A&M University. These indicate that the prevailing current at the outer edge of the shelf does run counter to the downcoast flow along the coast and so is in agreement with the pattern implied by the geopotential. (The Bakers Bank data were made available to Dr. McGrail by Continental Shelf Associates and Conoco.)

During the past year we have begun to feel that the countercurrent at the outer edge of the shelf is analogous to the countercurrents which occur farther offshore and usually deeper than coastal flows which accompany wind induced upwelling (Huyer et al., 1974). Such a countercurrent appear to be compatible with Pedlosky's (1974) model for a countercurrent accompanying upwelling. A major consideration in adopting such a view of the countercurrent on the outer shelf is the fact that the low in geopotential over the shelf is, according to GUS III data, reppears in September (Figure 1-42) very soon after the change in the prevailing longshore wind component.

In view of the success of the geopotential picture in explaining qualitatively the observed flow, it is desirable to test the geostrophic relationship (on which interpretation of the geopotential depends) quantitatively. This is done by comparing the alongshore velocity components measured at site C with vertical velocity change implied by the density at surrounding hydrographic stations. The change in geostrophic velocity (V) from one pressure surface to another is given by

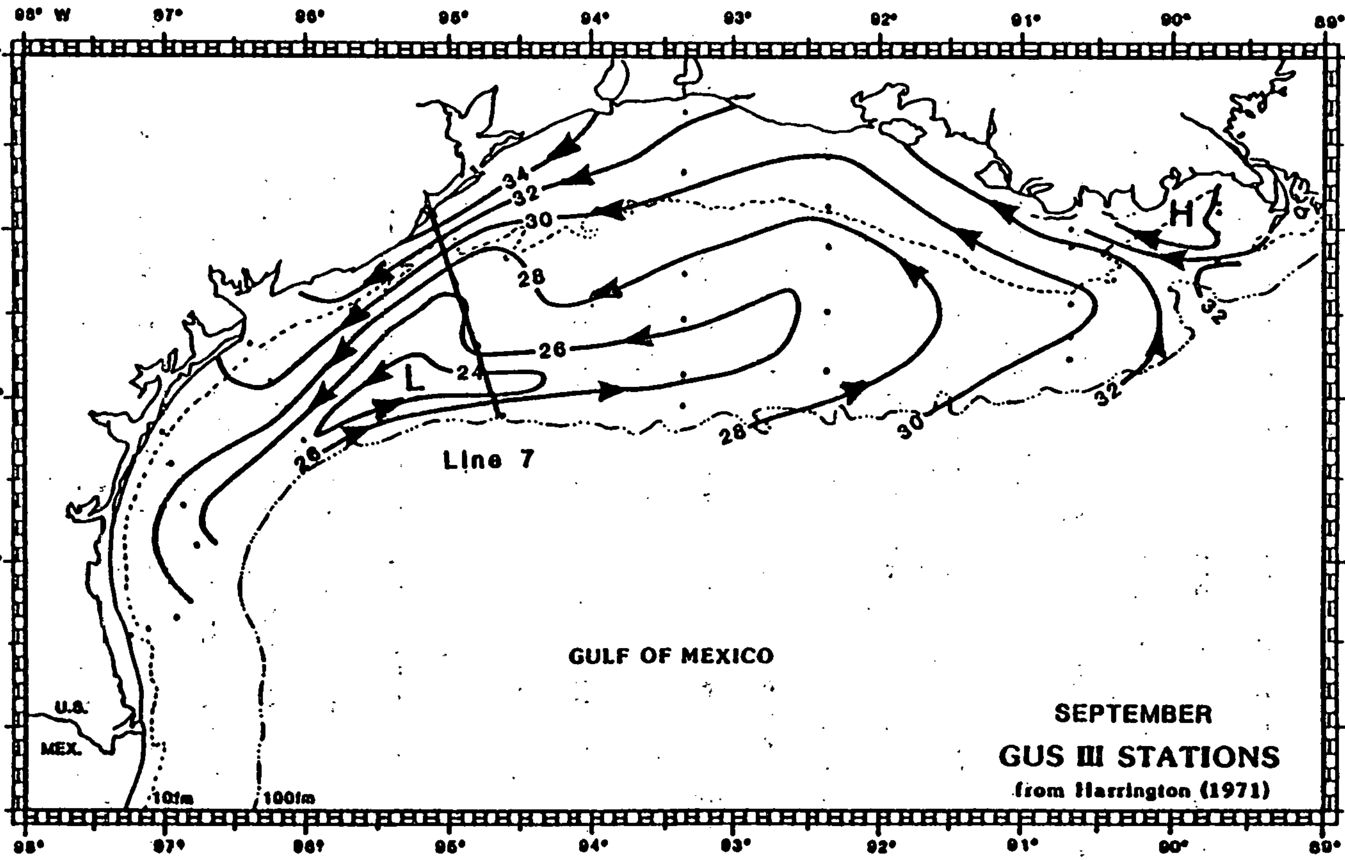


Figure 1-42. Mean geopotential anomaly (dyn.cm) of the sea surface relative to 70 db based on GUS III data for September.

$$V - V_0 = \frac{1}{fL}(\Delta\phi_B - \Delta\phi_A),$$

where $f = 2\Omega \sin\phi$ the Coriolis parameter, L is the distance between two hydrographic stations, A and B, and $\Delta\phi_A$ and $\Delta\phi_B$ are the geopotential anomalies for the two stations between the pressures for V_0 and V. Because flow below the middle current meter (11 m deep) at site C is in the bottom layer of frictional influence, as will be discussed below, the change in velocity between the middle and top current meter is considered. For non-summer months in the period from September 1979 to September 1982, the mean increase in alongshore speed from the middle to the top current meter is 7.8 cm/s. The geostrophic velocity shear $V - V_0$ for the same layer based on mean hydrographic data for stations 16 and 36 is 8.7 cm/s. The agreement is not bad and, as might be expected, the actual velocity increase is less than that implied by the geostrophic relationship which does not take friction into account.

In view of the reasonable agreement between measured and geostrophic current, it seems worthwhile to estimate the alongshore geostrophic transport on the inner shelf. This transport is the total alongshore volume flow above the bottom implied by the geostrophic relationship. Using the mean geopotential based on GUS III data for the three lines running offshore between the offing of Cameron, Louisiana and Pass Cavallo, Texas, we find a mean geostrophic transport for non-summer months in the coastal limb of the low in geopotential of 10^5 m^3/s. This is one half the mean winter baroclinic transport found by Bishop (1980) for the U.S. Middle Atlantic Shelf (off the U.S. east coast). The mean Mississippi-Atchafalaya River discharge is 2×10^4 m^3/s or about one fifth of the inshore transport on the Texas-Louisiana Shelf. That much of the latter transport is within a nearshore jet is suggested by the geostrophic transport between stations 16 and 36 for May which is $4 \times 10^4\ m^3/s$ or nearly half of the transport within a very small nearshore region. One would expect the jet described here to lie inshore of the salinity front. Its outcrop at the sea surface is not very well known, but probably is usually found within 35 km of the coast of Freeport.

Although geostrophic balance provides a fairly good approximation for mean conditions in the cross-shelf direction (alongshore velocity is of course involved in the balance), frictional forces must certainly be taken into account in looking at the alongshore (y) equation of motion. The latter may be written with reasonable approximation for steady conditions as

$$0 = -\int_{-h}^{0} \frac{\delta \phi}{\delta y}\, dz + \tau_y^0 - rv,$$

where the first term is essentially the alongshore slope of the sea surface, τ_y^0 the kinematic stress due to wind at the sea surface, and r, the bottom frictional parameter introduced by Csanady (1976). To evaluate r for the Bryan Mound disposal region, the wind stress based on the NDBC anemometer (Buoy 42008, see Figure 1-1) and the currents measure 2 m above the bottom at site C have been used. On the assumption that the alongshore slope is zero, the mean value of r based on eleven one- to three-day periods of fairly uniform wind from September 1981 to August 1982 was found to be 0.026 cm/s. The values for the individual period scatter rather widely about a regression line and so no satisfactory estimate of the alongshore stress was possible. Since, as Winant and Beardsley (1979) point out, the effect of longshore slope and synoptic-scale fluctuations in the Coriolis term can not be ruled out, the value of r may be overestimated. Beardsley and Haidvogel (1981) using a numerical model found that about 50% of the surface wind stress may be balanced by terms other than bottom stress. An appropriate value of r may therefore be nearer 0.01 cm/s, that is, half of the above noted value.

Another estimate of the value of r may be obtained by noting that at the top of the bottom logarithmic friction layer, $\tau = \rho C_D qV$. The value of r is $\rho C_D q$ where q is the RMS fluctuation of velocity. If the fluctuation is dominated by tidal motion as Csanady (1976) suggests, the values of r on the assumption that $C_D = 1.5 \times 10^{-3}$ is 0.008 cm/s. For the latter evaluation q was taken as the RMS tidal velocity based on K_1, O_1, M_2, N_2 and S_2 tidal constituents determined from 29 days of measurement at site C in May 1982 (Kelly et al., 1983a).

A very striking feature of the progressive vector diagrams for the current meters at site C (Figures 1-8, 1-16, 1-24 and 1-32) is the veering between the bottom meter CU (0.5 m above the bottom) and the middle current meter CM (11 m deep and above the bottom). The veering is counterclockwise with depth and for the season except summer, its mean angle is more than 40°. The veering appears to be Ekman veering. According to theories of Csanady (1974) and Weatherly and Martin (1978) such strong veering results under conditions of fairly large static stability. The influence of stability on veering is under investigation on the basis of the current data from site C in July and August 1983 when current meters were deployed at six levels on site C.

A perplexing feature of the progressive vector diagrams for the downwelling (non-summer) period is the fact that the middle progressive vector is offset slightly clockwise from that of the top meter (at 4 m below the sea surface). Ekman veering due to the prevailing wind with a downcoast component for those seasons would be in the opposite direction. Since it is difficult to believe that the witness buoy may influence the currents measured at site C or that pecularities of local topography might result in such paradoxical veering, we speculate that the shoreward transport due to wind farther offshore than the brackish wedge along the coast tends to sink along the salinity front bounding the wedge and that continuity normal to the coast is maintained by offshore flow in the surface layer as well as near the bottom.

1.6.1 Temperature-Salinity Relation at Stations 34 and 39

The relationship of temperature and salinity at the diffuser site (station 34) and of the upcoast ambient station 39 for the period September 1, 1982 through August 31, 1983 are illustrated in Figure 1-43. The upper half of Figure 1-43 shows the relationship for data collected 1 m below the surface. The lower half of Figure 1-43 shows the relationship for data which were measured with the CTD/DO instrument on the sea floor.

Station 34 is the location of the center of the diffuser, and station 39 is located on nearly the same isobath as station 34 but 7.4 km northeast (upcoast) of it. Station 39 is not impacted by the brine, and consequently, it serves as an ambient station. It is used here to illustrate the effect of the brine discharge on the temperature-salinity relationship at the diffuser station.

In September 1982, the surface temperature was at its maximum value of 29.9 and 29.8°C at stations 34 and 39, respectively. The salinity was 35.1 o/oo at both stations. In October, the surface waters at station 34 cooled and freshened, and a similar trend occurred at station 39. The decrease in temperature was the start of the annual temperature decrease,

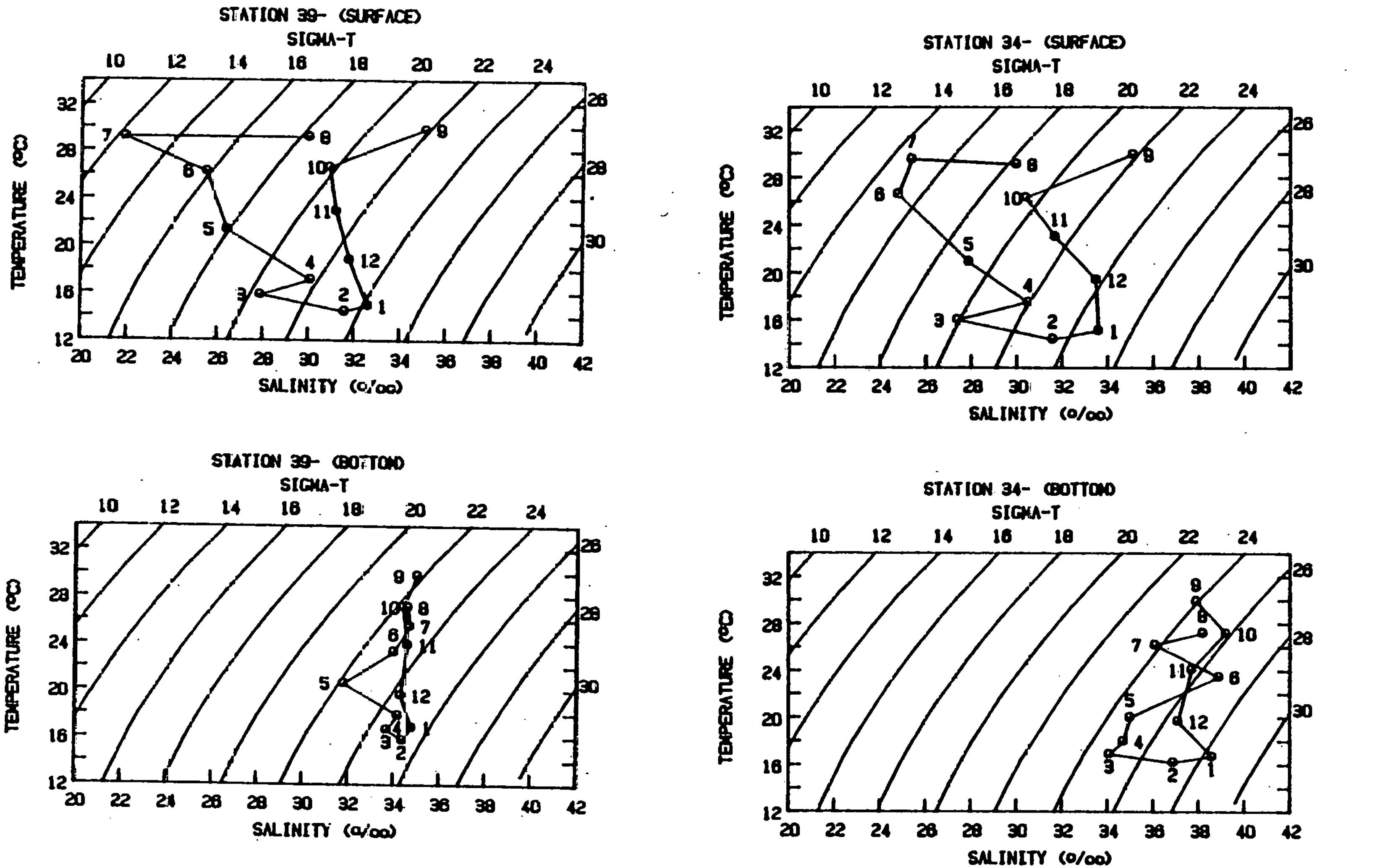


Figure 1-43. Temperature-salinity relationship for stations 34 and 39 for the period September 1982 through August 1983. The numbers alogside each data point indicate the month of the year.

and the freshening trend was the result of fresher water from the upper Texas and Louisiana coasts entering the area as a result of the shift from northeast to southwest in the prevailing surface current, which is an annual event. The November data show that the temperature at both stations continued to decrease to a minimum value in February 1983 of 14.4°C at both stations. However, the salinity data show a general increase from November through January with the salinity reaching values of 33.6 o/oo at station 34 and 32.6 o/oo at station 39. In March, the temperature at both stations increased to values near 16°C. The salinity at station 34 freshened to 27.4 o/oo while it increased similarly at station 39 to 27.9 o/oo. The surface waters continued to warm in April and became more saline with values of 30.5 and 30.1 o/oo at station 34 and 39, respectively. The annual freshening of the coastal waters in the spring and early summer as a result of increased fresh water outflow from Texas and Louisiana rivers, principally from the Mississippi/Atchafalaya River system, has been described in previous reports (Kelly and Randall, 1980; Kelly et al., 1982 and 1983a). This event is again evident in Figure 1-43. In May and June, the surface waters continued to warm and reached a temperature near 26°C in June. At the same time these waters were freshening to values of 24.8 o/oo at station 34 and 25.5 o/oo at station 39. The salinity continued to decrease at station 39 to 21.9 o/oo in July while it increased slightly to 25.4 o/oo at station 34. A general increase in salinity occurred in August at both stations with values of 30.0 o/oo. This is unusually fresh for August in comparison to the near 36 o/oo value reported in August 1982 (Kelly et al., 1983a). The summer temperature maximum was reached in July and August when the surface temperatures reached 29.5°C at station 34 in July and 29.1°C at station

39 in both July and August. The surface temperature-salinity relationship at stations 34 and 39 were very similar except for the fresher water at station 39 in July. Thus, it is concluded that the brine discharge did not affect the surface waters.

The temperature-salinity relationship for the bottom waters at stations 34 and 39 are discussed next. It should be kept in mind that the brine is discharged at station 34, and station 39 is considered an ambient station not affected by the brine plume. Therefore, the effect of the brine plume is expected to be illustrated by differences in the salinity and temperature at the two stations.

The bottom data (Figure 1-43) show the September temperature and salinity were 29.8°C and 35.1 o/oo at station 39 and 29.9°C and 37.9 o/oo at station 34. The salinity measured at the diffuser site was 2.8 o/oo higher than that at station 39. This increase in salinity is attributed to the brine being discharged at a rate of 41,189 barrels/hr, a salinity of 252 o/oo, and a temperature of 25°C. The temperature was 0.1°C higher at station 34, but the brine temperature was nearly 5°C less than the ambient temperature, so no apparent temperature effect was observed.

The October salinity data clearly show the effect of the brine discharge as evidenced by the salinity at station 34 being 4.8 o/oo above the 34.4 o/oo salinity measured at station 39. Brine was being discharged at a rate of 40,850 barrels/hr, a salinity of 254 o/oo, and a temperature of 29°C. In November and December the bottom water temperature continued to decrease and the ambient bottom salinity was 34.7 and 34.1 o/oo when the bottom salinity at station 34 was 37.7 and 37.1 o/oo, respectively, which was 3.0 o/oo above the ambient conditions.

The January and February 1983 data at station 39 show the same trend of decreasing temperature, and the bottom salinity was 34.8 and 34.4 o/oo, respectively. However, the bottom salinity at station 34 was 38.6 o/oo, 3.8 o/oo above the ambient salinity which again shows the effect of the brine discharge. The February data were collected when the brine discharge was at an average rate of 41,919 barrels/hr and a salinity of 246 o/oo. The lower brine salinity contributed to the low 2.5 o/oo above ambient salinity at station 34. The temperature reached a minimum value of 16.2°C which was only 0.4°C above the value at station 39 which indicated again that no significant thermal increase exists as a result of the brine discharge.

During the spring months of March, April and May, the hydrographic data at station 39 show that the temperature began its annual increase and that the bottom water freshened in March, became slightly more saline in April, and freshened again in May. The brine salinity was only 231 o/oo on the day of the March hydrographic cruise, and the data show the station 34 salinity was only 0.4 o/oo above that measured at station 39. In April, the station 34 salinity was only 0.5 o/oo above the ambient salinity when the brine salinity was 254 o/oo. It is not clear why the above ambient salinity was so low. The station 34 salinity was 3.2 o/oo above the station 39 salinity in May when the brine salinity was 256 o/oo which indicates the usual above ambient condition. The bottom temperatures on these dates were within 0.6°C of each other and thus no thermal effect was observed. The brine discharge rate in March, April and May was about 41,000 barrels/hr.

On June 9, 1983, the brine was being discharged at a rate of 33,384 barrels/hr, a salinity of 251 o/oo, and a temperature of 27°C. The hydrographic data at station 39 show the bottom temperature and salinity were 23.3°C and 34.0 o/oo, respectively. At station 34, the bottom salinity was 38.9 o/oo and the temperature was 26.2°C. Thus, the salinity was 4.9 o/oo above the ambient and the temperature was 0.9°C above that at station 39. The July data show the station 34 salinity was only 1.4 o/oo above the 34.7 o/oo value at station 39. This low above ambient condition is attributed to the strong halocline present in the bottom water. The August ambient temperature reached a maximum value of 27.1°C and the salinity was 34.6 o/oo while the temperature and salinity at the diffuser site was 27.2°C and 38.2 o/oo, respectively.

The temperature-salinity relationships during this study period at station 39 and at station 34 are similar to those previously reported prior to brine disposal (Kelly and Randall, 1980) and after brine disposal began (Kelly et al., 1982 and 1983a). The data show the coastal waters in the vicinity of the diffuser had salinity and temperature maxima (near 35 o/oo and 30°C) in the late summer which was followed by a freshening trend or salinity minimum (near 31 o/oo) in the fall in conjunction with a temperature decrease. During the winter, the salinity reached another maximum near 35 o/oo while the temperatures fell to a minimum near 14°C. In the spring and early summer, the temperature rapidly increases. The salinity decreased to a minimum near 25 o/oo in June and July before approaching the summer temperature and salinity maximums again. The salinity minimum in July was later than observed in previous years. The effect of the brine discharge on the temperature-salinity relationship was limited to near bottom depths, and at the bottom of station 34, the salinity ranged from 0.4 to 4.9 o/oo above that measured at station 39. The temperature data show no significant temperature change (less than 1°C) between the diffuser and ambient stations.

1.6.2 Temporal Variation of the Hydrographic Data at the Diffuser Site

The purpose of this section is to discuss the temporal variation of the temperature, salinity, sigma-t, and dissolved oxygen data at the diffuser site (station 34) to illustrate the seasonal trends, annual variation, and maximum and minimum values for the period September 1981 through August 1982. The monthly hydrographic data and the salinity data from the in situ meters are used. In addition, the temporal variation of the hydrographic data at station 34 is compared with the temporal variation of the hydrographic data measured at upcoast (station 39) and downcoast (station 33) control stations to illustrate the effect or noneffect of the brine discharge. The data are presented in several different formats to make interpretation easier.

The temporal variation of the diffuser site (site C) monthly mean temperature data is illustrated in Figure 1-44. The temporal variation of the monthly temperature data measured at station 34 is shown in the top part of Figures 1-45 and 1-46. The monthly surface and bottom temperatures in September were both 29.9°C The monthly mean temperature data (Figure 1-44) indicate a surface and bottom value of 29.3 and 29.0°C, respectively. The temperatures at both depths decreased to 26.3 and 27.2°C on October 5. There was a monthly mean of 25.9 (surface) and 25.0° (bottom) in October. This decreasing trend continued through February 1982. In November, December, and January the difference between surface and bottom temperature was between 0.3 and 1.6°C. The difference between the monthly mean bottom and surface temperatures was about 1° In February, a minimum temperature of 14.4°C at surface and 16.2°C at the bottom was reached. The February monthly mean surface and bottom

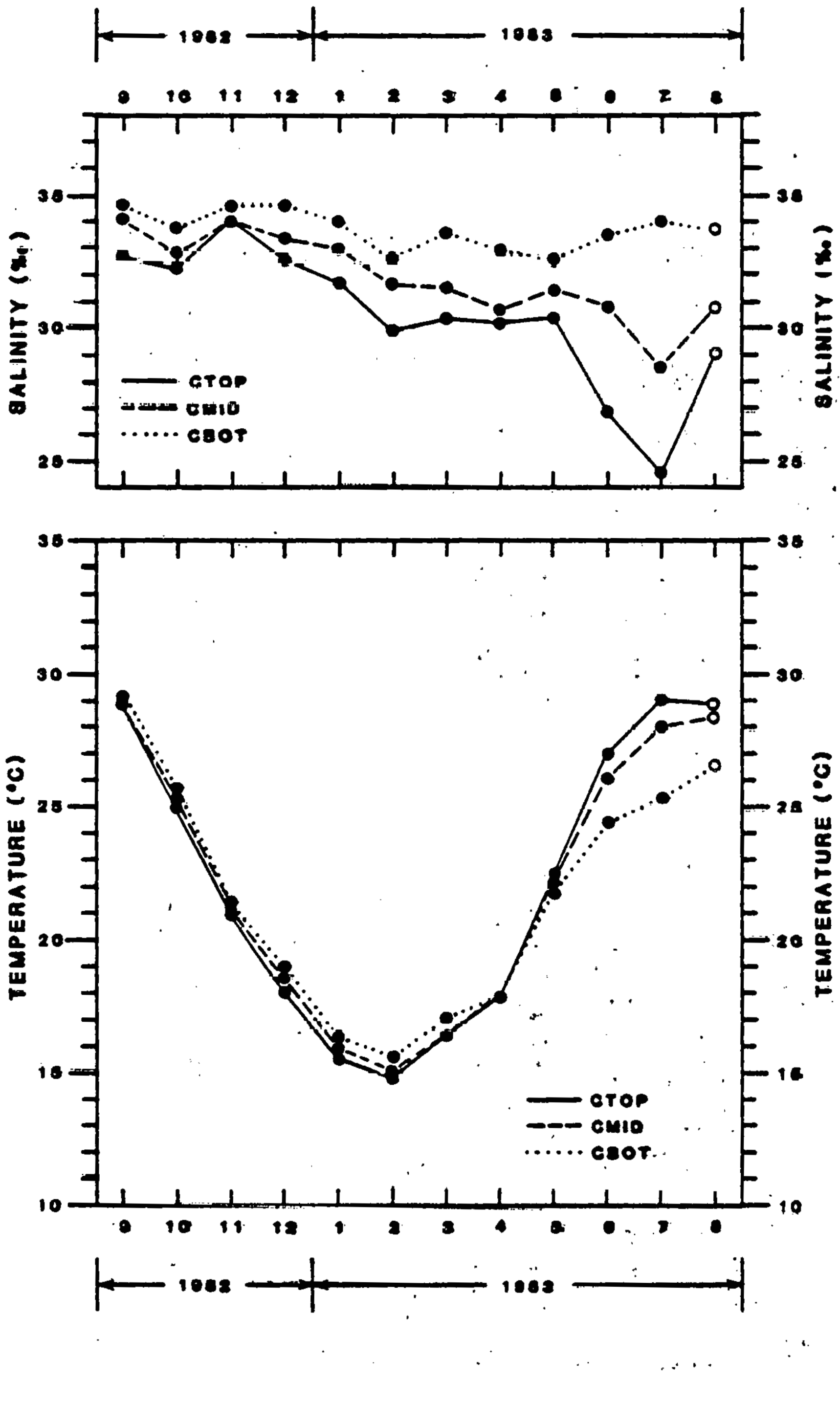


Figure 1-44. Variation of the monthly mean temperature and salinity data measured continuously at the diffuser site (site C).

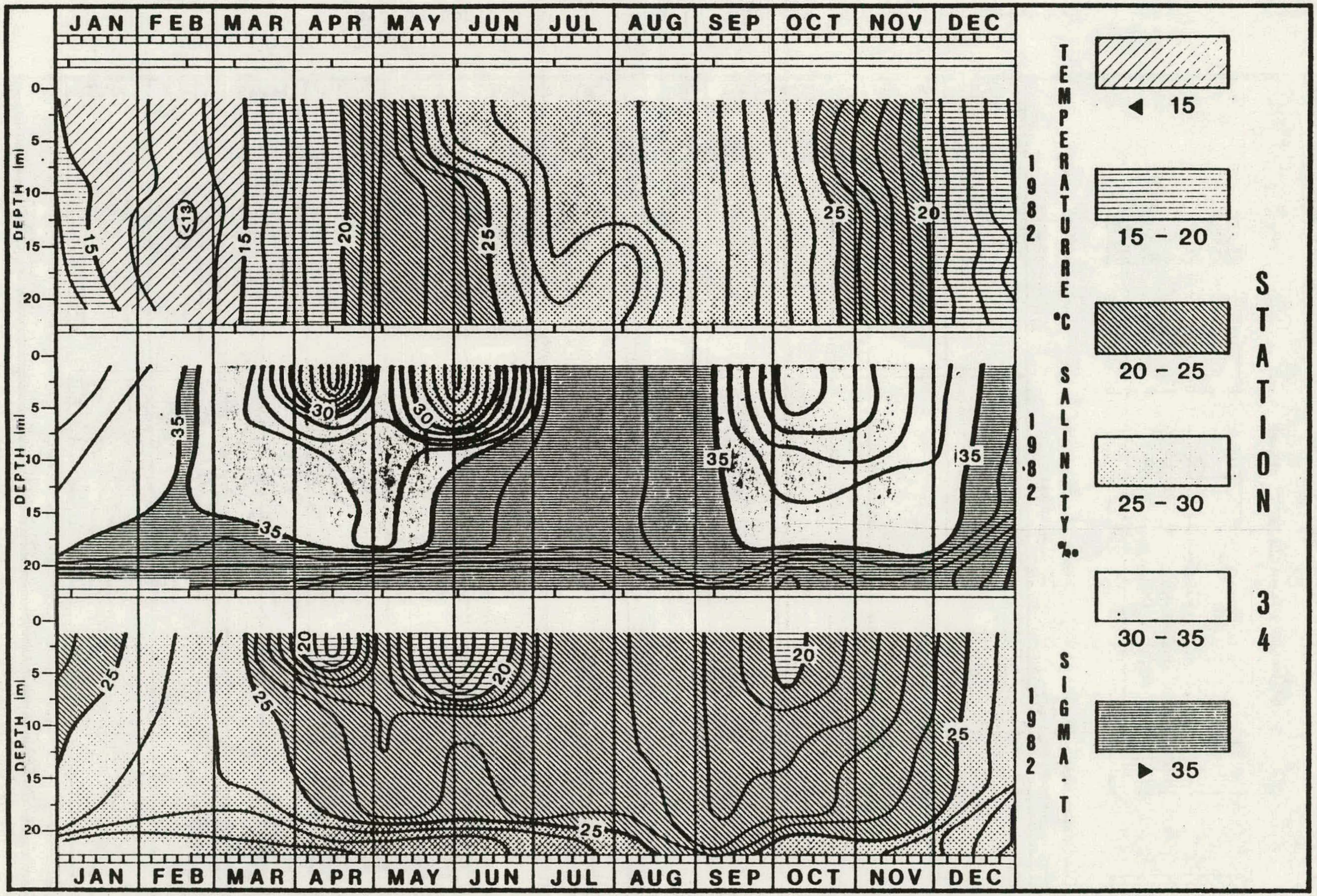


Figure 1-45. Time-depth plot of temperature, salinity and sigma-t at hydrographic station 34 during 1982.

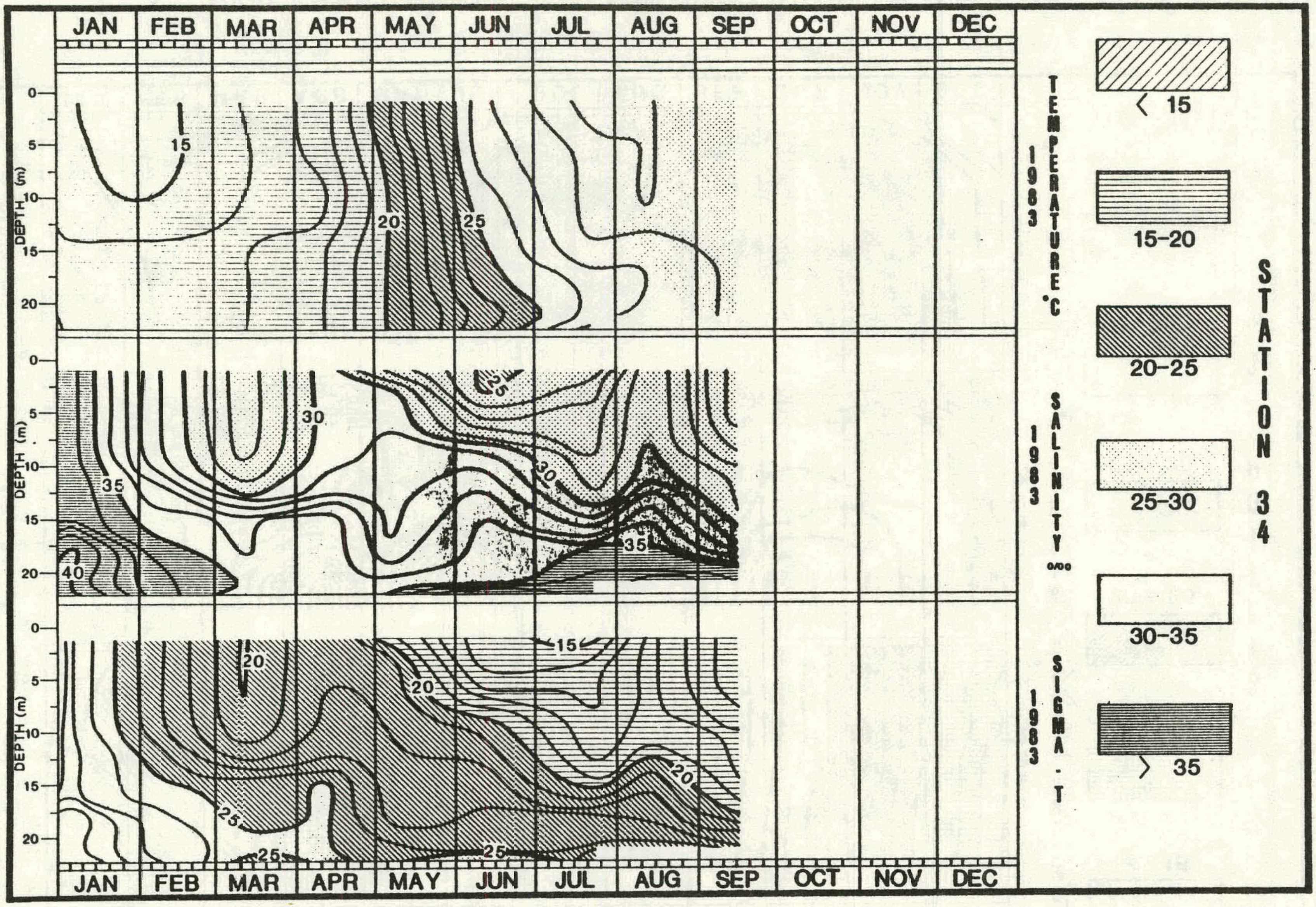


Figure 1-46. Time-depth plot of temperature, salinity and sigma-t at hydrographic station 34 during January through September 1983.

temperatures were 15.6 and 14.9°C, respectively. The temperature began an annual upward trend in March 1983 and the surface and bottom temperatures were very nearly the same through May. The annual summer thermocline was evident in the June, July, and August monthly data with the largest surface to bottom variation of 3.1°C occurring in June while the monthly mean data indicated the maximum variation was 3.7°C in July. The annual summer maximum temperature was approached in July with surface and bottom values of 29.5 and 27.2°C. These data show the maximum surface and bottom temperatures, both 29.9°C, occurred in September, and the minimum temperatures of 14.4 and 16.2°C were measured in February. The largest vertical temperature variation occurred in June 1982 when the surface water was found to be 3.1°C higher than the bottom water, and the largest mean vertical variation was 3.7°C in July 1982. In general, the surface waters were warmer than the bottom waters during the spring and summer months and the reverse was true during the fall and winter months.

The salinity variation is shown in the middle part of Figures 1-45 and 1-46. The monthly mean variation is illustrated in Figure 1-44. The sigma-t variation is shown in the bottom part of Figure 1-45 and 1-46. These figures show the bottom salinity and density at the diffuser site were always significantly higher than at the surface. The hydrographic surface salinity maximum and minimum values were 35.1 and 24.8 o/oo as compared to 39.2 and 34.1 o/oo at the bottom. The monthly mean of the in situ data indicate a minimum surface salinity of 24.5 o/oo in May 1982 and a maximum surface salinity of 34.0 o/oo in November 1982. These data show the minimum mean bottom salinity was 32.6 o/oo in February and May, and the maximum was 34.8 o/oo in September, November and December. The bottom salinities above 36.8 o/oo are attributed to the brine discharge because predisposal data showed maximum bottom salinities did not exceed 36.8 o/oo (Kelly and Randall, 1980; Randall and Kelly, 1981). The salinity data show the annual salinity cycle had a freshening trend in the early fall which was followed by increasing salinity with a maximum occurring in the late fall to early winter. This was followed by a freshening trend through February. The salinity of the water column remains relatively stable from March through May 1983. A strong freshening event occurred in June and July in the middle and upper part of the water column while the bottom waters showed a mile increase in salinity. Similar trends were observed in the density (sigma-t) data as shown in Figures 1-45 and 1-46.

The temporal variation of the monthly hydrographic data measured at the bottom of station 34 are compared with the bottom data measured at upcoast (station 39) and downcoast (station 33) control stations to illustrate the effect or noneffect of the brine discharge. The control stations 33 and 39 are located 7.4 km downcoast and upcoast of the diffuser station respectively and at nearly the same isobath.

The bottom temperature data measured at control stations 33 and 39 are compared to the diffuser station data in Figure 1-47. These results show bottom temperature at the diffuser site was within 1°C of the control stations during the entire reporting period. Therefore, these data show the thermal effect of the brine discharge is negligible with the largest temperature difference being 0.7°C in July 1983.

The results of the comparison of salinity data are illustrated in Figure 1-48. The salinity data show an obvious increase in the bottom salinity at station 34 over that which was measured at both stations 33 and 39 in all months except March and April. In general, the salinity at stations 33 and 39 were within 1 o/oo of each other. Brine was being

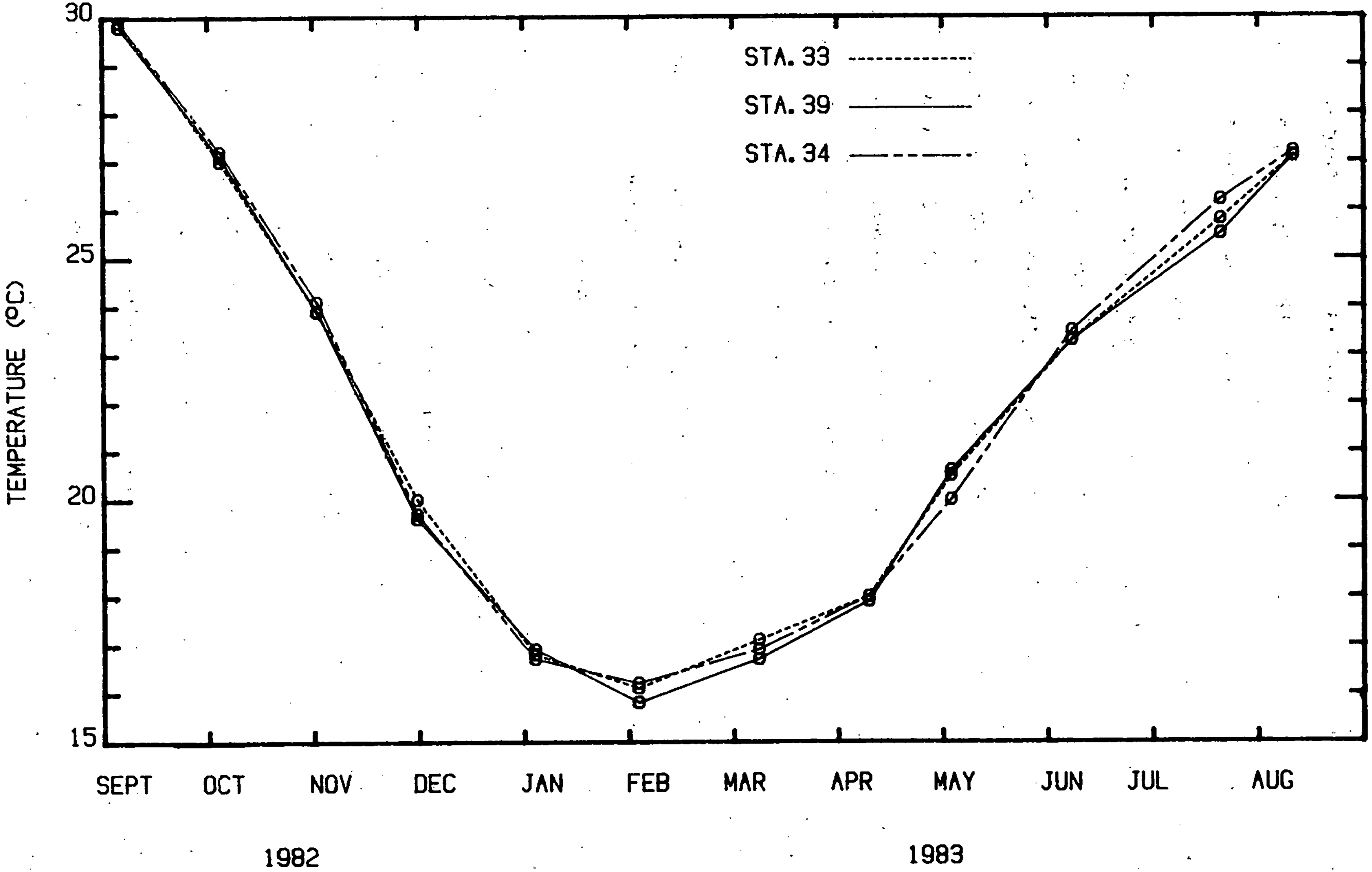


Figure 1-47. Comparisons of bottom temperature data at stations 33, 34 and 39.

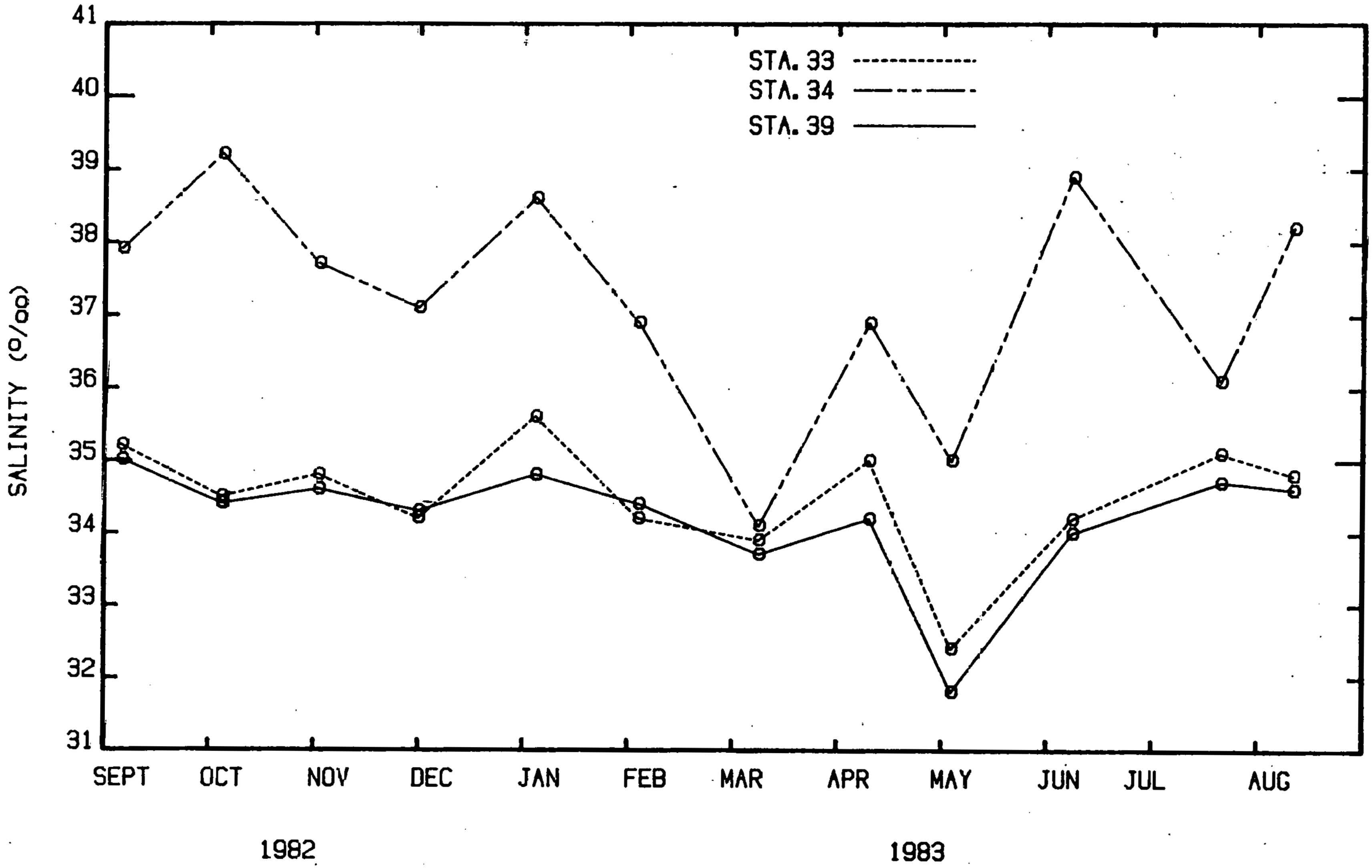


Figure 1-48. Comparisons of bottom salinity data at stations 33, 34 and 39.
occurs in the waters inshore of station 34. A comparison of the two also

discharged at a low 231 o/oo during the March cruise. The April alongshelf data unexplainably did not show the effect of the brine discharge which was probably a measurement error. Therefore, the results from the cross-shelf data were used. Excluding the March data, the salinity varied between 1.0 and 4.9 o/oo above either station 33 or 39. Thus, an increase in the bottom salinity of as much as 4.9 o/oo is attributed to the brine discharge. The extent of the areal coverage of the above ambient salinity is further discussed in Chapter 2.

A similar comparison of the dissolved oxygen data is illustrated in Figure 1-49. These results show the dissolved oxygen values at station 34 and 33 were nearly the same throughout the study period. At station 39 the dissolved oxygen was 1 mg/l lower than stations 33 and 34 in June, but other than that all stations were very nearly the same. Consequently, no apparent effect of the brine discharge on the dissolved oxygen was observed in this data.

Figures 1-50 and 1-51 show a time depth plot of the temperature, salinity and sigma-t at station 14, an inshore station. These can be compared to Figures 1-45 and 1-46 to show the variation in hydrography which occurs in the waters inshore of station 34. A comparison of the two also may indicated magnitude of cross-shelf gradient and the presence of frontal zones.

1.6.3 History of Annual Hydrographic Data Ranges Determined for the Bryan Mound Diffuser Site

Hydrographic data have been measured at the Bryan Mound diffuser site (station 34) since February 1978. A history of the range of temperature, salinity, sigma-t, and dissolved oxygen data for each annual period from September through August is tabulated in Table 1-4. These results show

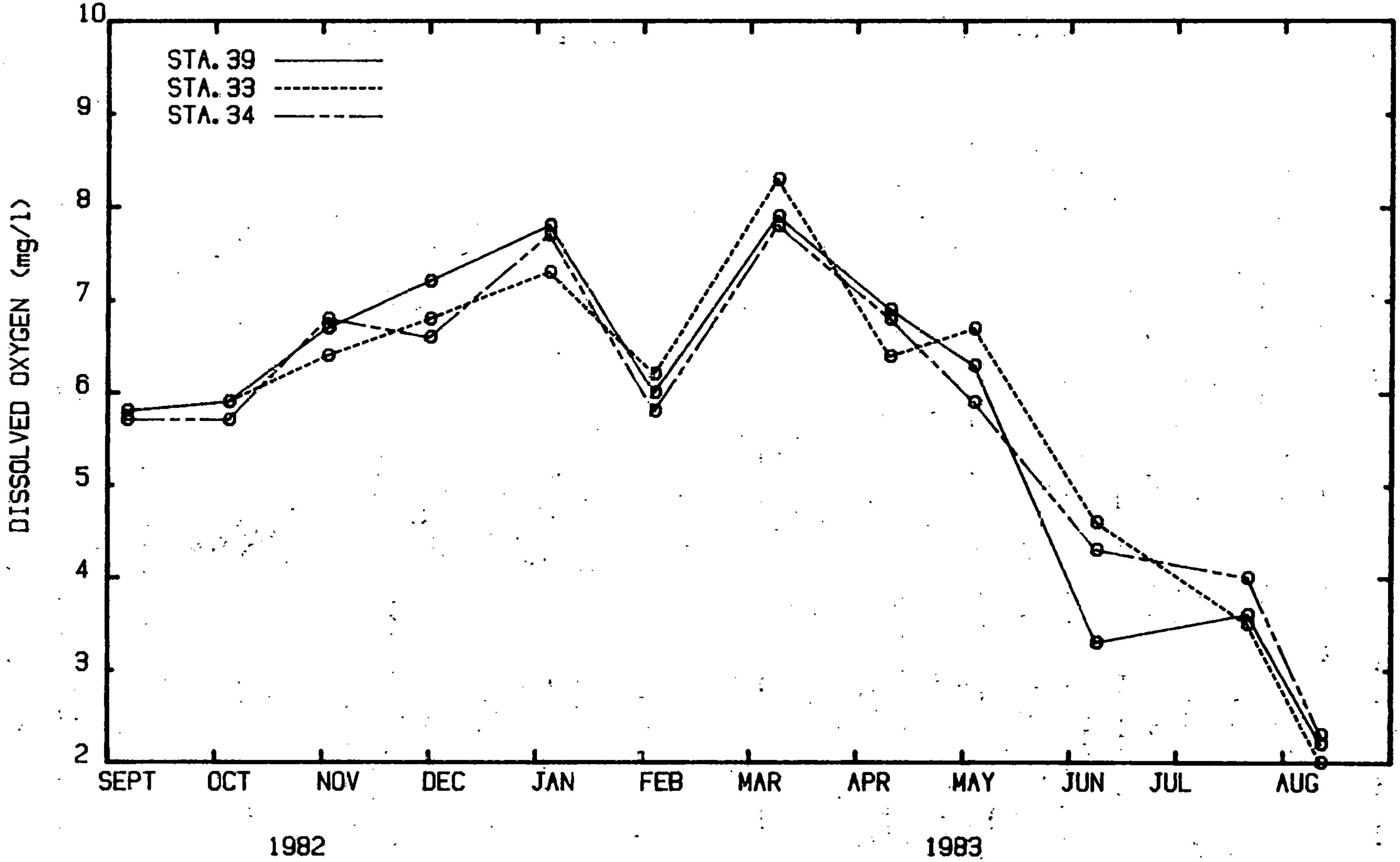


Figure 1-49. Comparison of botton dissolved oxygen data at stations 33, 34 and 39.

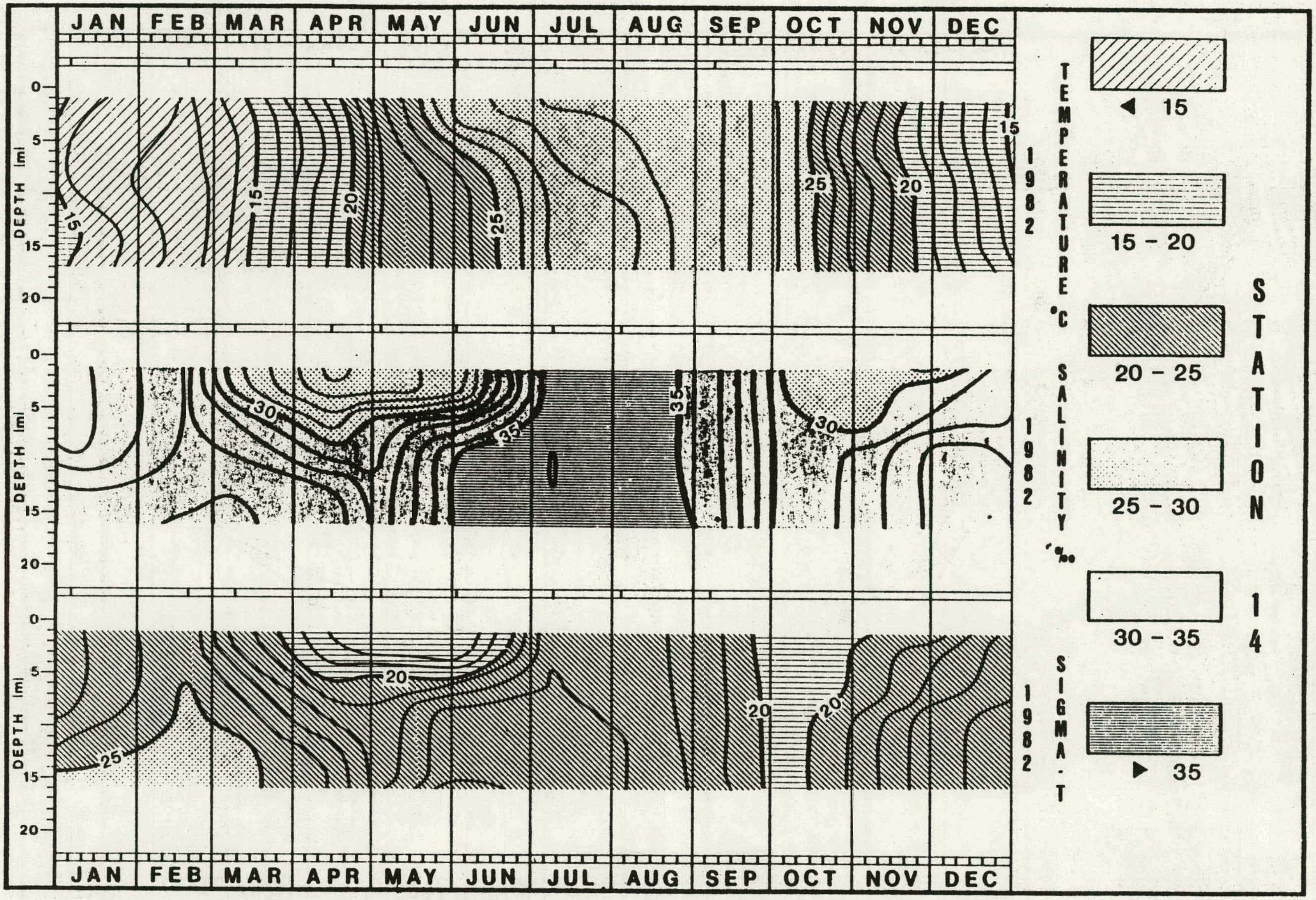


Figure 1-50. Time-depth plot of temperature, salinity and sigma-t at hydrographic station 14 during 1982.

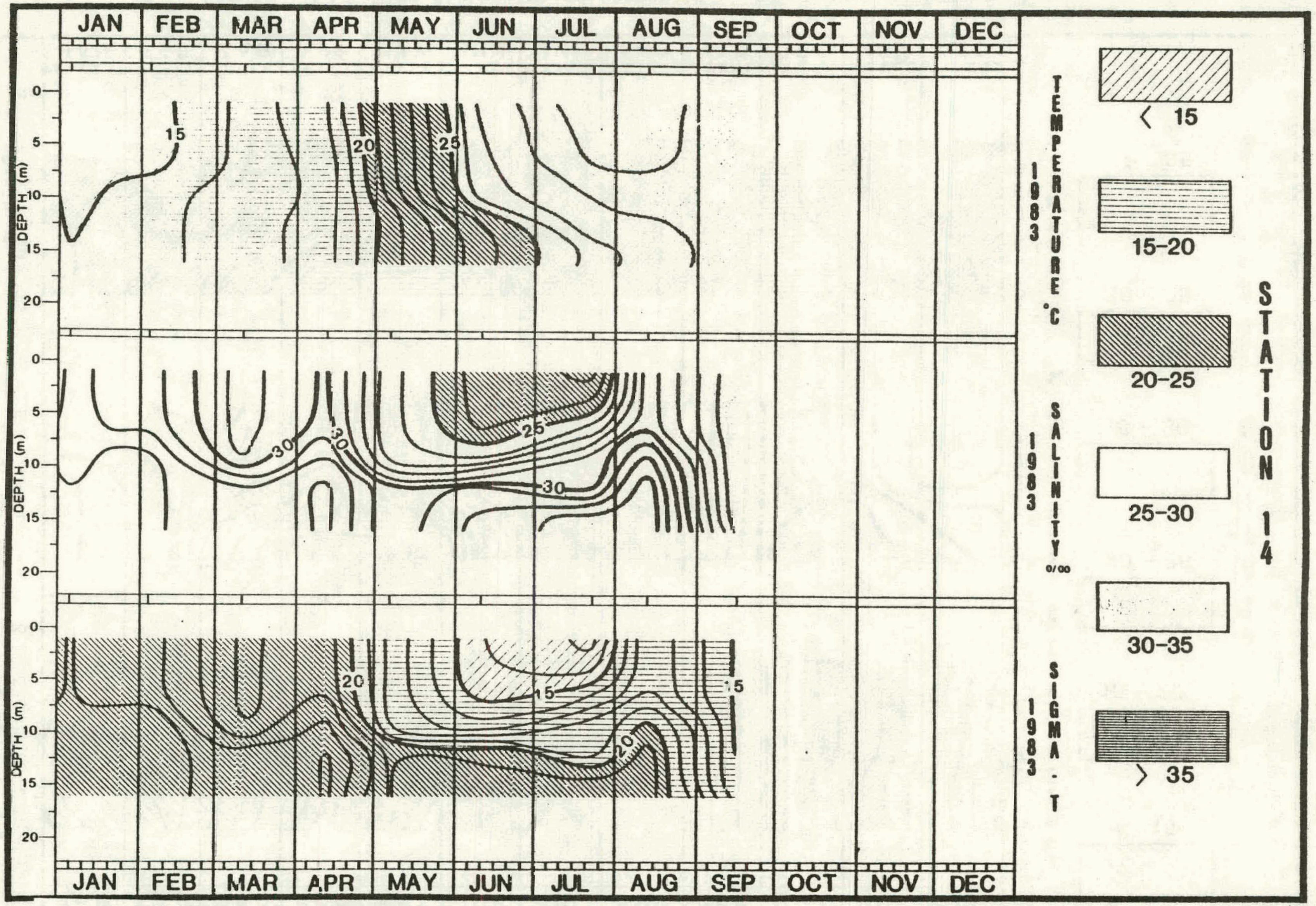


Figure 1-51. Time-depth plot of temperature, salinity and sigma-t at hydrographic station 14 during January through September 1983.

Table 1-4. History of the annual range of hydrographic data at the Bryan Mound diffuser site.

Period	Depth	Max or Min	Sal. (o/oo)	Date	Temp (°C)	Date	Sigma-t	Date	D.O. (mg/l)	Date
2/78-8/78	Surface	Max	35.7	07/26/78	30.1	07/20/78	27.9	02/03/78		
	Surface	Min	25.6	06/22/78	10.2	02/03/78	14.9	06/22/78		
	Bottom	Max	36.8	02/25/78	30.0	08/30/78	27.8	02/25/78		
	Bottom	Min	32.1	06/21/78	10.3	02/03/78	20.5	08/31/78		
9/78-8/79	Surface	Max	34.3	10/20/78	30.3	08/15/79	24.3	02/12/79		
	Surface	Min	19.0	06/21/79	9.7	02/21/79	10.5	06/21/79		
	Bottom	Max	35.8	06/21/79	30.0	09/01/78	27.3	02/12/79		
	Bottom	Min	32.5	09/25/78	10.7	02/12/79	20.6	09/25/78		
9/79-8/80	Surface	Max	36.3	07/09/80	29.7	08/27/80	23.2	07/09/80		
	Surface	Min	25.4	02/22/80	14.1	02/22/80	15.3	09/06/79		
	Bottom	Max	36.7	04/18/80	29.7	08/27/80	26.5	04/18/80		
	Bottom	Min	30.7	11/14/79	15.0	02/22/80	20.9	09/06/79		
9/80-8/81	Surface	Max	35.2	03/31/81	30.7	08/20/81	25.6	02/09/81		
	Surface	Min	26.6	09/11/81	12.7	02/09/81	15.8	09/11/80		
	Bottom	Max	38.9	07/08/81	29.8	07/28/81	27.5	03/31/81		
	Bottom	Min	33.8	06/19/81	12.9	02/09/81	21.3	07/28/81		
9/81-8/82	Surface	Max	36.5	07/08/82	29.6	09/03/81	26.3	02/19/82	9.0	04/14/82
	Surface	Min	25.3	04/14/82	13.7	02/19/82	15.7	06/01/82	5.9	08/03/82
	Bottom	Max	39.9	07/08/82	29.4	09/03/81	28.8	02/19/82	7.9	02/19/82
	Bottom	Min	34.2	12/02/81	13.0	02/19/82	23.1	09/03/81	2.8	06/01/82
9/82-8/83	Surface	Max	35.1	09/07/82	29.9	09/07/82	25.1	01/04/83	8.9	04/11/83
	Surface	Min	23.8	07/22/83	14.4	02/03/83	13.6	07/22/83	5.7	09/07/82
	Bottom	Max	39.5	08/12/83	29.9	09/07/82	28.4	01/04/83	8.6	03/10/83
	Bottom	Min	34.1	03/10/83	16.2	02/03/83	23.6	07/22/83	2.3	08/12/83

the maximum surface temperature range of 20.6°C occurred in the yearly period September 1978 through August 1979, and the minimum range was 15.5°C which occurred in the present yearly period September 1982 through August 1983. The maximum surface temperature was 30.7°C on August 20, 1981, and the minimum surface temperature was 9.7°C on February 12, 1979. The maximum bottom temperature range was 19.7°C in the yearly period September 1977 to August 1978 and the minimum range was 13.7°C in the September 1982 to August 1983 period. The maximum bottom temperature was 30.0°C on August 30, 1978 and the minimum value was 10.3°C on February 3, 1978.

The salinity data show the maximum surface salinity range was 15.3 o/oo in the September 1978 through August 1979 year, and the minimum range was 8.6 o/oo in the September 1980 through August 1981 year. The bottom salinity data show the period September 1979 through August 1980 experienced the maximum bottom salinity range of 6.0 o/oo which was the first year of brine discharge. During this reporting period, the surface and bottom salinity range was 12.3 and 5.4 o/oo, respectively. The minimum salinity range was 3.3 o/oo in September 1978 through August 1979 period. The maximum bottom salinity was 39.9 o/oo on June 1, 1982 and July 8, 1982, which was due to the brine discharge, and the minimum bottom value was 30.7 o/oo on November 14, 1979, which was before brine discharge began.

The dissolved oxygen data has only been collected at the Bryan Mound CTD/DO station locations since September 1981. These data show the surface dissolved oxygen range was 3.1 and 3.2 mg/l in the September 1981 through August 1982 and September 1982 through August 1983 study periods, repsectively. At the bottom, the range was 5.1 and 6.3 mg/l for the

September 1981 through August 1982 and September 1982 through August 1983 study periods, respectively.

The history of the vertical variations of the hydrographic data is illustrated in Table 1-5. These results show the maximum vertical variations of salinity, temperature, and sigma-t all occurred in June 1979 when values of 16.8 o/oo, 6.5°C, and 14.0 sigma-t units were measured. The brine discharge has increased the vertical salinity variation at the diffuser site, but the maximum variation occurred prior to brine discharge. The cause of the strong vertical variation in June 1979 was the high fresh water discharge from the Mississippi/Atchafalaya river system which experienced a flood year (Kelly et al., 1982).

1.7 Summary and Conclusions

A new in situ instrument site, designated "K," was established one nautical mile upcoast (northeast) from the diffuser in mid-June 1983. It has a surface witness buoy and a very near bottom current meter mooring system (see Figure 1-3) with two meters. One is a VNB meter at a height above the bottom of 0.43 m and the other is at a height of 1.8 m above the bottom. The purpose of this site was to serve as an ambient station for comparison with site C.

During the fall of 1982, the in situ site C current data indicate the most frequently recorded surface current (CT) speed range was 30 to 40 cm/s and southwest was the most frequently recorded direction. At mid-depth the speeds were distributed broadly, and the southwest was again the most frequently recorded direction. At the bottom (CU) and very near bottom (CZ) the speeds were broadly distributed between 5 and 25 cm/s, and south was the most frequent direction. Temperature decreased from a high of slightly less than 31°C at the beginning of the period to about 20°C

Table 1-5. History of the maximum vertical variation of the hydrographic data for the Bryan Mound diffuser site.

Period	Salinity		Temperature		Sigma-t		Dissolved Oxygen	
	ΔSal.	Date	ΔT	Date	$\Delta\sigma_t$	Date	ΔD.O.	Date
2/78-8/78	7.6	06/22/78	-3.5	03/23/78	6.8	06/22/78		
9/78-8/79	16.8	06/21/79	-6.5	06/28/79	14.0	06/21/78		
9/79-8/80	8.6	10/05/79	-5.3	07/17/80	6.3	02/22/80		
9/80-8/81	8.1	09/11/80	-2.9	06/10/81	6.6	07/08/81		
9/81-8/82	14.0	04/14/82 06/01/82	-4.2	06/01/82	11.8	06/01/82	-4.9	06/01/82
9/82-8/83	13.8	07/22/83	-4.5	06/09/83	11.6	06/09/83	-4.2	08/12/83

at the end. Vertical differences were usually less than 1.5°C and the bottom water was usually warmer. Despite the fact that the average bottom currents were strong, plume effects were quite evident. Assuming that the salinity at the bottom meter (1.8 m above the bottom) is approximately an ambient value, the salinity at the very near bottom meter (0.4 m above the bottom) salinity varied between ambient and 4 o/oo above ambient.

The fall 1982 hydrographic data showed relatively isothermal temperature structure and moderate cross-shelf and vertical salinity stratification. The plume effect on salinity at station 34 was most evident in the October 5, 1982 data when bottom salinities of up to 39.2 o/oo were recorded when the ambient salinity at station 39 was 34.8 o/oo. Dissolved oxygen ranged between 5 and 8 mg/l in the surface layers and between 5 and 7 mg/l at the bottom at station 34.

During the first month of the winter period the most frequent speed range at CT and CM was 30 to 40 cm/s. During January and February the CT speeds were somewhat bi-modal in distribution, but the most frequent speed range was 50 cm/s and up. At CM, however, the speeds fell most frequently in the 5 to 25 cm/s range. Speeds at CU were also mainly in the 5 to 25 cm/s range with the upper side preferred in December and the lower side in January. The most frequent direction sector during the winter at CT, CM and CU was southwest. Data were only collected during December at CZ. Its current rose shows a high percentage of currents fell in the 10 to 15 cm/s range and the currents were rotated more toward the south.

Water temperature dropped during the winter from values near 20°C to a minimum of 13 to 14°C in mid-Febraury. The water column at site C alternated between being isothermal and being thermally stratified with top to bottom temperatures of 2 to 3°C. Salinity was less variable than in the fall. Surface and mid-depth values fluctuated between 29 and 35 o/oo while they varied between 30 and 36 o/oo at the bottom. Plume effects were again evident with CZ salinity values being 2 to 4 o/oo greater than those measured at CU.

Winter 1982-1983 hydrographic data showed weak vertical stratification in temperature and salinity in December 1982 and January 1983 switching to horizontal stratification in February 1983. Dissolved oxygen was relatively homogeneous in all months. Plume effects were generally the same magnitude as in the fall.

The current data show that at CT and CM the most frequent speed range was 30 to 40 cm/s during the spring. While southwest was the most frequent direction sector for CT and CM in March and April, the second most frequent was northeast, reflecting the alternating nature of the currents. In May the currents became more persistent in the southwest and west direction.

Currents at CU were broadly distributed among the S, SW, N and NE sectors in March and April, and then became more persistently SW and S in May. Speeds at CU were also broadly distributed in magnitude in March and April, and then became more concentrated around the 10 to 15 cm/s range in May. At CZ currents were mostly in the south direction and in the 5 to 10 cm/s speed range in April and May. Water temperatures warmed from about 15 to 24°C. Bottom water was warmer than the surface water until the latter half of April when the relationship reversed. In May, a thermocline with a 3°C temperature difference developed as the surface water continued to warm, but the bottom water decreased in temperature slightly.

Salinity was more variable in the spring than in the preceeding season. The variability was as great near the bottom as at the surface, apparently because of cross-shelf movement of salinity fronts. The spring values of salinity at CT ranged from 25.4 to 33.3 o/oo and at CU from 29.6 to 36.7 o/oo. Plume effects in the spring were somewhat reduced in terms of persistence.

The spring of 1983 hydrographic data was dominated by the arrival of the fresher water from river discharge. The temperature field was relatively isothermal. Vertical stratification was present in all months with a strong halocline and pycnocline just below mid-depth in March and April. Stratification was still present in May, but the isohalines and isopycnals sloped from the bottom inshore to the surface offshore. Plume effects were evident in all three months but smaller than those in the fall and winter. Dissolved oxygen was relatively homogeneous in March and May and weakly stratified in April.

Mean currents were weak in the summer. At CT and CM they were southwest and west in June and August and northeast and south in July. At CU they were northeast in both June and July, but at CZ only in July. Currents were broadly distributed in direction and speed at all depths but CZ, which is consistent with the low vector mean values. Scalar average speeds, however, were in the 20 to 30 cm/s range at CT and CM.

Water temperature continued to warm during the summer with a summer thermocline clearly present. The largest vertical temperature difference was up to 7°C which occurred during upwelling events.

Strong vertical salnity differences, up to 18 o/oo, occurred in June and July as relatively fresh water from a late spring runoff was advected through the area. The lowest salinity, 15.7 o/oo at the surface, was recorded on June 24. The summer ranges were 15.7 to 33.4 o/oo at CT, 19.8

to 34.5 o/oo at CM and 28.4 to 36.6 o/oo at CU. Plume effects were much weaker during the period of strong salinity stratification.

The summer hydrographic data indicated the months of June and July experienced strong vertical stratification. This was caused by the continued influx of fresher water at the same time as currents switched to upcoast flow and upwelling conditions. A thermocline of 24 to 27°C in June and 25 to 29°C in July was present. A halocline, 24 to 35 o/oo, also lay between the surface and bottom. A normal plume increase of about 3 to 5 o/oo above ambient occurred at the bottom of station 34. Dissolved oxygen was strongly stratified, ranging from 8 mg/l at the surface at station 34 to less than 2 mg/l. Hypoxic conditions were detected over the entire sea floor covered by the transects on the August hydrographic cruise.

The monthly mean values of wind and currents indicate that as found previously, the mean alongshelf component of wind was well correlated with alongshelf and cross-shelf components of mean current. When the mean alongshelf wind was downcoast the alongshelf currents were downcoast at all depths. Cross-shelf currents were onshore at the top and middle and offshore at the bottom. When the wind switched to upcoast in July 1983 the alongshelf currents followed suit while the cross-shelf currents reversed their vertical relation. The current period was significantly different from the previous period, however, in several respects. During the fall of this period the currents were substantially stronger than the previous period. From December through April the currents decreased in strength; previously they had increased during December through April. Thus, seasonal changes in the currents were related to the alongshelf component of wind, as in previous years, but the pattern was significantly different compared to previous years.

Low frequency current fluctuations up to about 0.2 cpd were stongly coherent with the alongshelf component of wind at all depths; cross-shelf currents were coherent with the alongshelf wind at these frequencies only near the bottom.

A major step in understanding the circulation on the Texas-Louisiana Shelf, has been achieved in finding that the circulation indicated by monthly mean geopotentials fits together, at least qualitatively, the known facts about the circulation. In view of the success of the geopotential picture in explaining the observed flow qualitatively at least, it is desirable to test the geostrophic relationship (on which interpretation of the geopotential depends) quantitatively. This was done by comparing the alongshore velocity components measured at site C with vertical velocity change implied by the density at surrounding hydrographic stations. Because flow below the middle current meter are in the bottom layer of frictional influence, the change in velocity between the middle and top current meter is considered. For non-summer months in the period from September 1979 to September 1982, the mean increase in alongshore speed from the middle to the top current meter is 7.8 cm/s. The geostrophic velocity shear for the same layer based on mean hydrographic data for stations 16 and 36 is 8.7 cm/s. The agreement is not bad and, as might be expected, the actual velocity increase is less than that implied by the geostrophic relationship which does not take friction into account.

In view of the reasonable approximation afforded by geostrophic calculations, the transport of the current alongshore can be estimated. The mean total downcoast transport for non-summer months is found on the basis of GUS III data to be 10^5 m^3/s. Of this nearly half flows between stations 16 and 36 according to geostrophic calculations. This results points up how strong the coastal jet is: much of the lower-frequency water movement off Freeport occurs within about 30 km of the coast.

The persistence of bottom current speed was studied. Speeds below 3 cm/s were found to be not very persistent. During the 368 days of the record, there were 101 runs with speeds less than or equal to 3 cm/s, but none exceeded 13 hours duration. The mean duration was only 2.4 hours. At a 6 cm/s threshold the maximum duration found was only 27 hours and the mean duration for this threshold was only 3.6 hours. It is concluded, as in the previous annual report, that true stagnation does not occur and that persistence of currents less than about 6 cm/s for long periods, i.e. several days, would be a most unusual condition and one that has not been recorded.

The temperature-salinity relationships during this study period at station 39 and at station 34 are similar to those previously reported prior to brine disposal (Kelly and Randall, 1980) and after brine disposal began (Kelly et al., 1982 and 1983a). The data show the coastal waters in the vicinity of the diffuser had salinity and temperature maxima (near 35 o/oo and 30°C) in the late summer which was followed by a freshening trend or salinity minimum (near 31 o/oo) in the fall in conjunction with a temperature decrease. During the winter, the salinity reached another maximum near 35 o/oo while the temperatures fell to a minimum near 14°C. In the spring and early summer, the temperature rapidly increases. The salinity decreased to a minimum near 25 o/oo in June and July before approaching the summer temperature and salinity maximums again. The salinity minimum in July was later than observed in previous years. The effect of the brine discharge on the temperature-salinity relationship was limited to near bottom depths, and at the bottom of station 34, the salinity ranged from 0.4 to 4.9 o/oo above that measured at station 39. The temperature data show no significant temperature change (less than 1°C) between the diffuser and ambient stations.

The temporal variation of temperature, salinity and dissolved oxygen at the diffuser site was studied and compared to other control sites. The bottom temperature data at the diffuser site were within 1°C of the control stations, and thus, the thermal effect of the brine discharge was considered neglible. Both the hydrographic data and the data from the in situ very near bottom meters show that the plume induced salinity increases are normally limited to less than 5 o/oo above ambient and absolute salinity values are usually below 40 o/oo. The dissolved oxygen data show the values at the diffuser and control stations were within 1 mg/l of each other, and consequently no apparent effect of the brine discharge on the dissolved oxygen was observed in these data.

A history of the vertical variation and annual range of hydrographic parameters at the diffuser site since February 1978 was discussed. The maximum surface temperature range of 20.6°C occurred in the period September 1978 through August 1979, and the minimum range was 15.5°C which occurred in the present period September 1982 through August 1983. The maximum surface temperature was 30.7°C on August 20, 1981, and the minimum surface temperature was 9.7°C on February 12, 1979. The maximum bottom temperature range was 19.7°C in the period September 1977 to August 1978, and the minimum range was 13.7°C in the September 1982 to August 1983 period. The maximum bottom temperature was 30.0°C on August 30, 1978 and the minimum value was 10.3°C on February 3, 1978.

The maximum surface salinity range was 15.3 o/oo in the September

1978 through August 1979 year, and the minimum range was 8.6 o/oo in the September 1980 through August 1981 year. The period September 1979 through August 1980 experienced the maximum bottom salinity range of 6.0 o/oo which was the first year of brine discharge. During this reporting period, the surface and bottom salinity range was 12.3 and 5.4 o/oo, respectively. The minimum bottom salinity range was 3.3 o/oo for the September 1978 through August 1979 period. The maximum bottom salinity was 39.9 o/oo on June 1, 1982 and July 8, 1982, which was caused by the brine discharge, and the minimum bottom value was 30.7 o/oo on November 14, 1979, prior to brine discharge.

The dissolved oxygen data has only been collected at the Bryan Mound CTD/DO station locations since September 1981. These data show the surface dissolved oxygen range was 3.1 and 3.2 mg/l in the September 1981 through August 1982 and September 1982 through August 1983 study periods, repsectively. At the bottom, the range was 5.1 and 6.3 mg/l for the September 1981 through August 1982 and September 1982 through August 1983 study periods, respectively.

The history of the vertical variations of the hydrographic data show the maximum vertical variations of salinity, temperature, and sigma-t all occurred in June 1979 when values of 16.8 o/oo, 6.5°C, and 14.0 sigma-t units were measured. The brine discharge has increased the vertical salinity variation at the diffuser site, but the maximum variation occurred prior to brine discharge, and it was caused by high fresh water discharge from the Mississippi/Atchafalaya river system which experienced a flood year (Kelly et al., 1982).

CHAPTER 2

BRINE PLUME

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2.1 Introduction

The Department of Energy began discharging brine through the Bryan Mound multiport diffuser in March 1980. The Bryan Mound diffuser is located 20 km offshore of Freeport, Texas in a water depth of 21.6 m, and near monthly brine plume measurements have been conducted in the vicinity of the diffuser since the initiation of discharge. The purpose of this chapter is to describe the results of the plume measurements for the period from September 1982 through August 1983. Prior to this report, five additional publications were published concerning the results of the plume measurements. The first two, Randall (1981a and 1981c), describe the immediate postdisposal plume measurements which were conducted during the first two months of discharge, March and April 1980. The third report, Randall (1981b), describes the results obtained during the first 12 months, the fourth report (Randall, 1982) discusses the results of the initial 18 months of discharge from March 1980 through August 1981, and the fifth report (Randall and McLellan, 1983) describes the results from September 1981 through August 1982.

The brine discharge is the result of a leaching or filling process at the Bryan Mound site of the Strategic Petroleum Reserve near Freeport, Texas. The leaching process is used to create storage caverns in the underground salt dome located at Bryan Mound, and the filling process consists of filling the storage caverns with oil. The resulting brine is first pumped to a brine pit for temporary storage and settling before being pumped to the Gulf of Mexico via a buried pipeline as illustrated in Figure 2-1. The last 933 m of the pipeline is a multiport diffuser which has 52 diffuser ports extending vertically from the pipeline 1.2 m above the bottom. These ports have an inside diameter of 7.6 cm and are spread 18.3 m apart. As the brine exits from the diffuser ports, it is diluted initially due to jet mixing, and then it falls to the bottom as a result of its greater density and simultaneously spreads laterally. The plume is then dispersed by advection due to currents and diffusion due to turbulence.

The behavior of the brine plume is characterized as a negatively buoyant plume which can be divided into three areas (NOAA, 1977) as shown in Figure 2-2. These three areas depend upon the physical processes by which the plume is being dispersed. The first area is called the near field area where the effluent dilution is affected by turbulent jet mixing which is a function of the ambient current velocity, diffuser design, and water depth. This area is defined as the distance downstream where the individual plumes from each diffuser port merge to form a continuous plume. This distance has been estimated to be on the order of 30 m for the Bryan Mound diffuser. In the intermediate field area, the plume experiences buoyant lateral spreading and vertical collapse, and the outer boundary of this area is estimated to be on the order of 305 m from the diffuser. The final plume area is called the far field which is the largest area and is affected most by the physical processes of advection and diffusion.

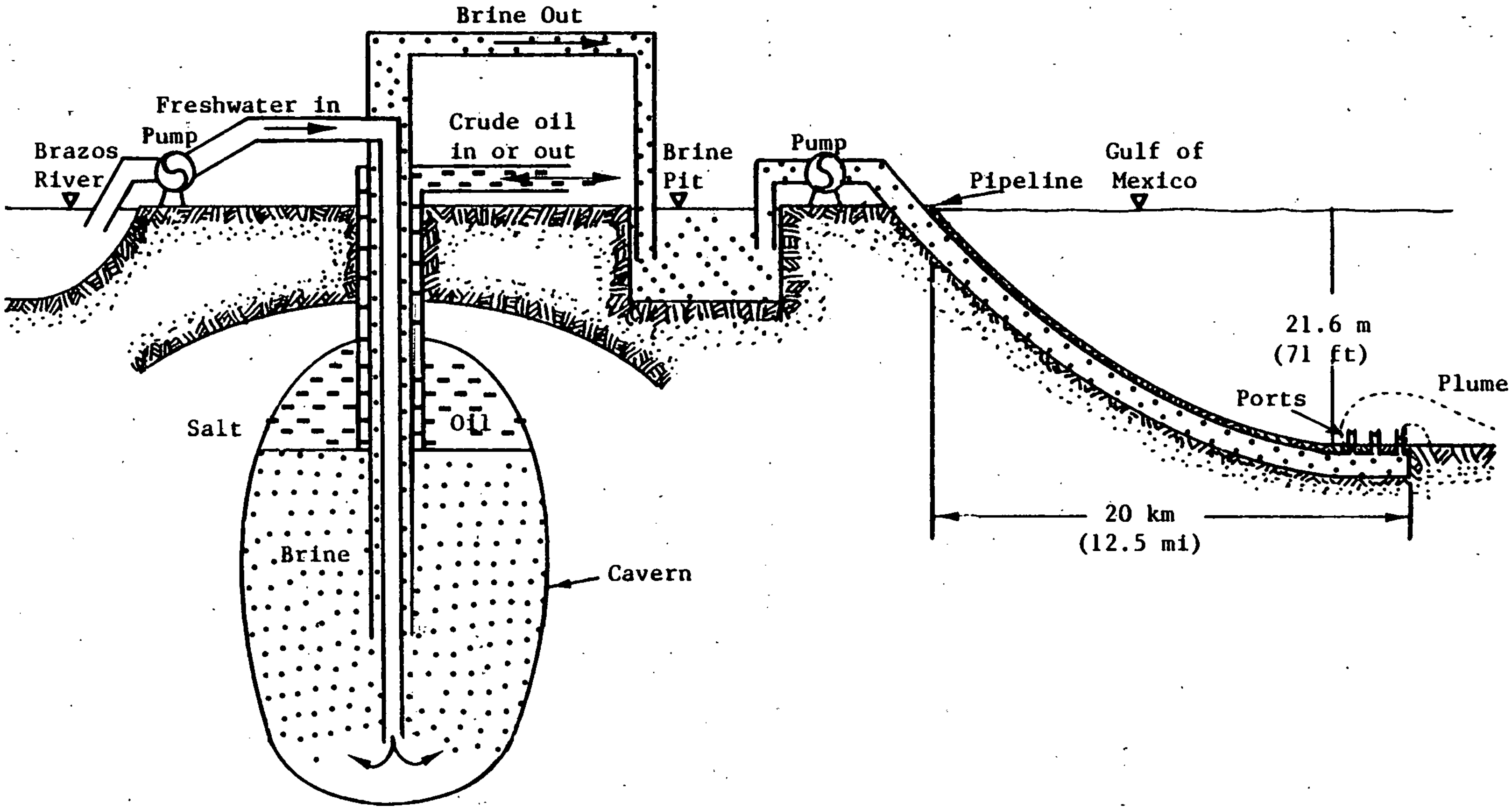


Figure 2-1. Schematic of Bryan Mound leach, fill and discharge operation.

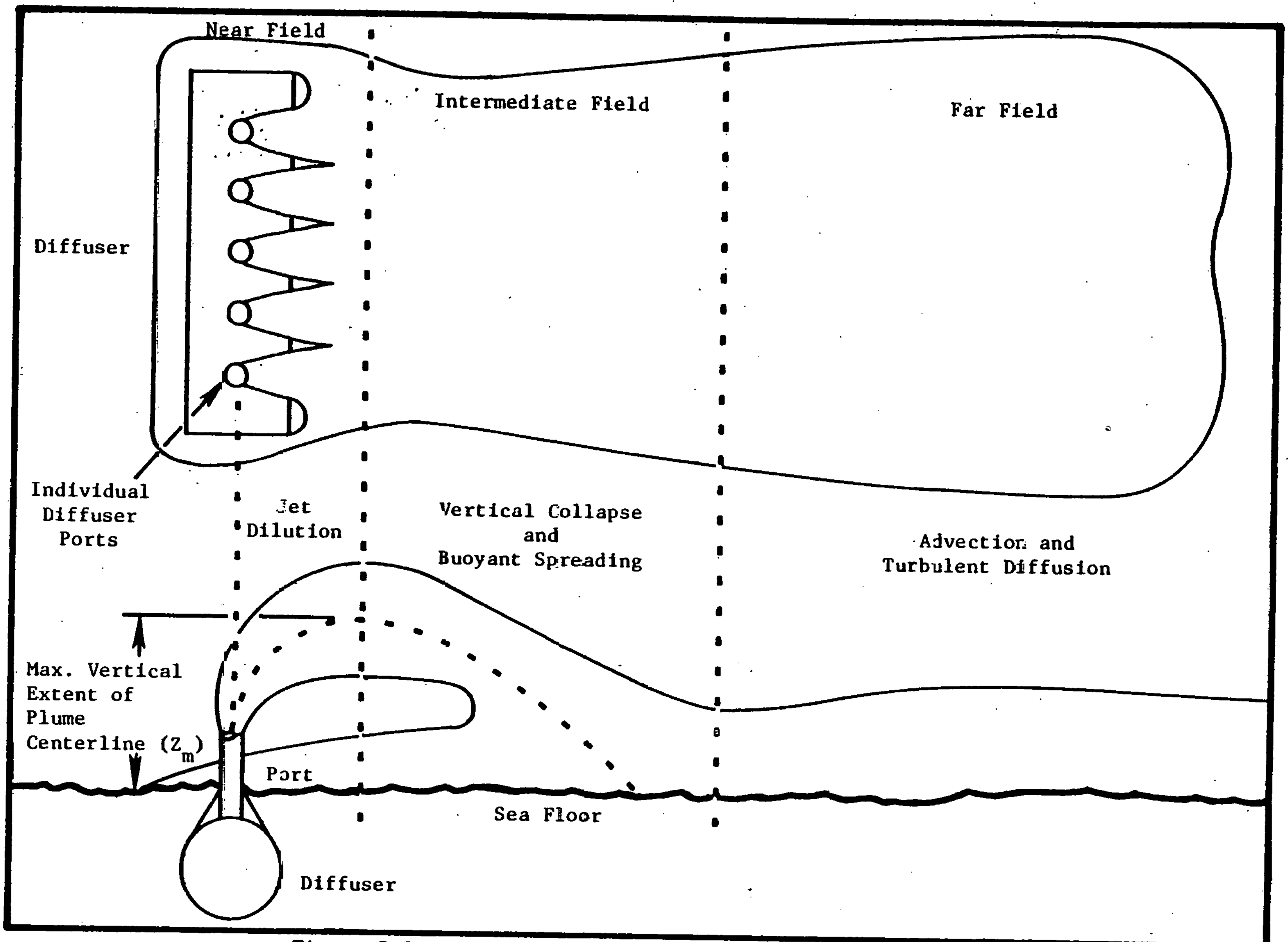


Figure 2-2. Schematic of brine plume characteristics.

An initial brine discharge rate of approximately 250,000 barrels/day was begun on March 10, 1980 through the 15 ports which were open at the offshore end of the diffuser. The diffuser was operated with 15 open ports from March 10 until July 10, 1980. At that time, 16 additional ports inshore of the original 15 were opened for a total of 31 open ports. The target discharge rate during that period was 680,000 barrels/day. A little over a year later, three additional ports were opened on August 24, 1981 which resulted in the present total of 34 open ports and the target discharge rate of 750,000 barrels/day. On January 22, 1982 the brine discharge was increased to its present target rate of one million barrels/day. Thus, the brine discharge rate has been near the one million barrels/day rate for the entire reporting period.

The above ambient brine concentration (salinity) in the far field has been predicted using the MIT transient plume model developed by Adams et al (1975). Predictive results from this model for the Bryan Mound diffuser in several design configurations are described by NOAA (1977). The results of these studies showed that strong ambient currents produced long narrow plumes and during periods of near slack currents, the plume expanded in all directions and stayed close to the diffuser. The concentrations near the diffuser were generally higher during slack currents, and a buildup of concentration was also predicted during slack periods.

The plume measurements which were made from March through October 22, 1980 were compared to the predictions of the MIT transient plume model by NOAA (1981). This report concluded that the transient plume model underestimates excess salinity in the near and intermediate field and overestimates the excess salinity in the far field. An increase in the model horizontal diffusion coefficients was suggested to improve agreement between model and measured plumes.

Gaboury and Stolzenbach (1979) discuss the development of a non-dimensional formulation of the MIT transient plume model. This formulation is used to evaluate alternate levels of acceptable impact based on the terms of organism mortality as a function of concentration and exposure time. Tong and Stolzenbach (1979) reported on an analytical and experimental study of the discharge of a negatively buoyant fluid. These experiments were directed toward the investigation of near field dilution and vertical height of the discharge from a single diffuser port with varying discharge rates and cross flow. Laboratory empirical equations were developed for estimating the near field dilution and vertical height of the brine jet. The vertical height of negatively buoyant jets has also been investigated using laboratory experiments as reported by Vergara and James (1979), Turner (1966), Abraham (1967), Fan and Brooks (1968), and Zeitoun et al (1970).

Empirical procedures based upon actual field measurements have been developed for predicting the brine plume areal extent, brine jet vertical extent and for estimating the percent time selected bottom areas are exposed to above ambient brine concentrations. The empirical procedures and results are discussed by Randall (1981b, 1982), Randall and McLellan (1983), and McLellan (1983). They were used to estimate the areal and vertical extent of the brine plume emanating from the proposed Big Hill diffuser (Randall and Kelly, 1982).

This report briefly describes the instrumentation used in tracking the brine plume and the procedures employed to attain the isohaline contours which describe the areal coverage of the plume 25 cm above the bottom. The results of the plume tracks are described which define the areal extent and the above ambient brine concentrations. Vertical salinity profiles which permit the evaluation of the plume vertical extent are discussed and compared with empirical predictions. The data from the plume tracks measured during the two and a half years of discharge were used to further develop procedures for empirically predicting brine plume contours, and these empirical procedures and their results are also discussed.

2.2 Plume Tracking System and Procedures

A complete description of the current plume tracking procedures and system are described in the Field and Laboratory Procedures Manual by Randall (1983a). The plume tracking instrumentation consists of a conductivity, temperature, and depth (CTD) probe mounted in a sled which is towed on the sea floor by a research vessel, as shown in Figure 2-3. The length of the sled is 1.8 m. The sled's cross section is an equilateral triangle with the probe located at its centroid. Thus, the probe is always 25 cm above the bottom no matter which set of runners is in contact with the sea floor. Since the sled is towed on the sea floor, the possibility of snagging is always present. Therefore, weak links were designed for releasing the sled and probe from the tow cable and conductor cable respectively. When all the weak links have released, the sled is completely free from the towing vessel and marked with a surface buoy which is attached at all times during the tracking operation. In order to recover the sled, the research vessel first recovers the surface buoy, and then the buoy line is used to winch the sled to the surface.

The conductivity, temperature and depth (CTD) system manufactured by the Hydrolab Corporation, Hydrolab (1980), is used in the plume tracking

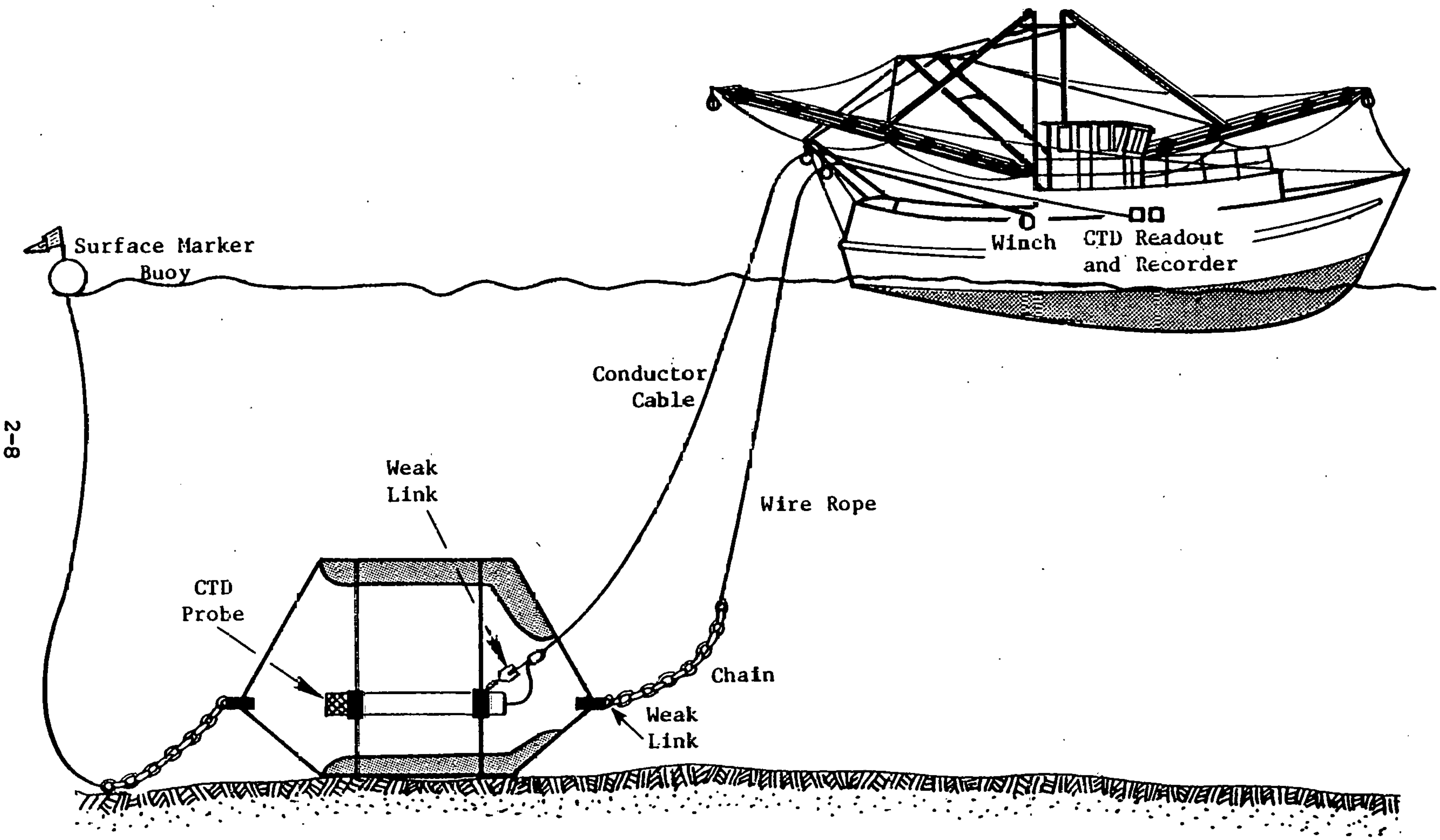


Figure 2-3. Schematic of the plume tracking system.

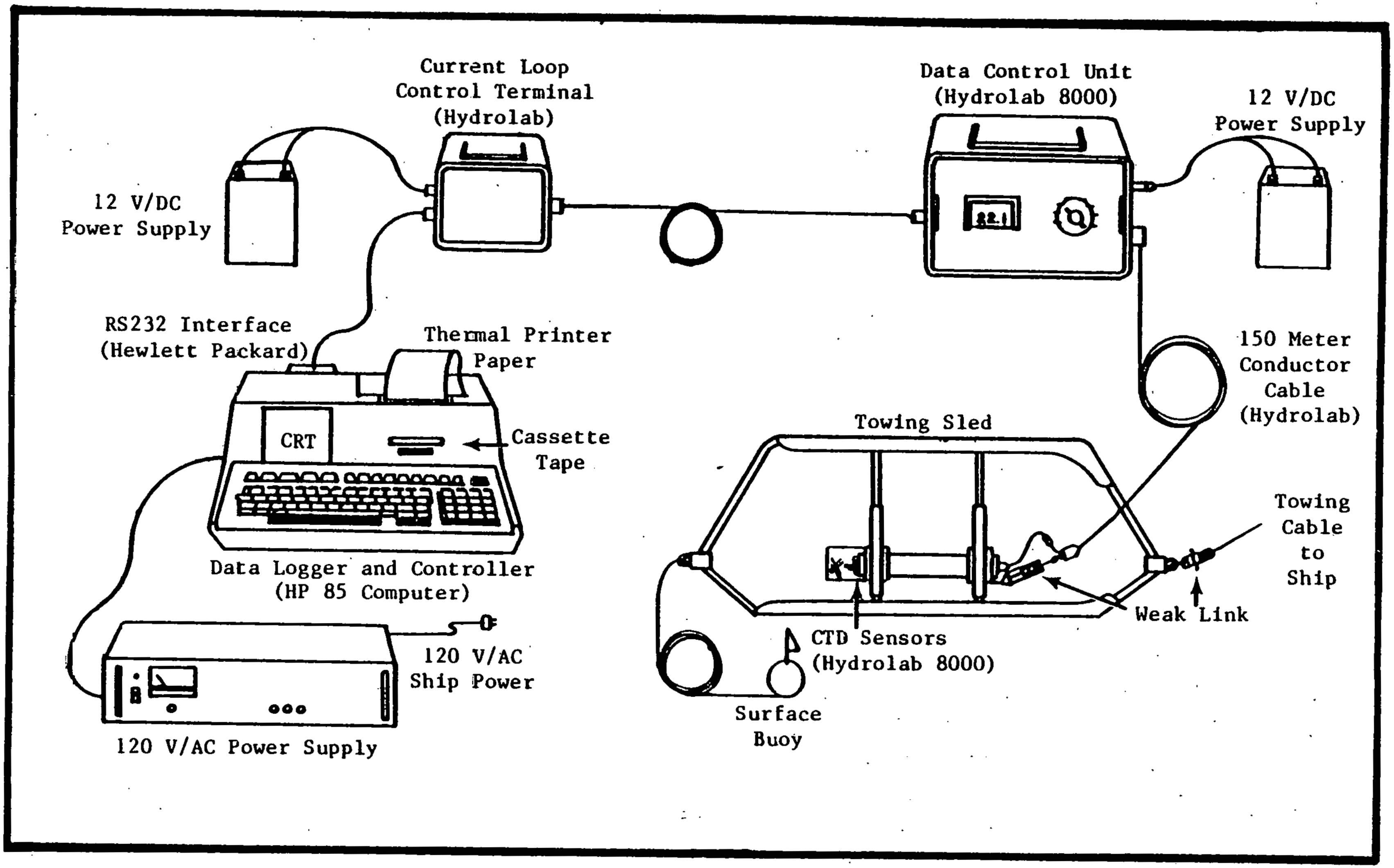


Figure 2-4. Schematic of brine plume measurement system with data logger.

system which is illustrated in Figure 2-4. The CTD system has three components: the data transmitting unit (probe), the conductor cable, and the data control unit (readout). The probe is capable of measuring conductivity (0 to 200 mmho/cm), depth (0 to 200 m), and temperature (-5 to +45°C). The conductor cable is 150 m long and 1 cm in diameter. The CTD system is interfaced with a Hewlett Packard 85 computer for data logging and presentation. A CRT display on the computer provides a continuous update of the CTD data measured by the underwater probe. This display allows the operator to continually observe the salinity data which determines when the sensor is in and out of the plume and alerts the operator when problems arise. The computer is programmed such that it automatically records the data at a predetermined interval on cassette tape and prints it on a thermal paper output.

The accuracy of the salinity data is ±0.5 o/oo after calibrating with standard solutions using a Grundy laboratory salinometer which has an accuracy of ±0.003 o/oo, Grundy (1978). The temperature and depth sensors have an accuracy of ±0.2°C and ±1 m. The CTD system is calibrated in the laboratory before and after each plume measurement. Prior to each plume measurement, the research vessel heads for the three control stations (stations 39A, 39 and 39B) located 7.4 km up the coast from the diffuser. Station 39 is on the same depth contour as the diffuser and stations 39A and 39B are located 3.7 km inshore and offshore of station 39, respectively. A continuous vertical profile of conductivity, salinity, temperature, and depth are recorded at each station. These data are used to determine the expected ambient conditions for the sea water in the vicinity of the diffuser. Next, the vessel anchors near buoy C at the diffuser site, and the current at the top, middle, and bottom depths are measured with a remote reading Endeco Type 923 current meter. The bottom current measurements provide an indication of the expected direction of the plume.

The plume track starting point is normally located inshore and on the upstream side of the diffuser as shown in Figure 2-5. At this point, the towing sled is deployed and the CTD system is activated. The towing cable and the conductor cable are let out simultaneously until 107 m are in the water. This is the optimum length of cable for towing at a normal speed of 5.6 km/hr while the sled remains on the bottom.

The ship steers a constant LORAN C line course which is nearly parallel to the diffuser and at a distance of approximately 122 m away as illustrated in Figure 2-5. This course is maintained while the sensor shows the salinity increasing as the sled enters the plume and until the salinity decreases to a value indicating the 1 o/oo above ambient contour is reached. At this point, the ship reverses course and follows a constant LORAN C line approximately 1 km away from the diffuser. This course is maintained as the ship re-enters the plume and until the 1 o/oo above ambient contour is again reached. This zig zag pattern is continued until one complete leg is outside the 1 o/oo above ambient area. When the 1 o/oo above ambient contour is defined on one side of the diffuser, the same procedure is repeated on the opposite side of the diffuser. These plume tracking procedures normally take six to eight hours to complete.

During the tracking procedure, the conductivity, temperature, and depth are recorded every minute on cassette tape and thermal paper by the automatic data logger. Along with conductivity readings, the ship's location in terms of LORAN C coordinates is recorded in a log book every minute. Watches with sweep hands are synchronized at the start to insure

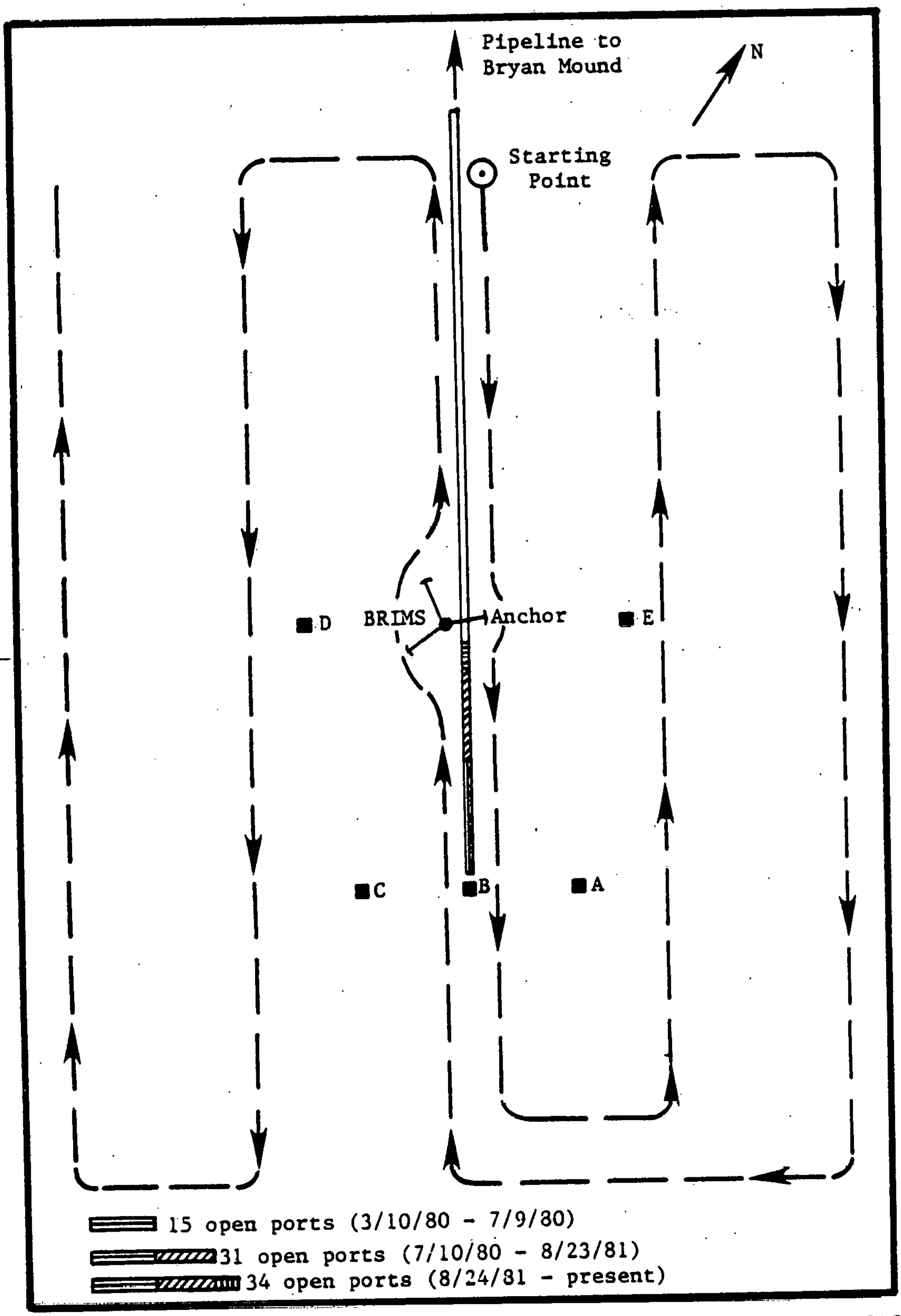


Figure 2-5. General schematic of the plume tracking course in the diffuser area.

simultaneous recording of data. The depth data indicate whether the sled is staying on the bottom, and the temperature data are used to determine the presence of any thermal plume resulting from the brine discharge.

The isohaline contours are determined by plotting the location of the sled every minute during the plume tracking period. The conductivity is converted to salinity and the corresponding salinity values are recorded along side the location of the sled. Once this is completed for the entire plume track, linear interpolation is used to locate the isohaline contours.

After the plume tracking is completed, the ship returns to the diffuser area to measure the vertical salinity profiles, which permit the evaluation of the vertical extent of the plume. These profiles are obtained by lowering the CTD probe to the bottom and back to the surface while the conductivity, temperature and depth are simultaneously recorded on cassette tape by an automatic data logger. The vertical profile stations are located along a transect corresponding with the measured bottom current direction and passing through the center of the diffuser. The goal is to obtain data directly over the diffuser and at several stations upstream and downstream of the diffuser.

The LORAN C navigation system and a specially constructed LORAN C chart are used for all plume tracking operations. The two secondary transmitting stations used are the X (25000) and the Y (46000) LORAN C stations. The lines for station X (25000) run approximately parallel to the pipeline, and the lines for station Y (46000) run normal to the pipeline. The chart is used to plot the ship's track during the plume track and to plot the ship's location and corresponding salinity readings from which the salinity contours are determined.

The LORAN C receiver displays the LORAN C coordinates to the nearest 0.1 of a microsecond (μs). For the X (25000) the accuracy is estimated to be ±15.5 m and ±84.1 m for the two stations used. The LORAN C coordinates of the BRIMS buoy are recorded from the LORAN C receiver before each plume track and compared with those on the chart in order to determine correction factors. These corrections are applied to all data in order to obtain the most accurate ship position.

The ambient bottom salinity is very hard to determine exactly. Kelly and Randall (1980) and Randall and Kelly (1981) described the variation of bottom salinity at the diffuser site over a two-year period prior to brine discharge. Daily salinity variations of up to 3 o/oo were reported. Salinity fronts in the vicinity of the diffuser were described which tended to move inshore and offshore depending on environmental conditions. It was shown that the largest salinity variation occurred in the cross shelf direction. The alongshore salinity variation was observed to be approximately 1 o/oo over 7.4 km. In previous reports, the bottom salinity measured at station 39 which is 7.4 km up the coast and at the same depth contour as the diffuser was compared to the measurements taken just outside the measured plume area in order to determine the ambient condition. The salinity measurement at station 39 was used as the ambient bottom salinity unless the vertical profile measurements just outside the plume area indicated there was a significant difference. In this case, the smallest upstream bottom salinity was selected as the ambient value.

It became apparent that the cross shelf salinity variation was sometimes large enough to affect the above ambient contours. The cross shelf salinity variation effect on the above ambient salinity contours was also observed at the West Hackberry diffuser site during similar measurements by Randall (1983b). Consequently, two additional ambient stations, 39A and 39B, were located 3.7 km inshore and offshore, respectively, of station 39. The bottom salinity at these three stations were used as the ambient conditions with linear interpolation between stations unless the transects measured outside the plume during the plume tracking procedure indicated the salinity variation was different from stations 39A, 39 and 39B, and then the salinity data for the transect were used as the ambient values for determining the above ambient isohaline contours.

2.3 Description of Selected Brine Plume Areal and Vertical Extent Measurements

2.3.1 September 16, 1982

On September 16, 1982, the brine was being discharged through 34 ports at an average rate of 41,046 barrels/hour, a salinity of 255 o/oo, and a temperature of 29°C. The average bottom current was 12 cm/s in the direction of 040°T, and the ambient bottom salinity at station 39 was 34.7 o/oo. The areal extent of the brine plume located 25 cm above the sea floor is defined by the closed isohaline contours in Figure 2-6 and the above ambient salinity contours in Figure 2-7.

The area inside the 39, 38, 37, 36 and 35 o/oo isohaline contours was 0.1, 3.5, 14.4, 26.0 and 41.0 km^2, respectively while the area inside the +5, +4, +3, +2 and +1 o/oo above ambient salinity contours was 0.1, 0.2, 6.3, 17.7 and 29.3 km^2, respectively. The +1 o/oo contour extended 13.5 km upcoast (055°T) and 2.6 km downcoast (235°T) from the center of the diffuser. In the offshore (145°T) and inshore (325°T) directions, the +1 o/oo contour reached distances of 2.6 and 2.5 km, respectively. The farthest distance from the center of the diffuser to the +1 o/oo contour

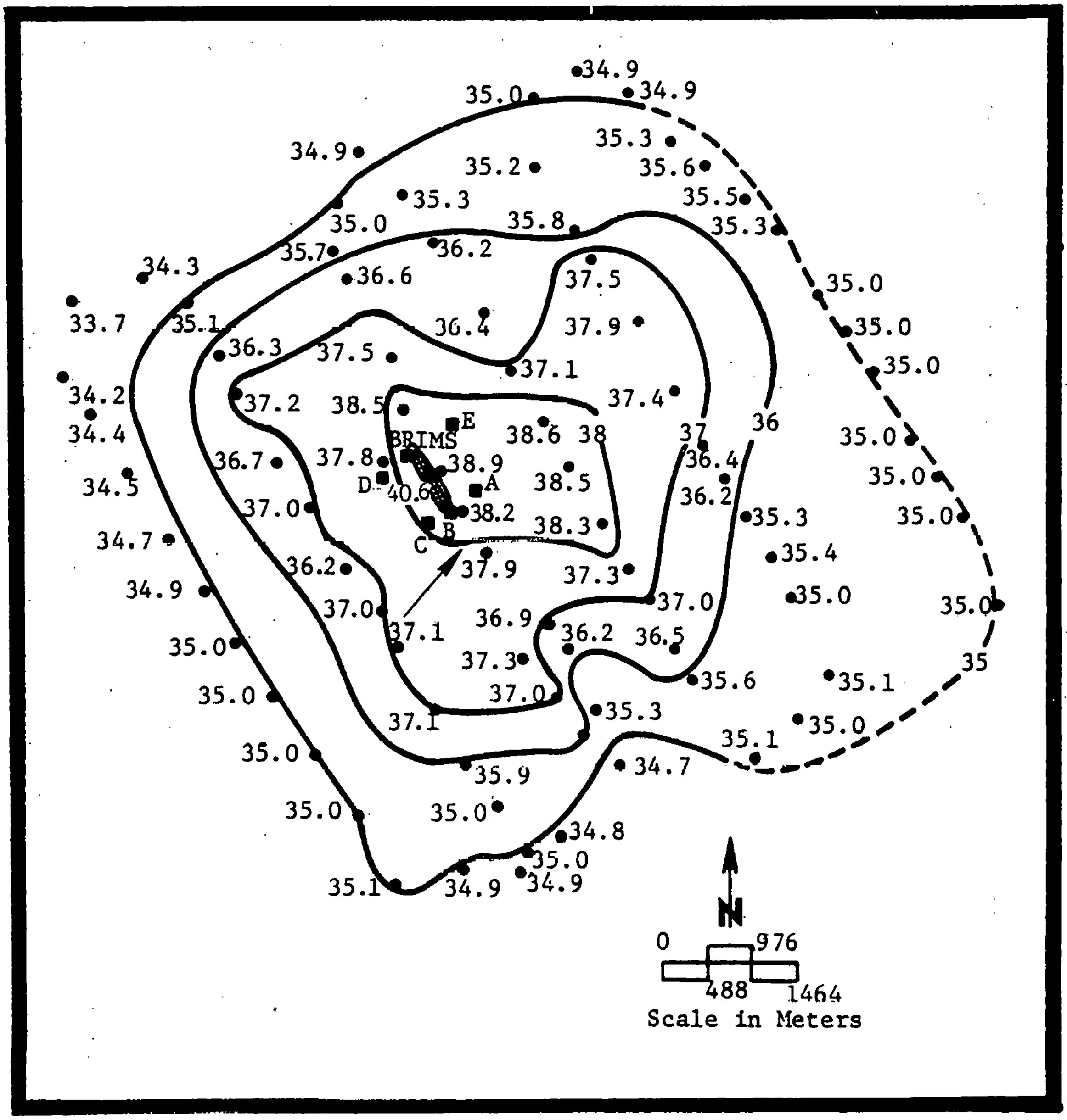


Figure 2-6. Brine plume isohaline contours for September 16, 1982. The average brine discharge rate, salinity, temperature, and the ambient bottom salinity at station 39 were 41,046 barrels/hr, 255 o/oo, 29°C, and 34.7 o/oo. The average bottom current was 12 cm/s in the direction of 40°T as indicated by the arrow.

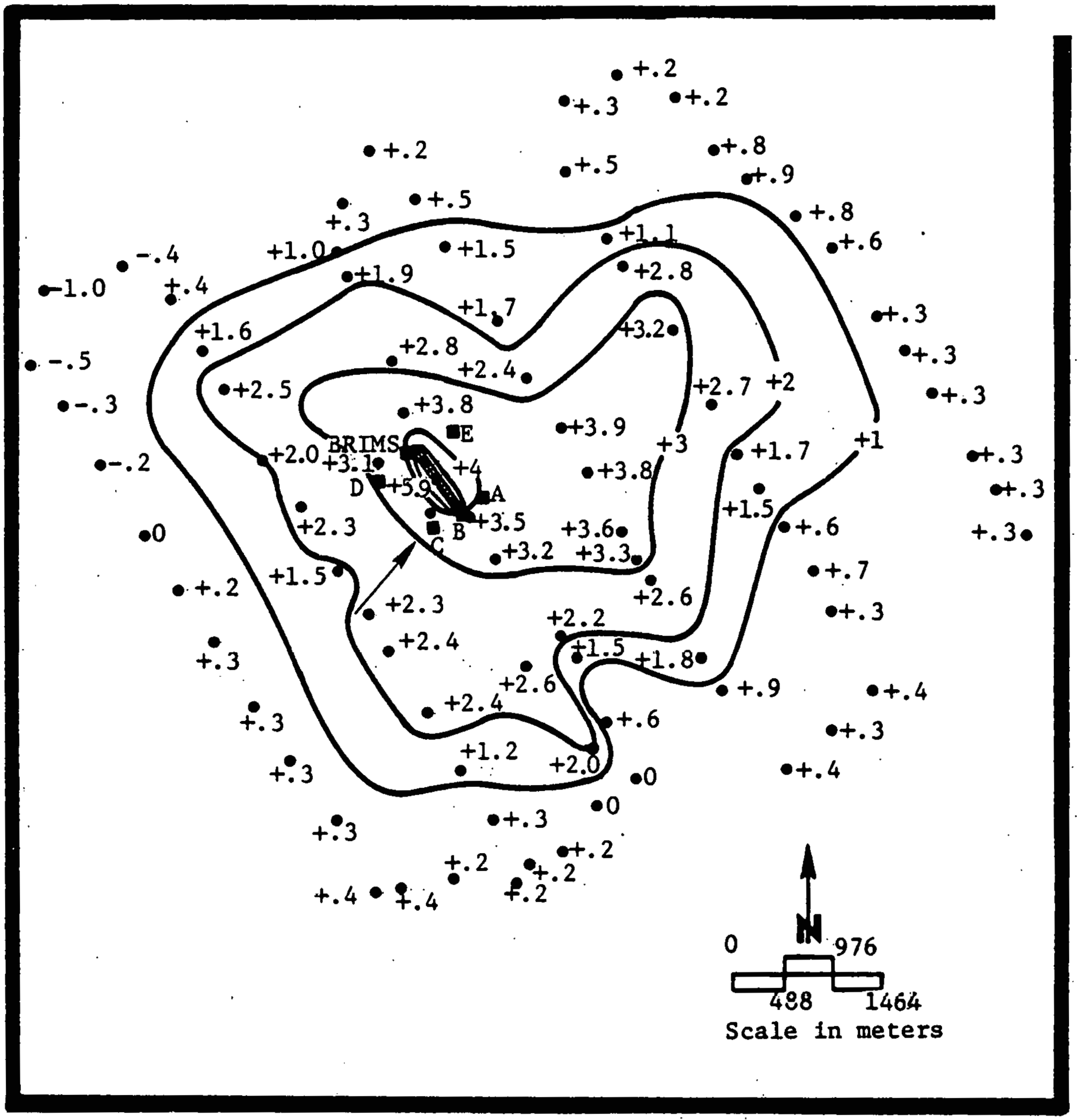


Figure 2-7. Brine plume above ambient salinity contours for September 16, 1982. The average brine discharge rate, salinity, temperature, and the ambient bottom salinity at station 39 were 41,046 barrels/hr, 255 o/oo, 29°C, and 34.7 o/oo. The average bottom current was 12 cm/s in the direction of 40°T as indicated by the arrow.

was 4.3 km in the direction of 081°T which was just east of the average botttom current direction of 042°T. The +5 o/oo contour on this date was the highest and the only +5 o/oo above ambient contour measured during this reporting period. The average bottom current was determined from the in situ current meter data collected near buoy C at a depth of 19.6 m. Hourly stick vectors of the current meter data for this plume track are shown in Appendix A. The salinity data points for this plume track were collected over a 7.5 hour period from 1030 to 1800 hours.

Temperature data were measured simultaneously with salinity during the plume track. The data show the bottom temperature varied between 28.7 and 29.0°C which indicates the water temperature was nearly constant over the entire plume area. No evidence of a thermal plume was detected.

The vertical salinity profiles measured immediately following the areal measurements are illustrated in Figure 2-8. The ambient salinity profile was measured at station 39 which is located 7.4 km northeast of the diffuser, and it shows the salinity increased from 27.7 o/oo at the surface to 31.8 o/oo at the 3.5 m depth. The salinity continued to increase slightly to a value of 34.3 o/oo at a depth of 15.1 m, and it remained isohaline to the bottom (21.5 m). Similar results were obtained at station 8 which was outside the +1 o/oo contour and upstream of the diffuser. Stations 1, 2, 3 and 4 were located downstream of the diffuser as shown on the last page of Figure 2-8. These profiles indicate the existence of the brine plume at the bottom where the salinity increases sharply in comparison to the ambient profiles near the 20 m depth mark. The highest measured salinity of 40.6 o/oo was observed on the profile measured directly over the diffuser (station 5). Also, a salinity of 63.3 o/oo was measured at a depth of 18.3 m, and this was the result of the

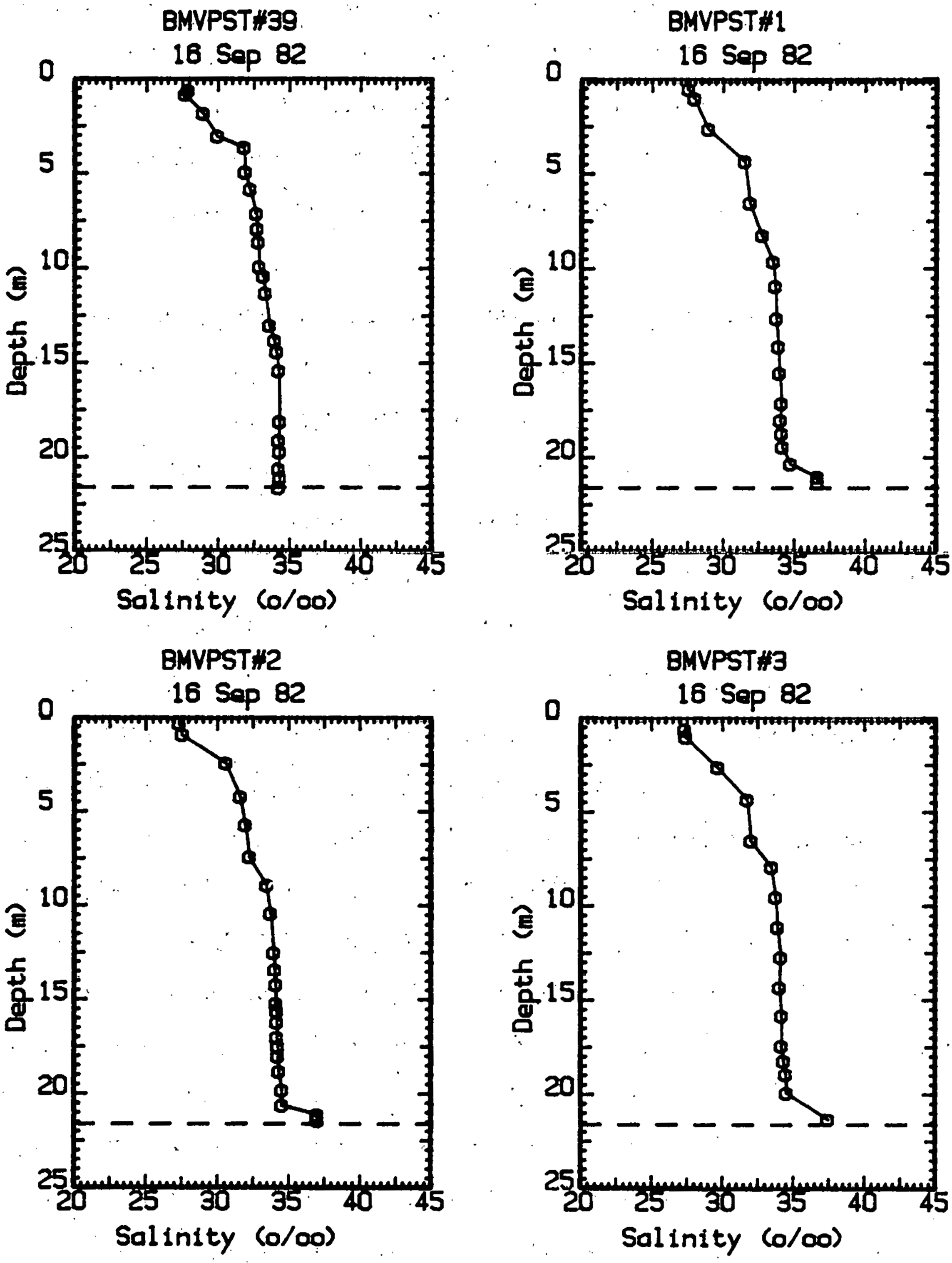


Figure 2-8. Vertical salinity profiles for September 16, 1982. The dashed line indicates the depth (21.6 m) of the natural sea floor.

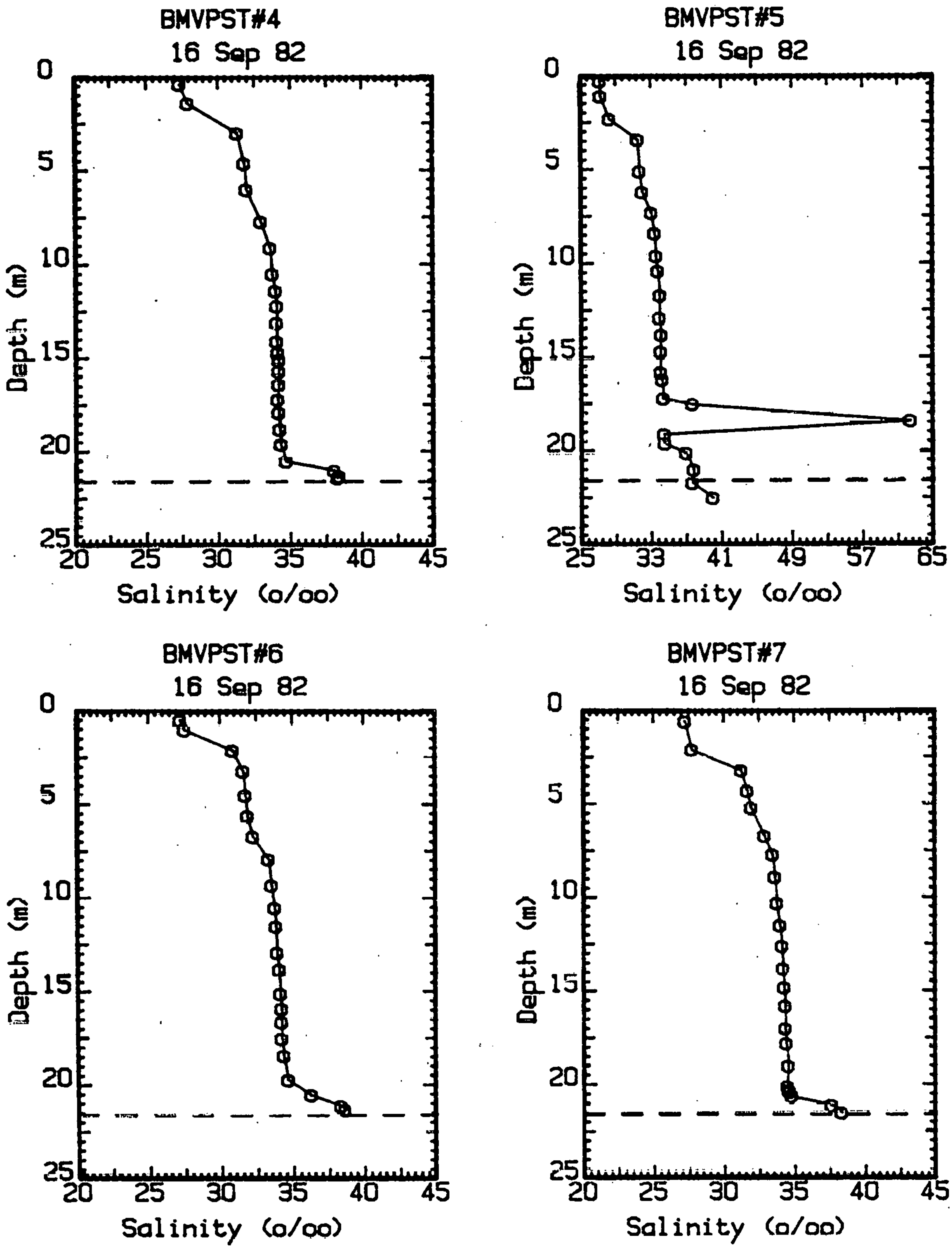


Figure 2-8. Continued.

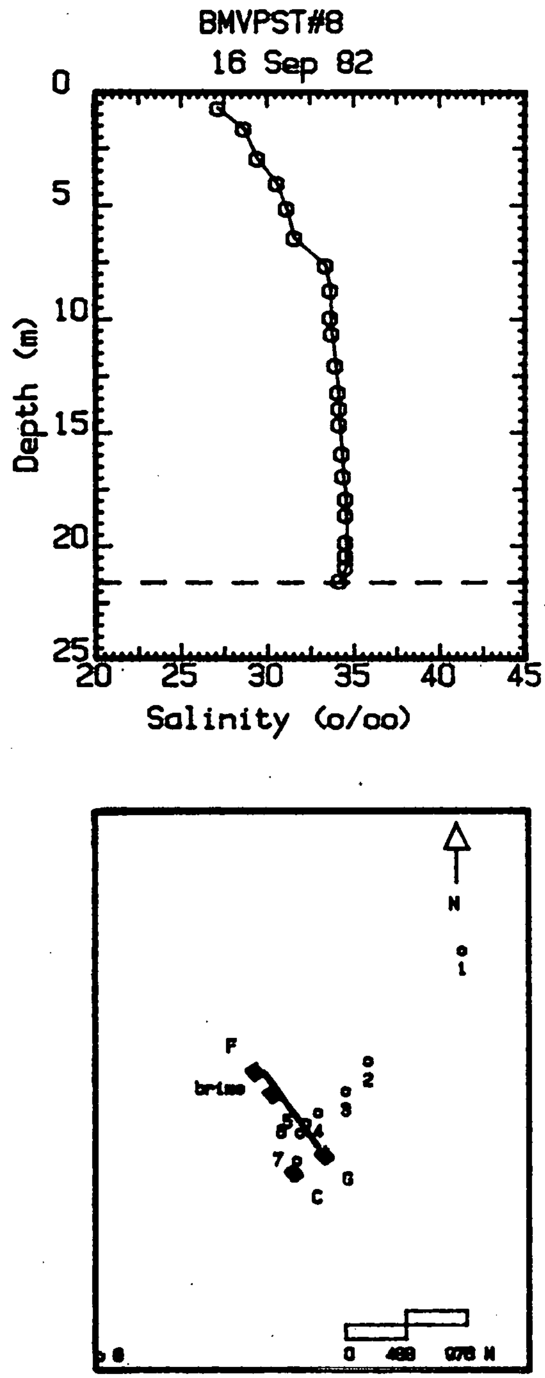


Figure 2-8. Continued.

sensor passing through a brine jet. This profile also indicated the maximum vertical extent of the brine plume was 4.5 m above the natural sea floor depth of 21.6 m. Stations 6 and 7 were measured on the upstream (southwest) side of the diffuser. These profiles show a similar salinity structure as was measured on the downstream side, and the brine plume was evident near the 20 m depth where the salinity increased sharply from the ambient condition. In summary, these profiles show the bottom salinity at stations 1 through 8 was 36.9, 37.3, 38.0, 38.8, 40.4, 39.0, 38.8, and 34.3 o/oo, respectively. Thus, the bottom salinity was maximum at the diffuser and decreased with distance away from the diffuser in both the upstream and downstream directions.

2.3.2 January 11, 1983

The January 11, 1983 plume measurements were conducted when the brine was being discharged at an average rate of 42,208 barrels/hour, a salinity of 249 o/oo, and a temperature of 20°C. The bottom salinity at station 39 was 34.6 o/oo. The average bottom current of 16 cm/s was flowing in the direction of 037°T during the period of the plume measurements which began at 0930 hours and ended at 1900 hours for a total period of 9.5 hours.

The isohaline and the above ambient salinity contours are illustrated in Figures 2-9 and 2-10. The data show three closed isohaline contours of 36, 37 and 38 o/oo which enclosed areas of 33.8, 3.4 and 0.7 km^2, respectively. The salinity data indicated there was a cross shelf salinity variation which prevented the use of the station 39 bottom salinity as the ambient salinity for determining the above ambient contours. Therefore, an ambient salinity scale based upon the furthest upstream leg of the plume measurements was used. The ambient salinity

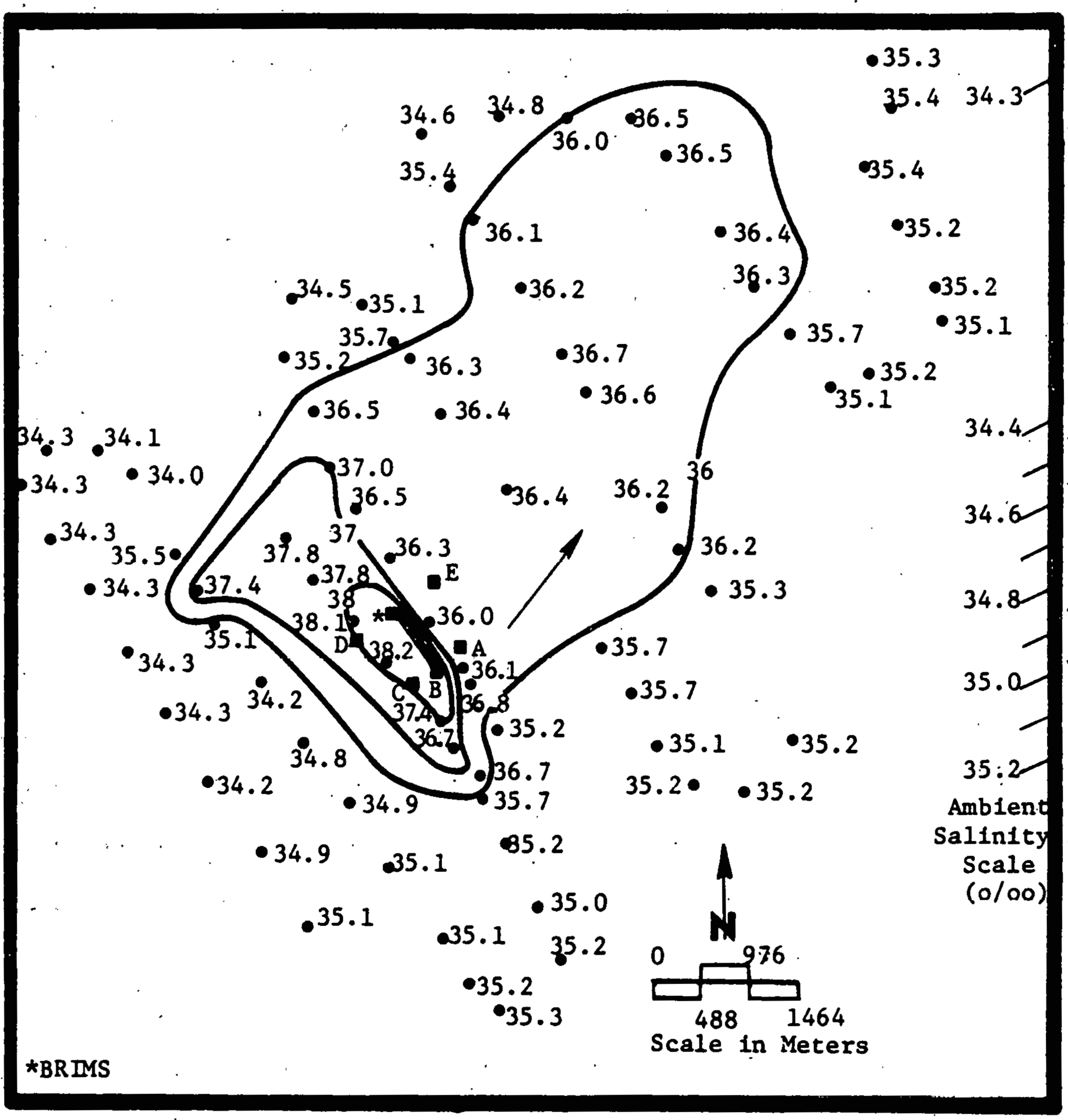


Figure 2-9. Brine plume isohaline contours for January 11, 1983. The average brine discharge rate, salinity, temperature, and the ambient bottom salinity at station 39 were 42,208 barrels/hr, 249 o/oo, 20°C, and 34.6 o/oo. The average bottom current was 16 cm/s in the direction of 37°T as indicated by the arrow.

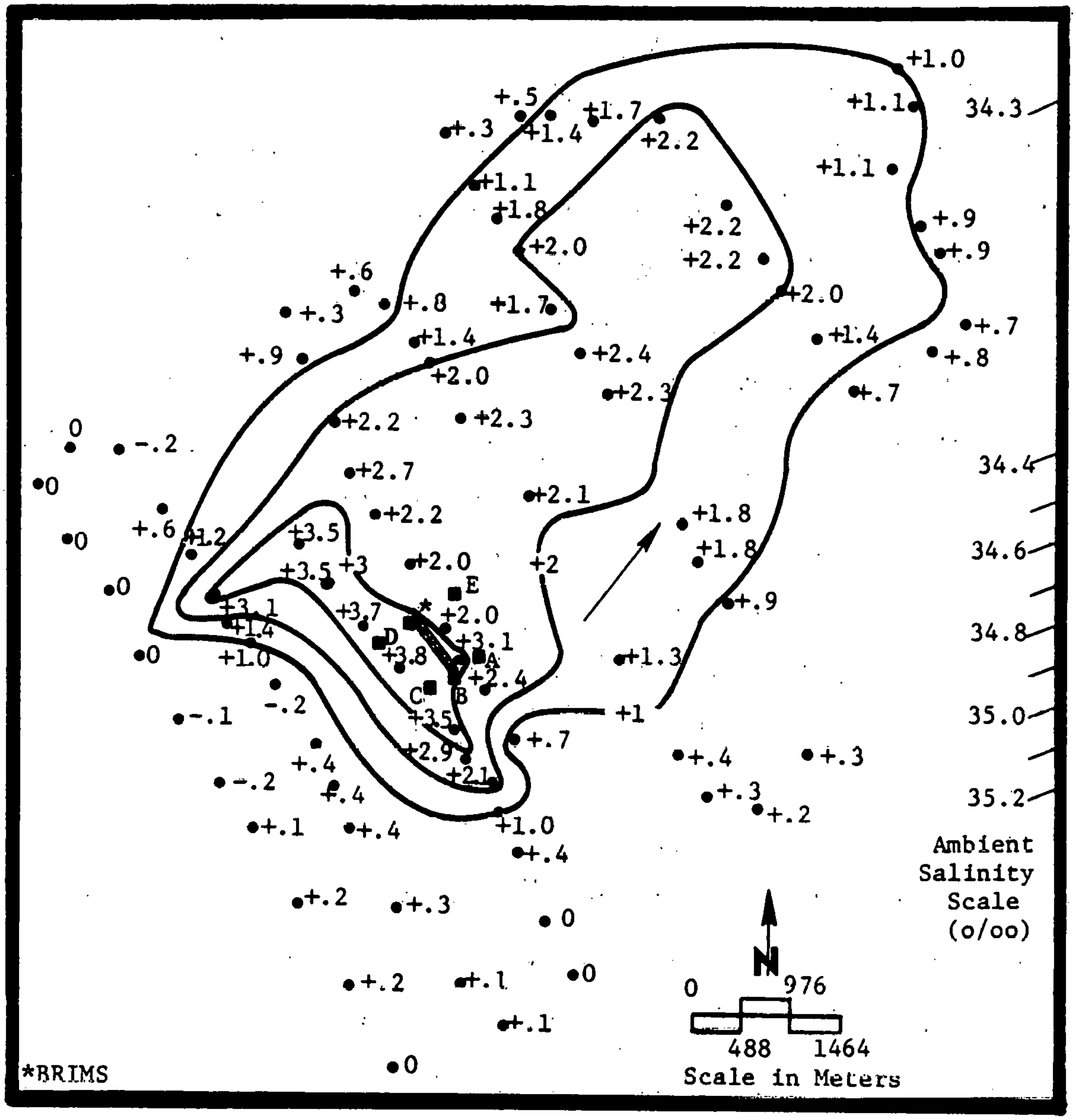


Figure 2-10. Brine plume above ambient salinity contours for January 11, 1983. The average brine discharge rate, salinity, temperature, and the ambient bottom salinity at station 39 were 42,208 barrels/hr, 249 o/oo, 20°C, and 34.6 o/oo. The average bottom current was 16 cm/s in the direction of 37°T as indicated by the arrow.

scale is shown at the right hand margin of Figure 2-9. Using this scale, the above ambient salinity contours of +1, +2 and +3 o/oo were determined as shown in Figure 2-10 and enclosed areas of 33.3, 15.9 and 2.0 km^2, respectively. The longest distance to the +1 o/oo contour was 7.4 km in the direction of 041°T which is very close to the average bottom current direction. The distance to the +1 o/oo contour in the upcoast, downcoast, offshore and inshore directions was 6.2, 1.2, 1.3 and 2.9 km, respectively. The highest salinity, 38.2 o/oo, was 3.8 o/oo above the ambient salinity.

The temperature data collected during the areal measurements show the bottom temperature varied between 16.7 and 18.4°C while the average brine temperature was 20°C. The bottom temperature increased from inshore to offshore, but the temperature data did not show increases near the diffuser followed by decreases away from the diffuser. Thus, no indication of a thermal plume was observed.

Figure 2-11 shows the results of the plume vertical extent measurements. The ambient profile at station 39 shows the salinity at the surface was 26.1 o/oo, and it increased to 34.5 o/oo at 15.9 m. The salinity then increased slightly to 34.6 o/oo at the bottom. The presence of the brine plume is indicated at stations 1 and 2 on the downstream side of the diffuser where the bottom salinity was 36.6 and 36.7 o/oo, respectively. The vertical profile measured directly over the diffuser, station 3, shows the maximum bottom salinity was 37.7 o/oo and the vertical extent was 2.6 m. On the upstream side, stations 4, 5 and 6 show the bottom salinity was 37.4, 36.5 and 34.8 o/oo, respectively. The vertical height of the plume is based upon the depth at which the profiles deviate from the ambient profile, and for stations 1 through 6, it was

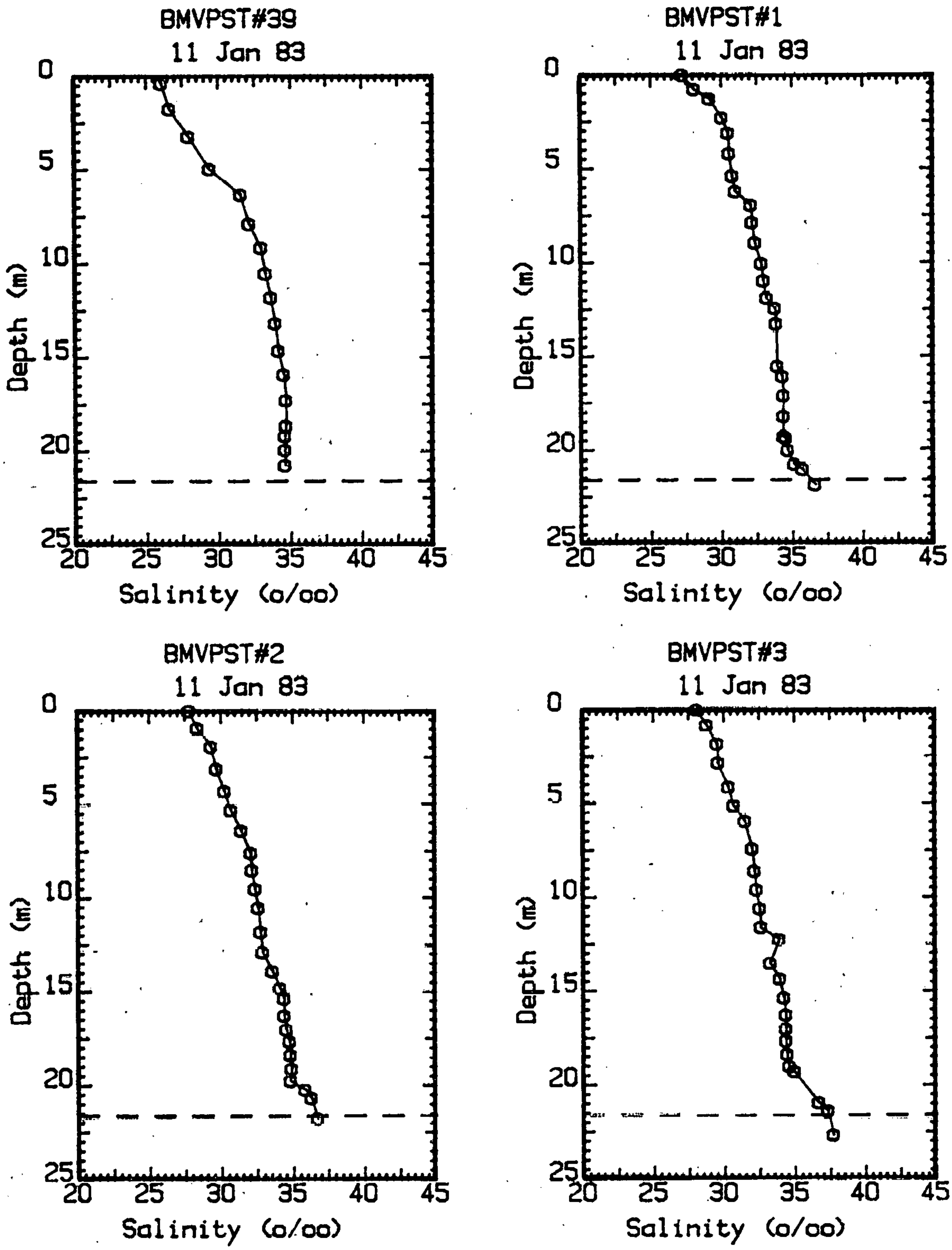


Figure 2-11. Vertical salinity profiles for January 11, 1983. The dashed line indicates the depth (21.6 m) of the natural sea floor.

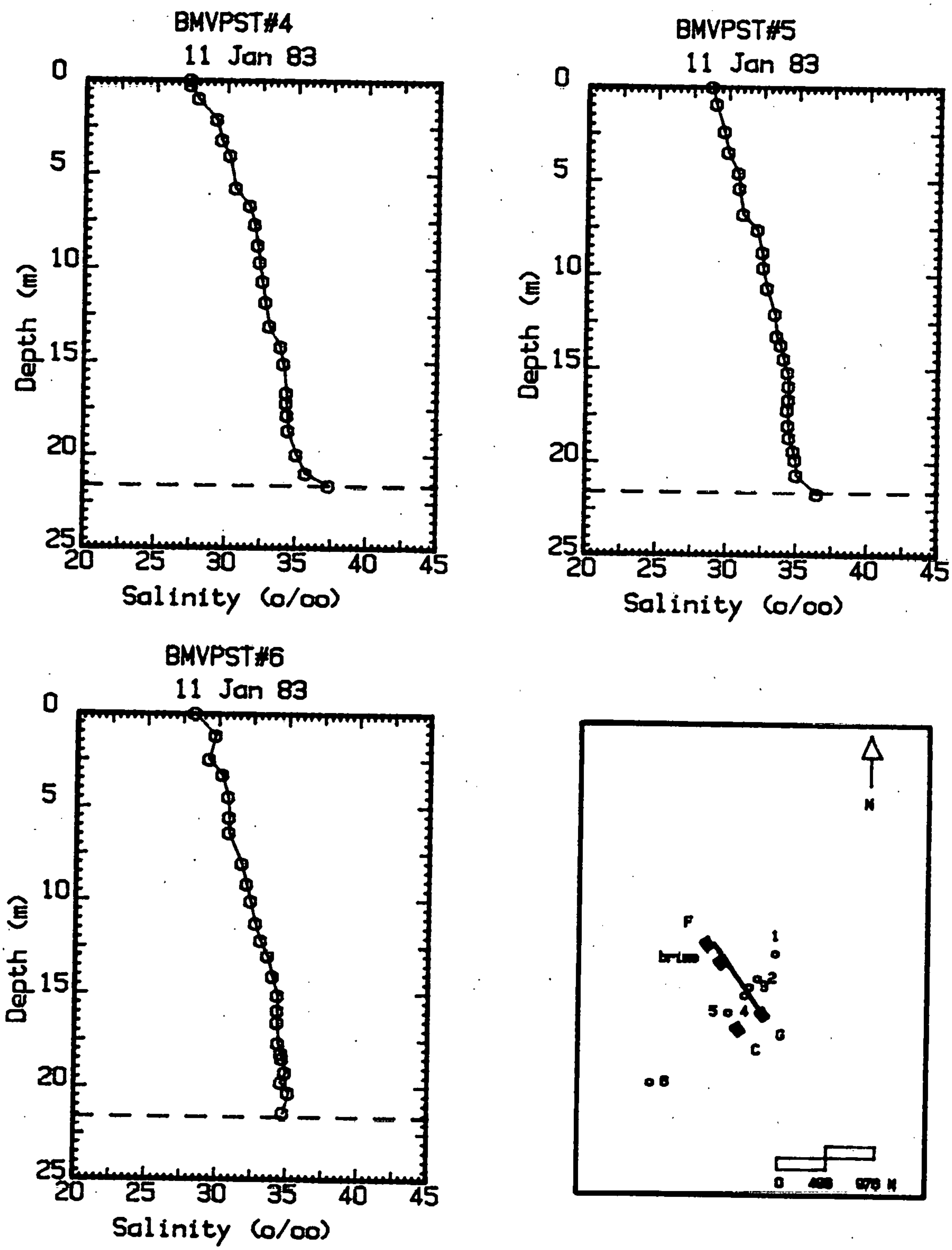


Figure 2-11. Continued.

2.2, 3.0, 2.6, 3.0, 3.0 and 3.0 m, respectively.

2.3.3 May 4, 1983

On May 4, 1983, the brine was being discharged at an average rate of 41,813 barrels/hour, a brine salinity of 258 o/oo and a temperature of 24°C was measured. Two additional ambient stations were added to evaluate the cross shelf salinity variation. Stations 39A and 39B are located 3.7 km inshore and offshore of station 39. The bottom salinity at stations 39A, 39 and 39B was 31.0, 31.5 and 32.5 o/oo, respectively. The average bottom current was 6 cm/s in the direction of 015°T.

The areal extent of the May 4, 1983 brine plume is illustrated by the closed isohaline contours in Figure 2-12 and the above ambient salinity contours in Figure 2-13. The area inside the 35, 34, 33 and 32 o/oo isohaline contours was 0.7, 3.2, 6.7 and 11.9 km^2 respectively. Stations 39A, 39 and 39B indicated there was a strong cross shelf salinity gradient, and therefore an ambient salinity scale was used in the evaluation of the above ambient isohaline contours. The plume track transect farthest away from the diffuser on the southwest side was selected as the ambient salinity scale. The area inside the +1, +2, +3 and +4 o/oo contours was 9.9, 5.4, 1.7 and 0.1 km^2. These areas are smaller than expected for the low bottom current condition encountered on this date. The ambient bottom salinity was near its lowest annual value and the bottom currents were shifting direction during the day. Areal extents for the +1 o/oo contour were expected to be near 32.5 km^2 based upon empirical predictions discussed later in this chapter. The extent of the brine plume as defined by the +1 o/oo above ambient salinity contour was 1.8 km upcoast, 2.2 km downcoast, 1.3 km inshore and 1.5 km offshore of the diffuser center. The farthest distance from the diffuser center to

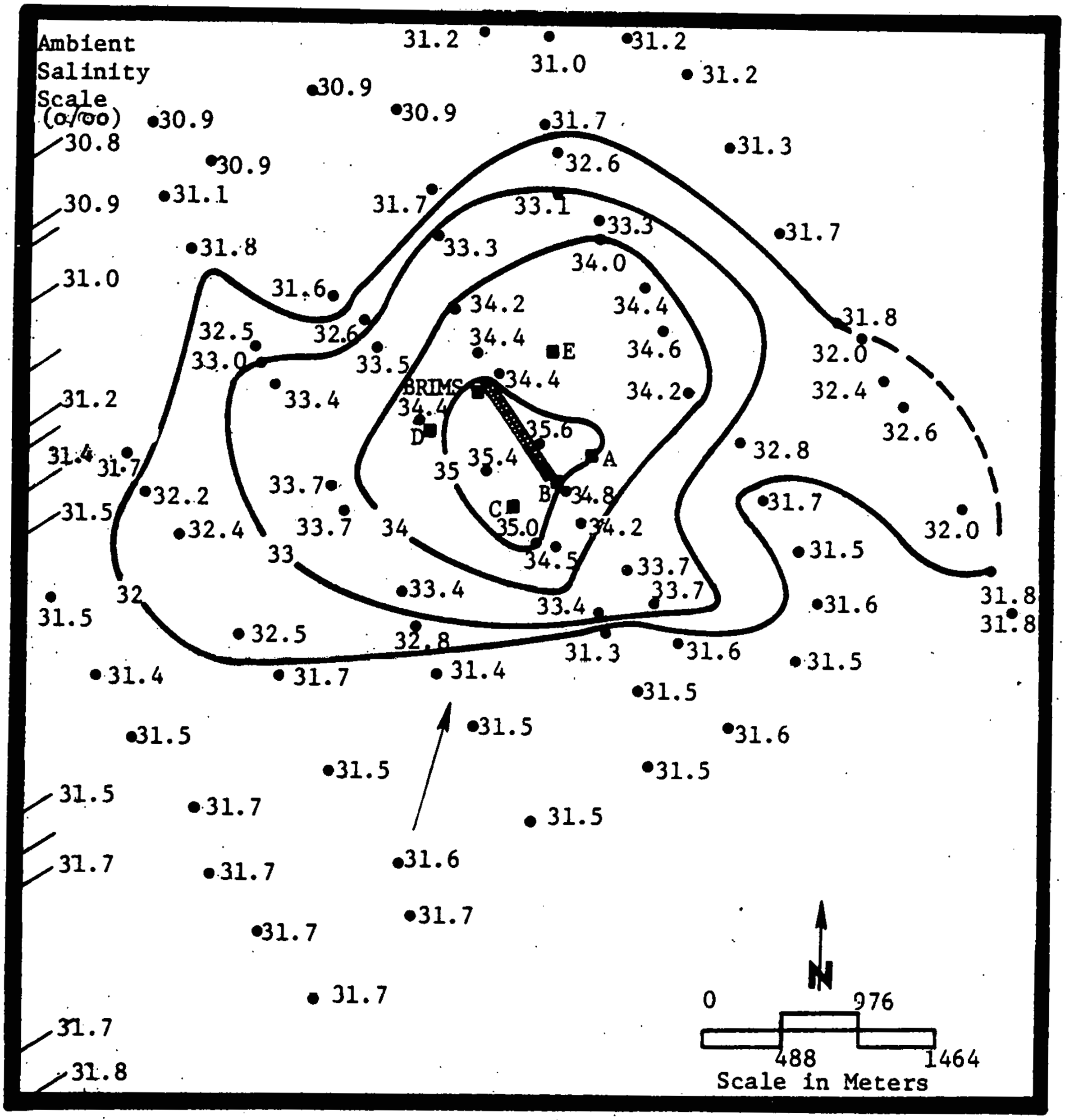


Figure 2-12. Brine plume isohaline contours for May 4, 1983. The average brine discharge rate, salinity, temperature, and the ambient bottom salinity at station 39 were 41,813 barrels/hr, 258 o/oo, 24°C, and 31.5 o/oo. The average bottom current was 6 cm/s in the direction of 15°T as indicated by the arrow.

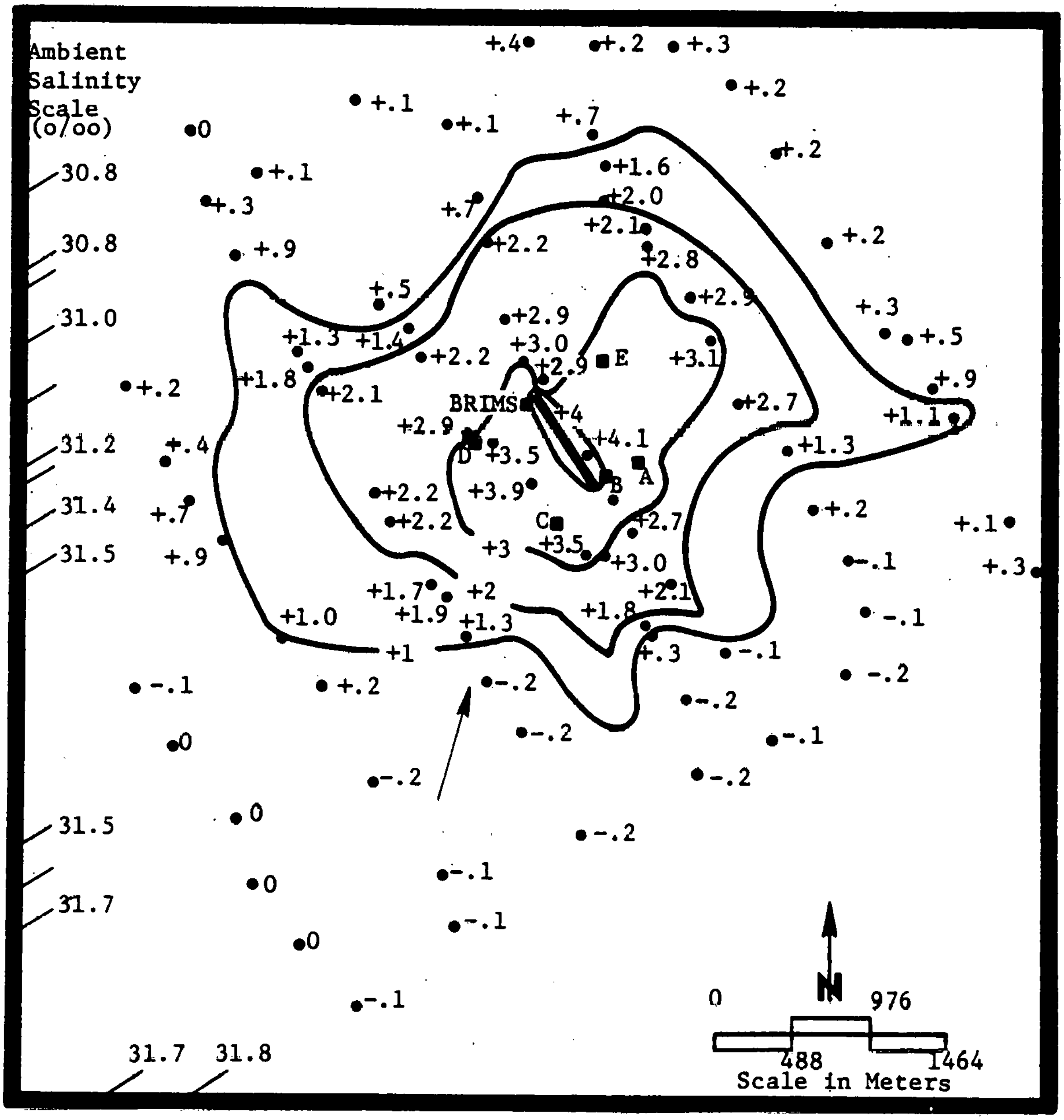


Figure 2-13. Brine plume above ambient salinity contours for May 4, 1983. The average brine discharge rate, salinity, temperature, and the ambient bottom salinity at station 39 were 41,813 barrels/hr, 258 o/oo, 24°C, and 31.5 o/oo. The average bottom current was 6 cm/s in the direction of 15°T as indicated by the arrow.

the +1 o/oo contour was 2.5 km in the direction of 087°T. The highest salinity was 35.6 o/oo which was 4.0 o/oo above the ambient salinity.

The salinity data were collected over a period of 6 hours from 1030 to 1630 hours. The bottom temperature data collected at the same time as the salinity data show the bottom temperature varied between 19.5 and 19.8°C and did not indicate the existence of a thermal plume.

The vertical salinity profiles measured on this date and their location are illustrated in Figure 2-14. Station 39 shows the salinity increased from a surface value of 27.3 o/oo to 31.7 o/oo at 18.8 m and remained isohaline to the bottom. Station 1 is located 0.9 km north northeast of the diffuser, and it shows the salinity increased from 28.7 o/oo at the surface to 31.4 o/oo at 20.2 m and then increased sharply to 34.5 o/oo at the bottom indicating a plume vertical extent of 1.0 m. Station 2, 3 and 4 were very close to the diffuser with station 3 being directly over the diffuser. The bottom salinities at these stations were 35.2, 35.6 and 35.5 o/oo, respectively, and the vertical extent was 2.0 m at each station. Stations 5, 6 and 7 were located south southwest of the diffuser where the bottom salinity was 34.8, 32.5 and 32.0 o/oo, and the plume vertical height was 2.6, 2.0 and 1.0 m, respectively. These data show the bottom salinity and, with the exception of station 6, the plume vertical height decreased with distance from the diffuser.

2.3.4 July 21, 1983

The July 21, 1983 plume measurements were conducted when the brine was being discharged at a daily average discharge rate of 44,237 barrels/hr, a brine salinity of 241 o/oo, and a brine temperature of 28°C. The average bottom current of 18 cm/s was in the direction of 020°T. The ambient stations 39A, 39, and 39B show a strong halocline was

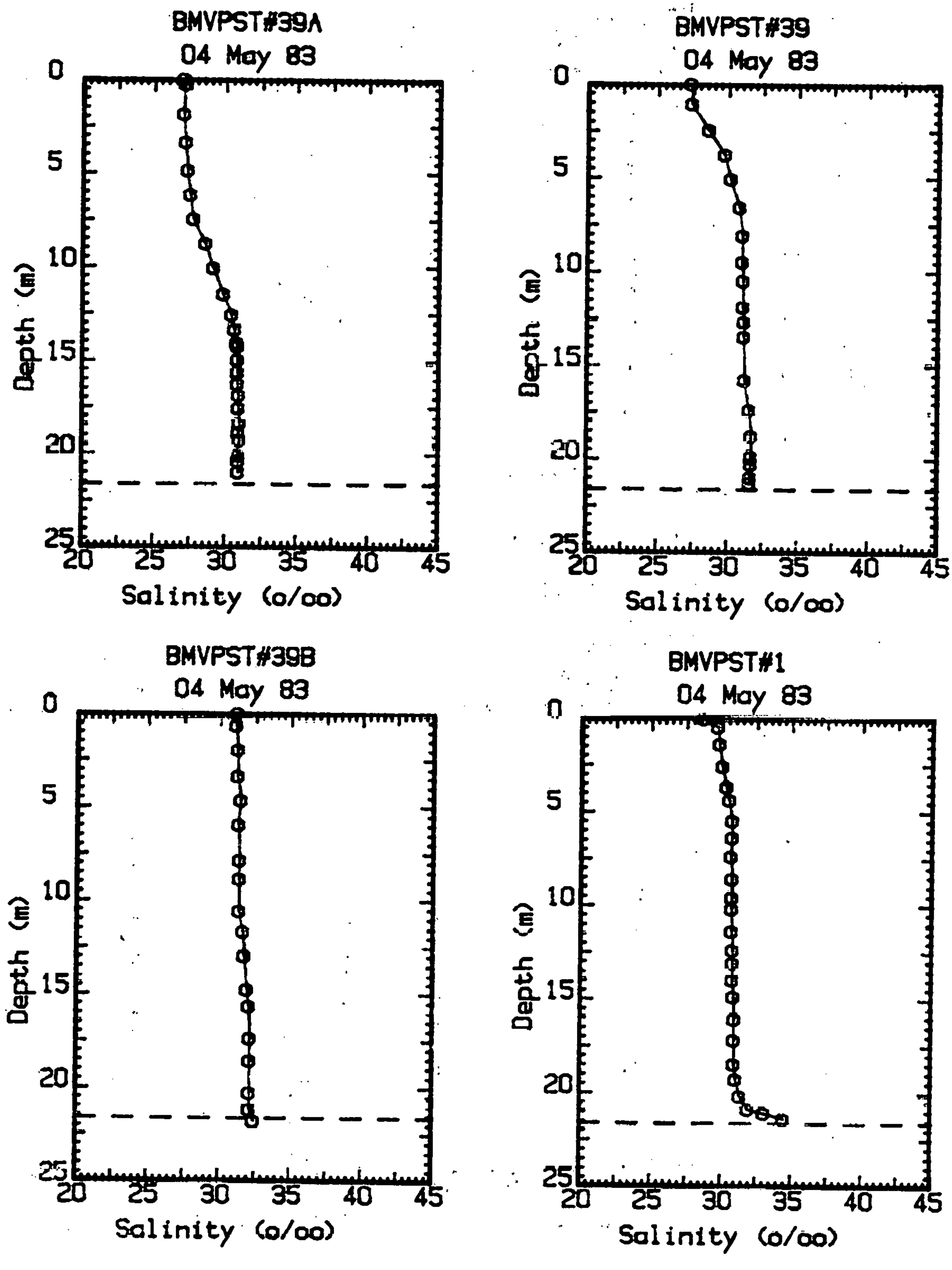


Figure 2-14. Vertical salinity profiles for May 4, 1983. The dashed line indicates the depth (21.6 m) of the natural sea floor.

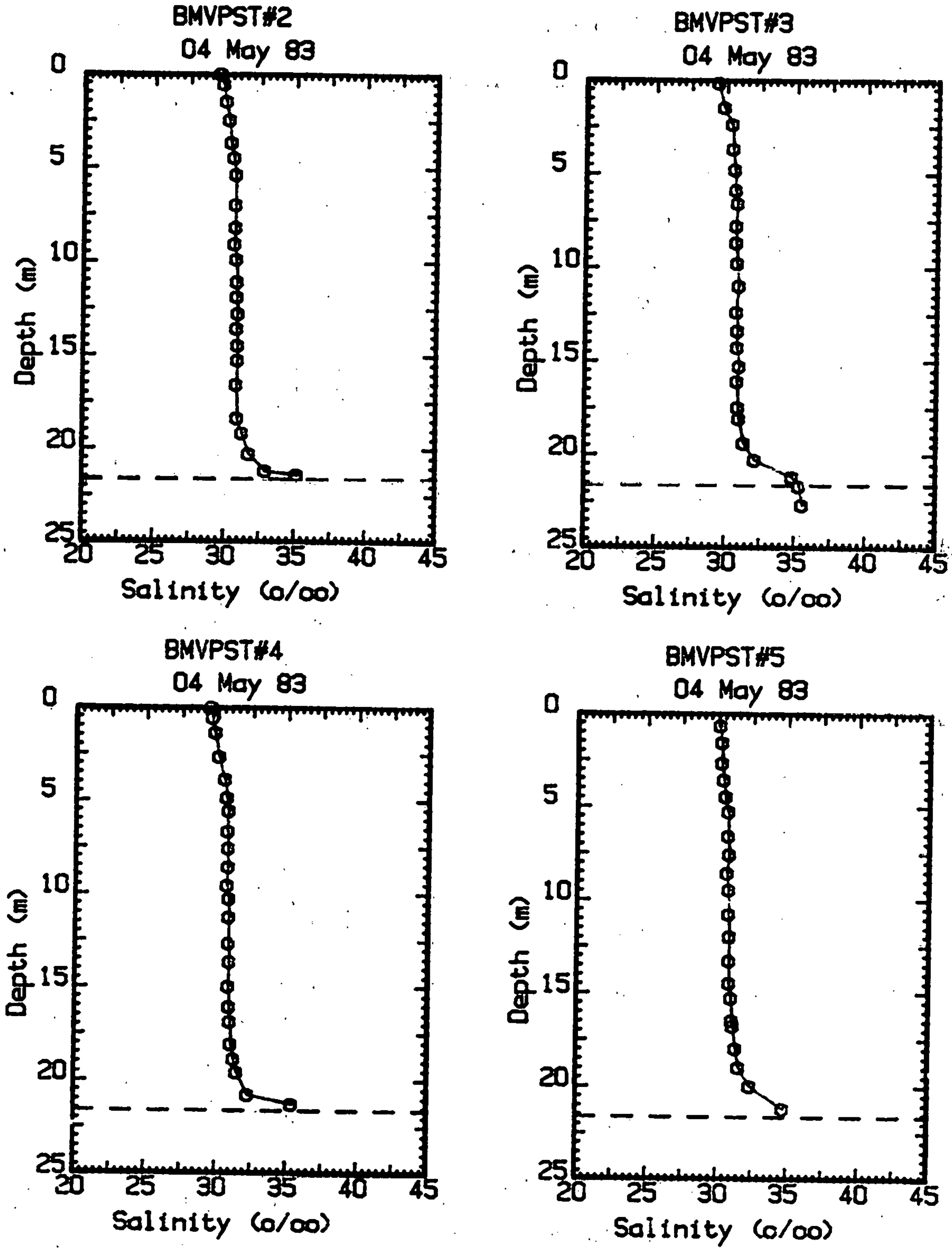


Figure 2-14. Continued.

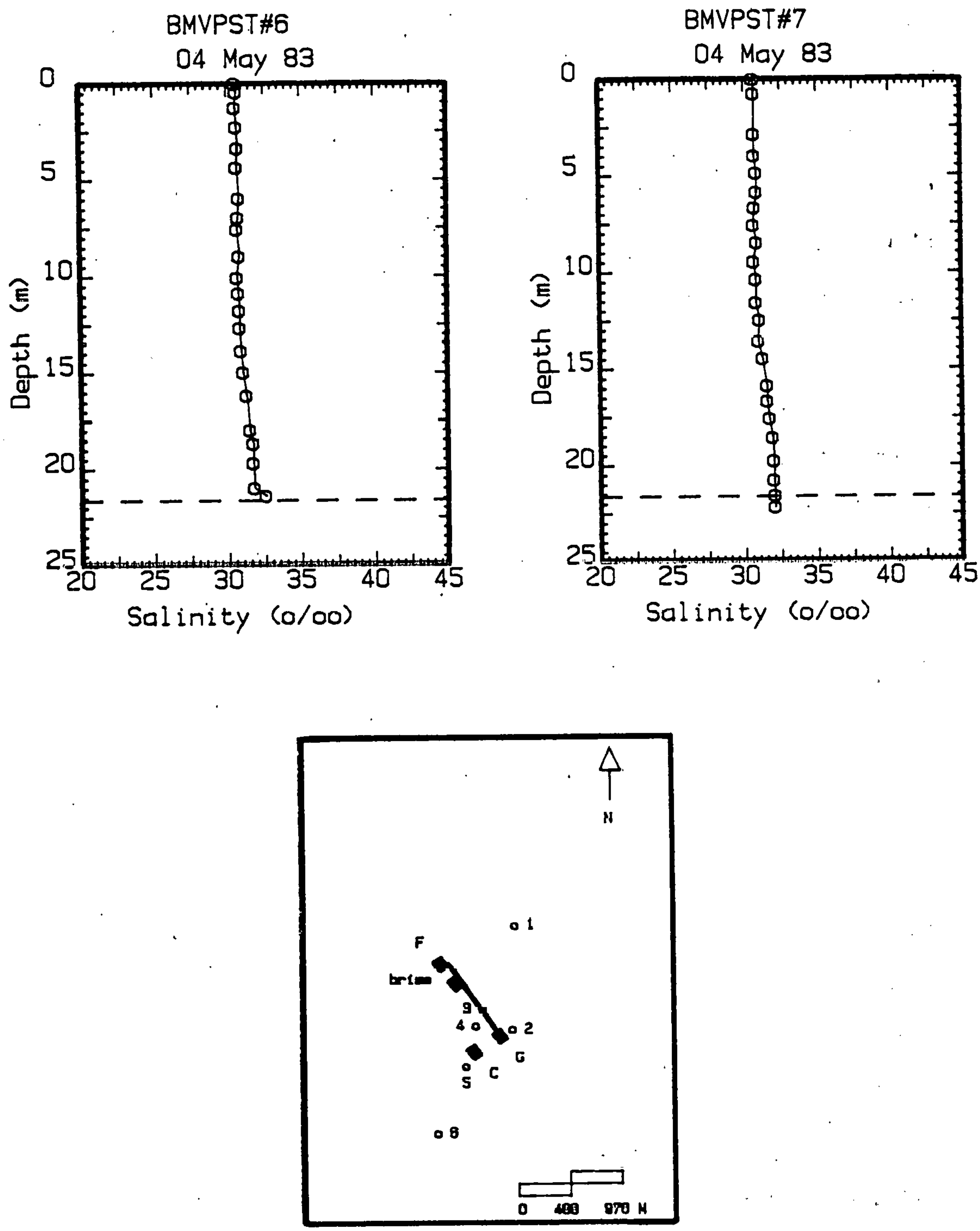


Figure 2-14. Continued.

present between depths of 15 and 20 m, and the bottom salinities increased from 33.8 o/oo at 39A to 34.3 o/oo at 39B.

The areal extent of the plume measured on July 21, 1983 was very unusual in that no closed contours around the diffuser were obtained as illustrated in Figure 2-15. The 34 o/oo isohaline is shown to be distorted such that it passes along the east side of the diffuser, around the inshore end of the diffuser, and along the west side of the diffuser. It did not close on the offshore end. During the plume measurements, a second transect was made extremely close to the diffuser because the normal distance away did not show the presence of the plume. On this transect several data points near the center of the diffuser were obtained which indicated the 34 o/oo isohaline looped around the diffuser as shown. The vertical profile measured directly over and at the center of the diffuser, station 4, also indicated a bottom salinity of 34.1 o/oo.

The brine was being discharged continuously during the plume track at an average salinity of 241 o/oo. Empirical predictions indicated that the above ambient salinity should have been +3.4 o/oo and the areal extent of the +1, +2, and +3 above ambient salinity contours should have enclosed an area of 13.5, 4.9, and 2.8 km^2, respectively. The discrepancy is attributed to the ambient salinity structure of the water column encountered on this date. The vertical profile at station 39, Figure 2-16, shows that the water column was isohaline (23.5 o/oo) from the surface to a depth of 9.2 m. The salinity increased to 34.0 o/oo at the 19.6 m depth, and it was isohaline from that depth to the bottom. The other vertical profiles show a similar strong halocline in the bottom waters. The vertical extent of the brine jet was predicted to be 7.3 m above the bottom using the vertical extent equation developed in a

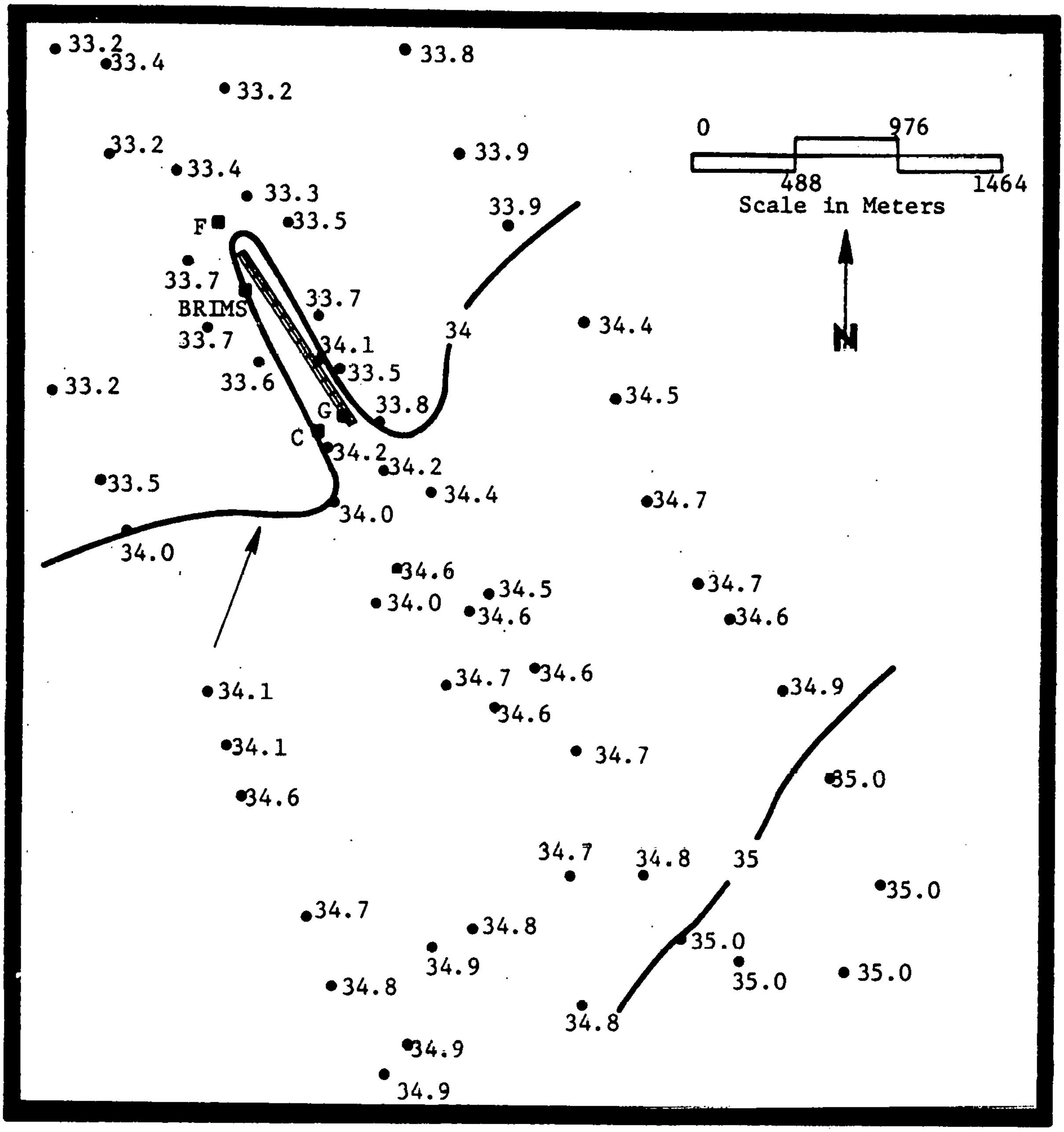


Figure 2-15. Brine plume isohaline contours for July 21, 1983. The average brine discharge rate, salinity, temperature, and the ambient bottom salinity at station 39 were 44,237 barrels/hr, 241 o/oo, 28°C, and 34.0 o/oo. The average bottom current was 18 cm/s in the direction of 20°T as indicated by the arrow.

previous report, Randall and McLellan (1983). As a result, the brine jets should have reached a depth of 14.3 m where the salinity was 28.0 o/oo at station 39 and an average value of 29.7 o/oo at the vertical profile stations. Therefore, the brine jets were discharging brine into water which was as much as 4.4 o/oo less than the bottom salinity. The empirical equations assume the ambient water is isohaline. It is concluded that the cause of the inability to measure closed isohaline contours on this date was the unusually strong halocline in the bottom receiving waters.

The vertical salinity profiles illustrated in Figure 2-16 show the bottom salinity at all stations was near 34.0 o/oo. Station 1 was used as the ambient profile, and only stations 4 and 5 showed slight increases in salinity in the bottom water. Thus, the vertical extent was very difficult to determine, and the values at stations 4 and 5 were 4.8 and 3.0 m, respectively.

2.3.5 August 11, 1983

On August 11, 1983, the brine was being discharged at an average rate of 38,306 barrels/hr, a brine salinity of 251 o/oo, and a temperature of 29°C. The average bottom current was 8 cm/s in the direction of 086°T. The bottom salinity at stations 39A, 39, and 39B was 34.2, 34.0, and 34.1 o/oo, and therefore, an ambient salinity of 34.1 o/oo was selected.

The areal extent of the plume measured on August 11, 1983 was the largest measured during the period of this annual report. The isohaline contours are shown in Figure 2-17, and the above ambient salinity contours are illustrated in Figure 2-18. The area inside the 35, 36, 37, and 38 o/oo isohaline contours was 44.4, 23.2, 2.2, and 0.6 km^2, respectively.

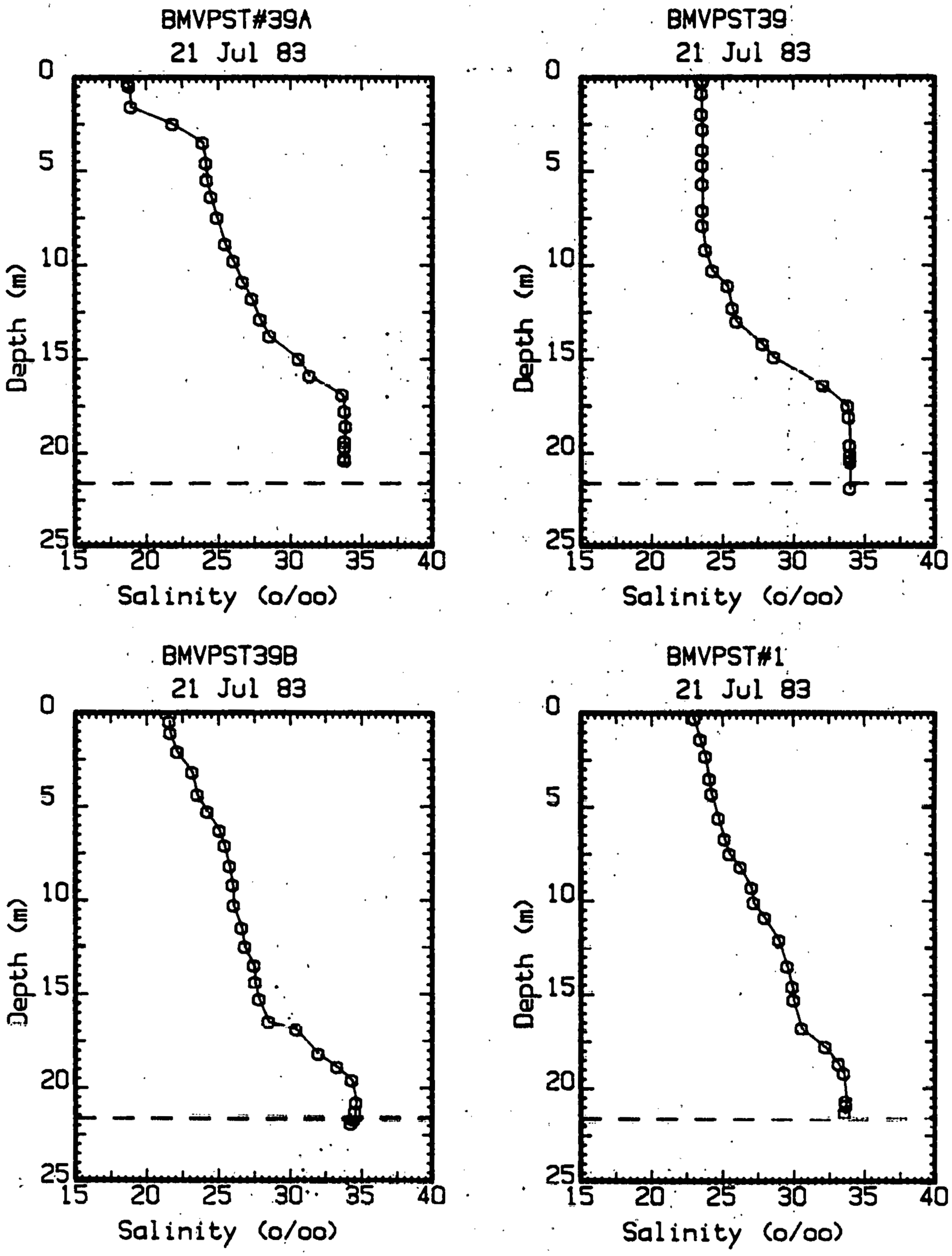


Figure 2-16. Vertical salinity profiles for July 21, 1983. The dashed line indicates the depth (21.6 m) of the natural sea floor.

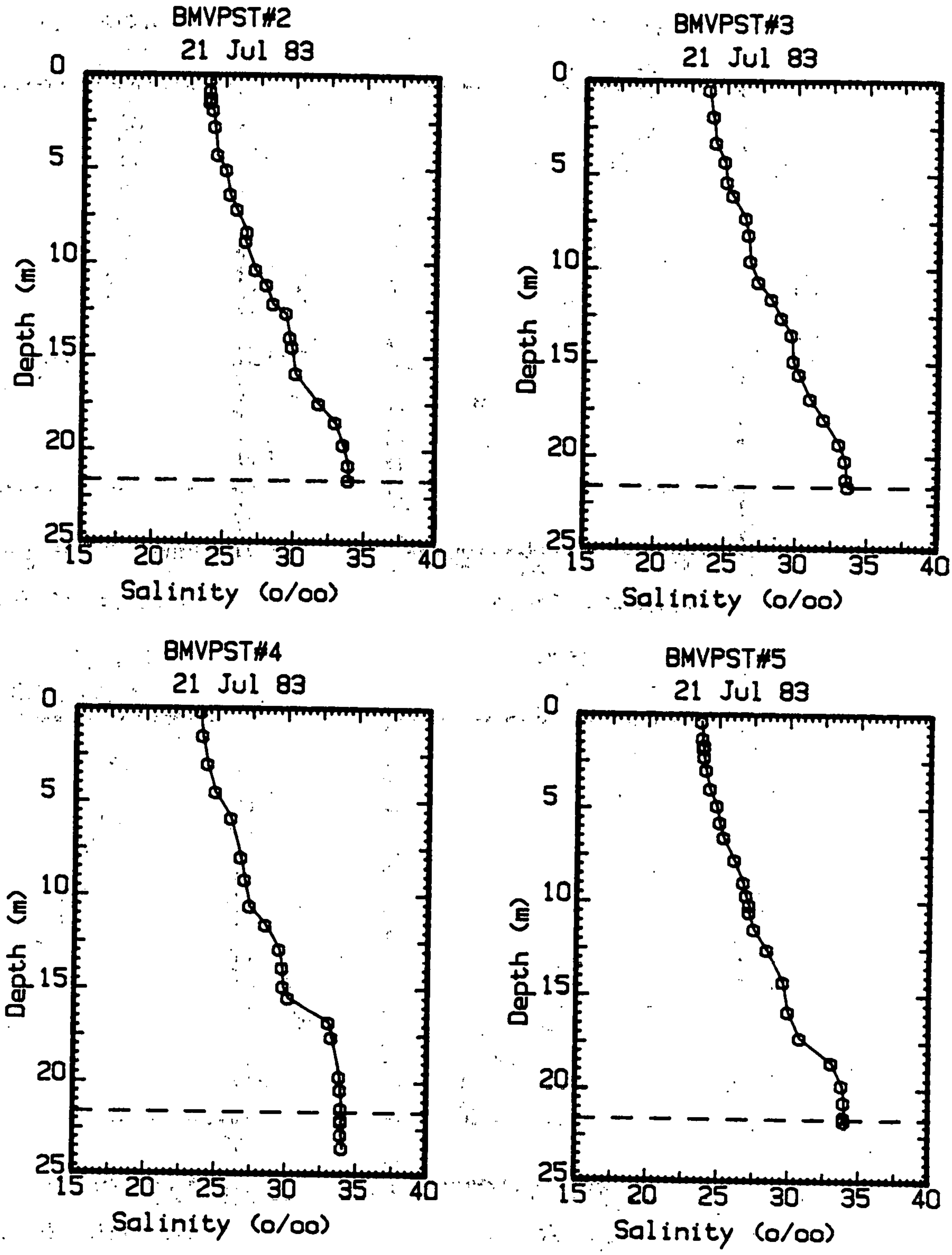


Figure 2-16. Continued.

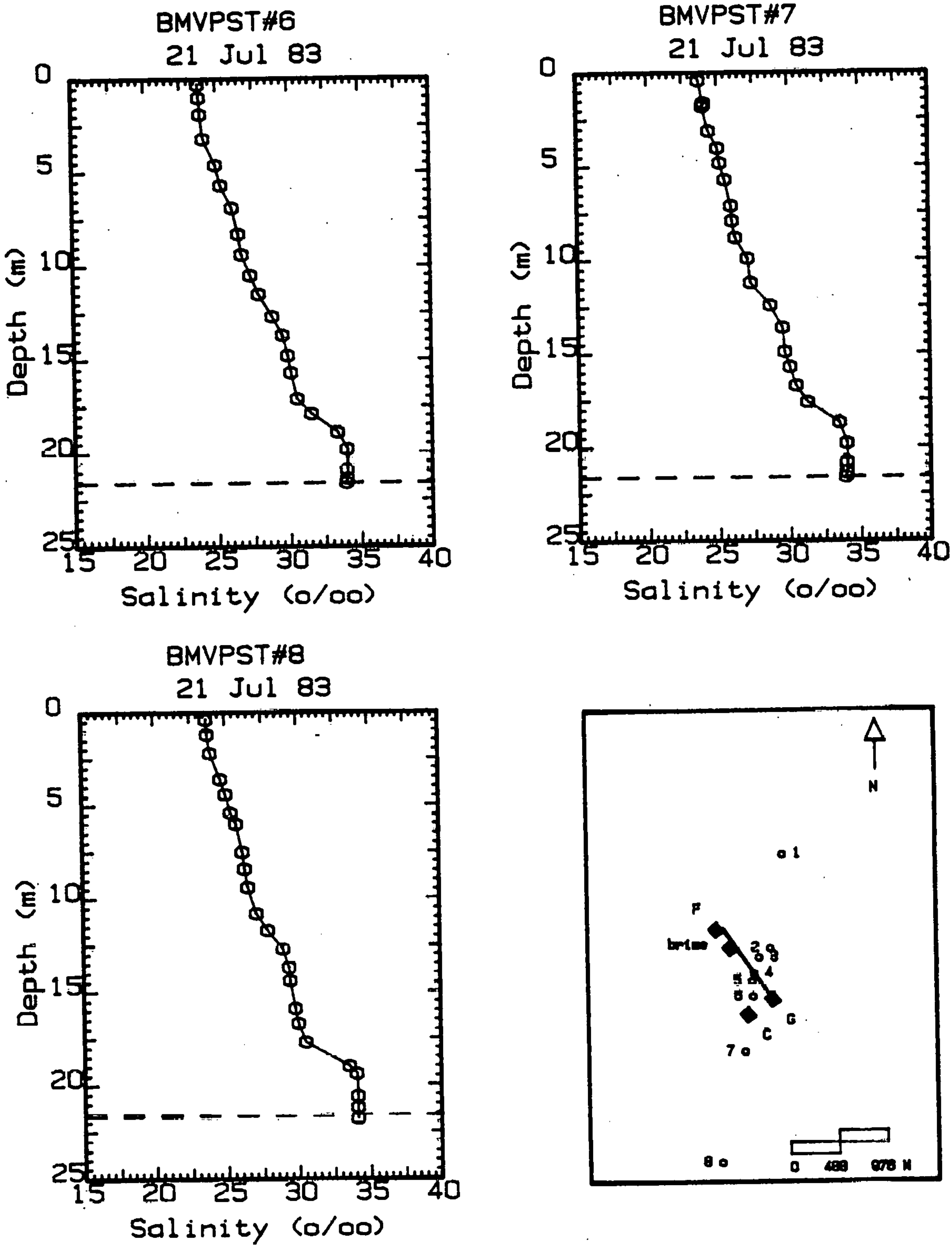


Figure 2-16. Continued.

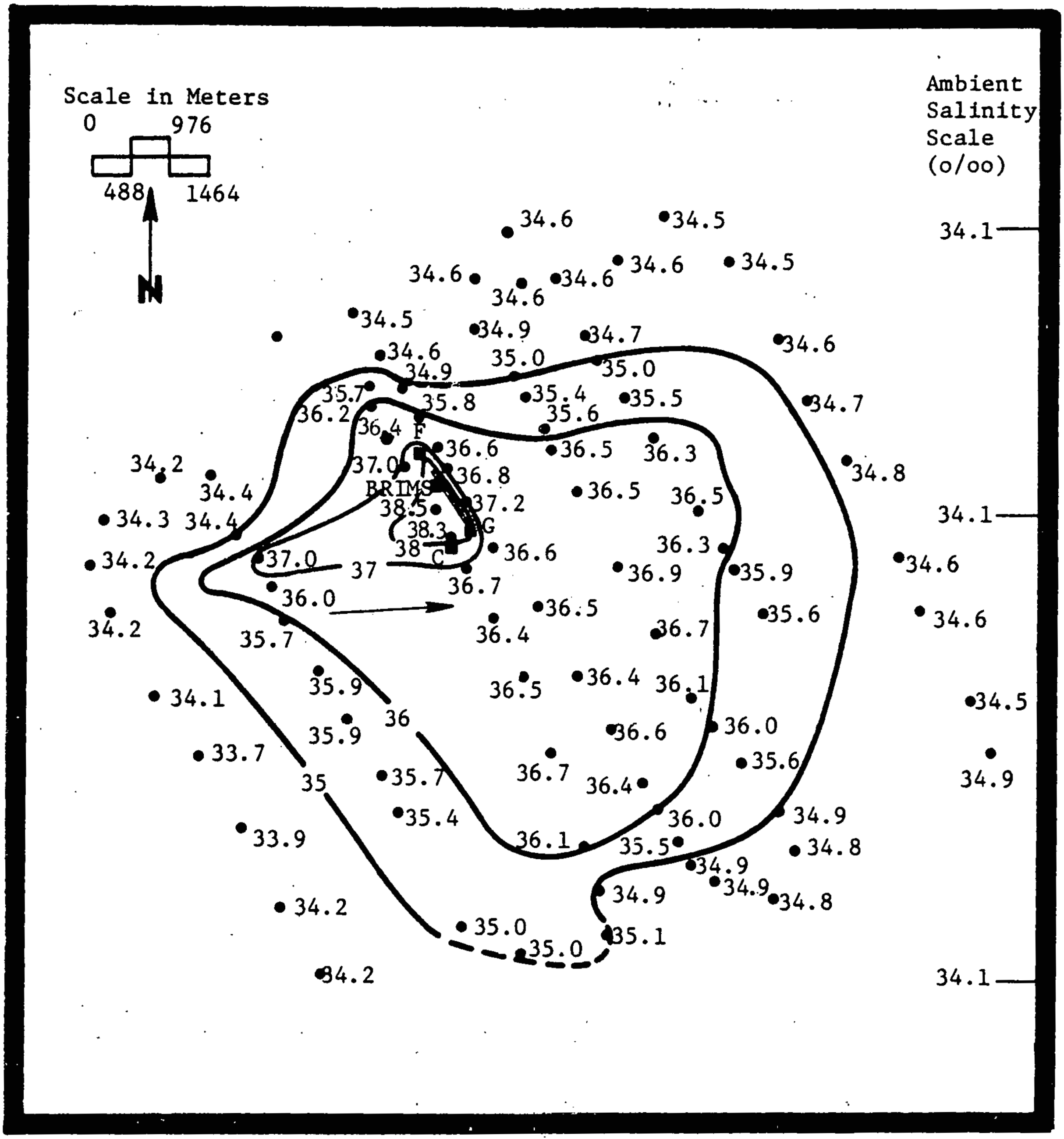


Figure 2-17. Brine plume isohaline contours for August 11, 1983. The average brine discharge rate, salinity, temperature, and the ambient bottom salinity at station 39 were 38,306 barrels/hr, 251 o/oo, 29°C, and 34.0 o/oo. The average bottom current was 8 cm/s in the direction of 86°T as indicated by the arrow.

Inside the +1, +2, +3, and +4 above ambient salinity contours, the areas were 40.0, 20.9, 1.9, and 0.5 km^2, respectively. The +1 o/oo contour extended 1.6 km upcoast (055°T) and 3.4 km downcoast (235°T) from the diffuser center. In the offshore (145°T) and inshore (325°T) directions, the +1 o/oo contour reached distances of 2.1 and 5.4 km, respectively. The maximum distance to the +1 o/oo contour was 5.5 km in the direction 086°T which was the same as the average current direction. The large areal extent was caused by a combination of low bottom current, near isohaline structure of the lower third of the water column in all directions, and the low brine exit velocity.

The salinity data were collected over a period of 12 hours from 1030 to 2230 hours. The bottom temperature data varied between 25.6 to 26.9°C and again did not show an indication of a thermal plume.

The vertical salinity profiles measured on August 11, 1983 are illustrated in Figure 2-19. The vertical profiles at station 39A, 39, and 39B were very similar. At station 39, the surface salinity was 29.4 o/oo which was nearly isohaline down to a depth of 7.2 m. Salinity increased to 34.0 o/oo at 18.6 m and was isohaline from that depth to the bottom. Station 1 was located 1.2 km west of the diffuser center, and the presence of the brine plume is indicated by the 37.1 o/oo bottom salinity. The vertical extent was determined by comparison with the station 39 profile, and this showed the vertical extent was 5.3 m. Stations 2, 3, and 4 were in the immediate vicinity of the diffuser, and the bottom salinity and vertical extent were 38.5, 37.5, and 38.0 o/oo and 5.2, 5.6, and 5.6 m, respectively. Station 5 was 1 km east of the diffuser, and the bottom salinity and vertical extent was 37.3 o/oo and 5.6 m, respectively. The vertical extents were the highest measured for this annual report period.

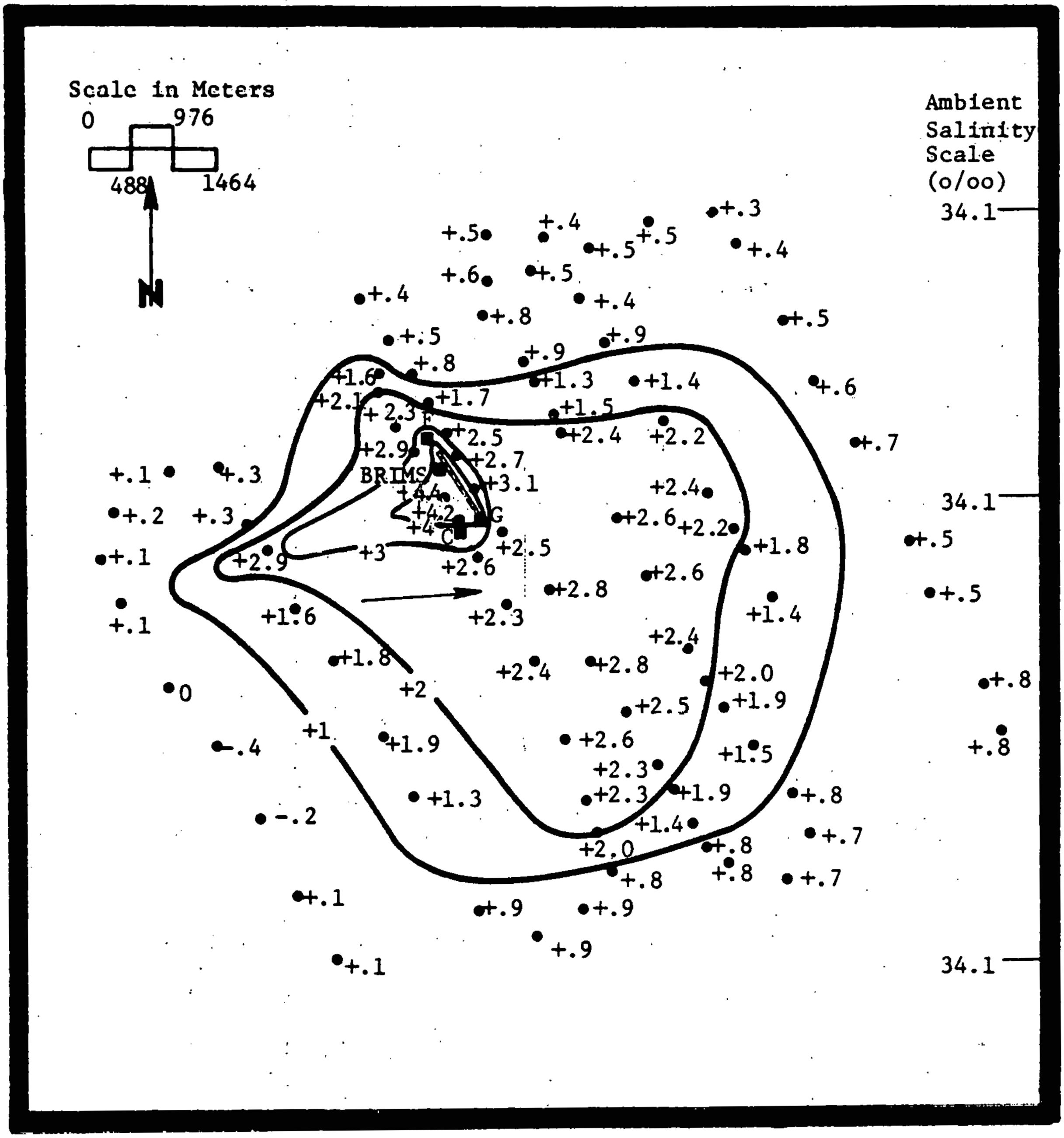


Figure 2-18. Brine plume above ambient salinity contours for August 11, 1983. The average brine discharge rate, salinity, temperature, and the ambient bottom salinity at station 39 were 38,306 barrels/hr, 251 o/oo, 29°C, and 34.0 o/oo. The average bottom current was 8 cm/s in the direction of 86°T as indicated by the arrow.

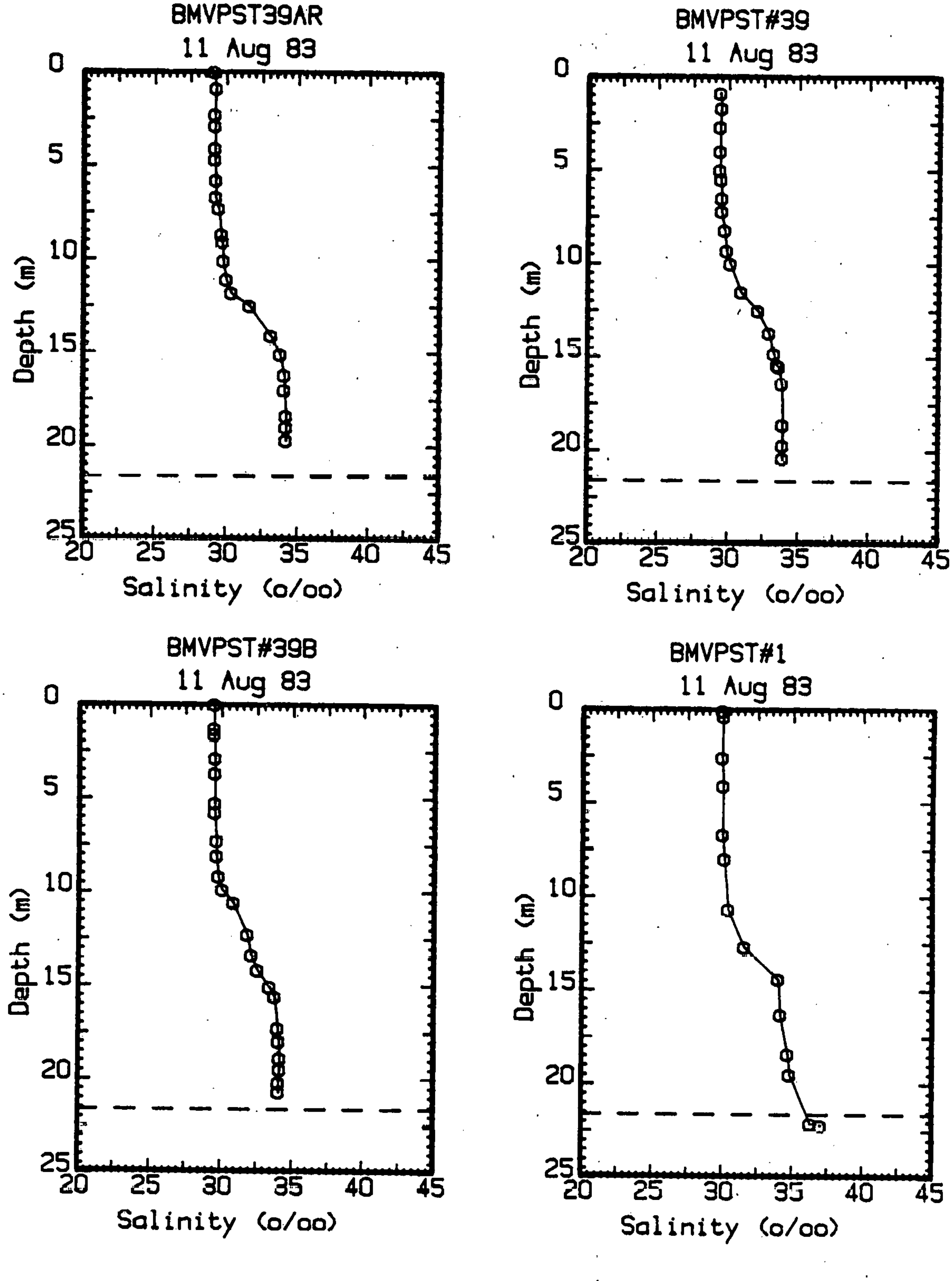


Figure 2-19. Vertical salinity profiles for August 11, 1983. The dashed line indicates the depth (21.6 m) of the natural sea floor.

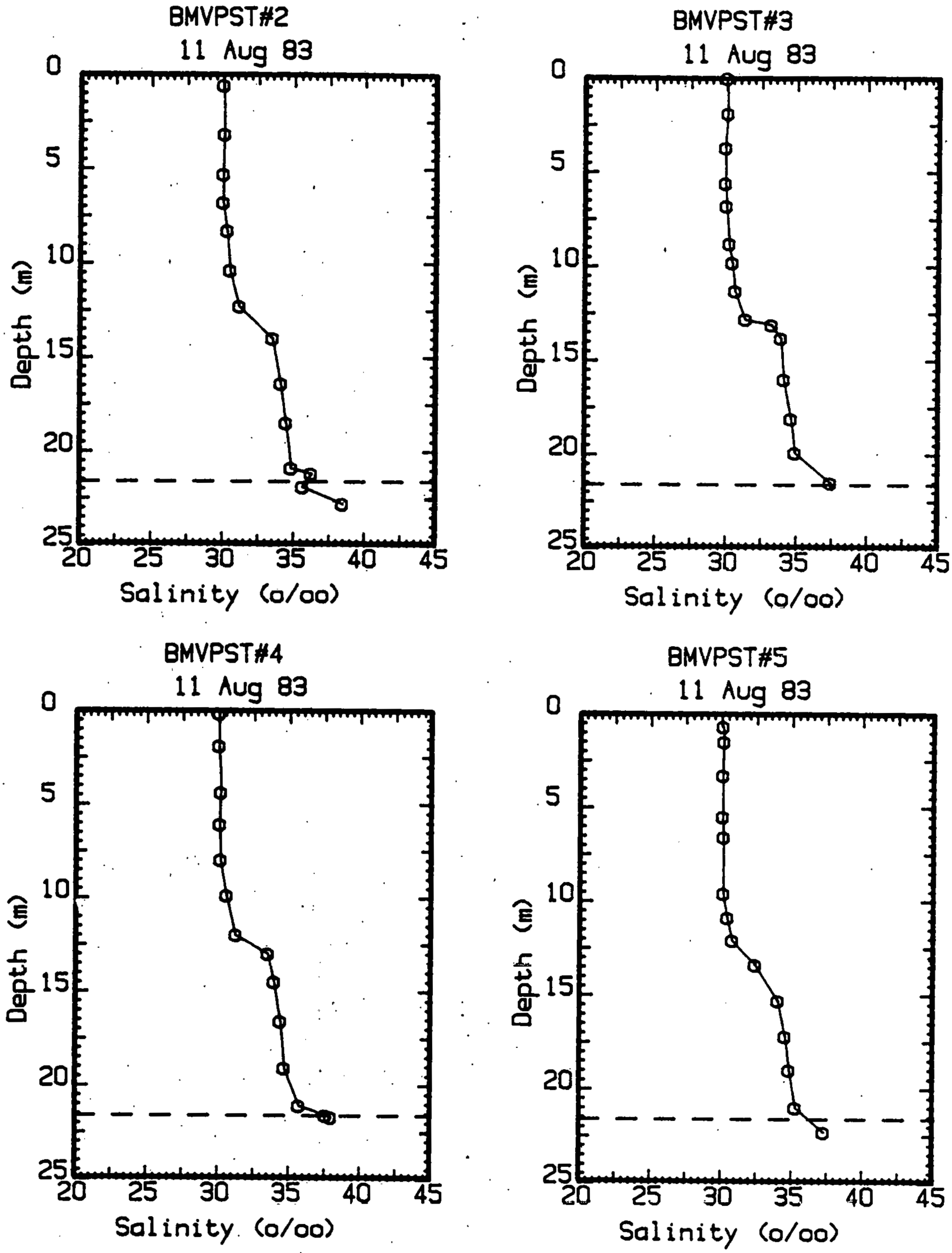
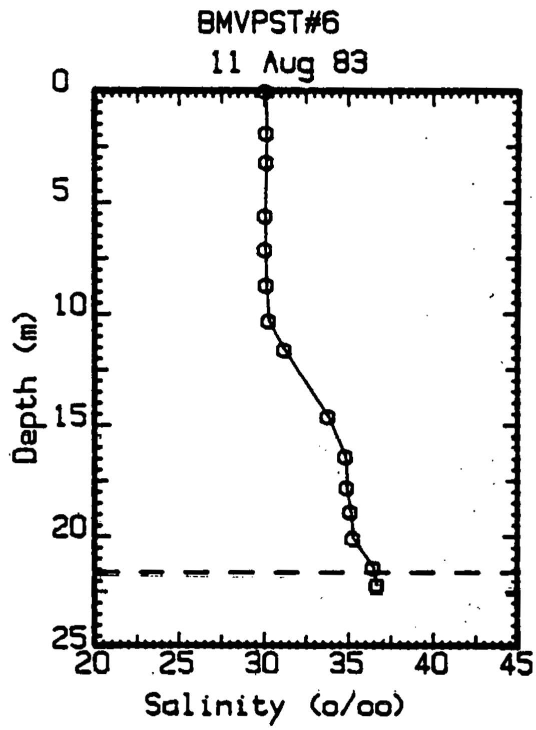


Figure 2-19. Continued.



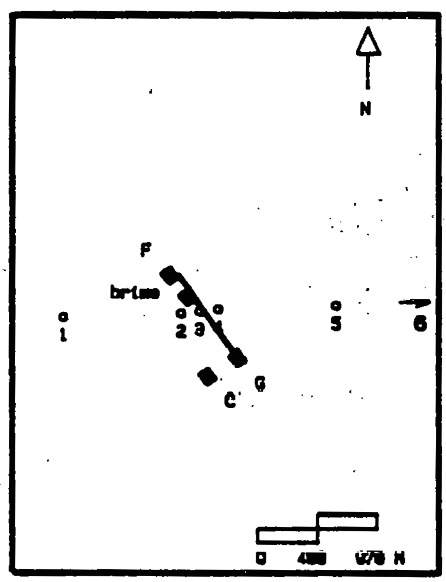


Figure 2-19. Continued.

2.4 History of the Brine Plume Areal and Vertical Extent Measurements

A history of the areal extent data determined from the plume measurements conducted during the 42 months of brine discharge are tabulated in Table 2-1. This table shows the average bottom current speed and direction for the plume tracking period, the daily average brine salinity, the average brine discharge rate and the bottom salinity at station 39 which is 7.4 km northeast of the diffuser and on the same depth contour, and the area within the isohaline and above ambient salinity contours.

Table 2-1 shows the largest areal extent within the +1, +2, +3, +4, +5, and +6 o/oo above ambient salinty contours was 50.4 km^2 on 1/24/82, 24.5 km^2 on 1/24/82, 9.3 km^2 on 1/24/82, 5.6 km^2 on 2/25/81, 1.2 km^2 on 2/25/81, and 0.1 km^2 on 11/5/81 respectively. The highest measured above ambient salinity contour was 41.6 o/oo which was +6 o/oo above the ambient salinity of 35.6 o/oo on April 20, 1981. During the 42 months of discharge, a +6 o/oo above ambient contour was found on only two occasions (April 20 and November 5, 1981), and +5 o/oo above ambient contours were found on eleven occasions which were 6/13/80, 10/1/80, 12/29/80, 2/25/81, 3/30/81, 4/20/81, 6/25/81, 10/9/81, 11/5/81, 4/25/82, and 9/16/82. The largest areal extent within the +1, +2, +3, +4, and +5 o/oo above ambient contour during the present reporting period was 40.0 km^2 on August 11, 1983, 20.9 km^2 on August 11, 1983, 6.3 km^2 on September 16, 1983, 0.5 km^2 on August 11, 1983, and 0.1 km^2 on September 16, 1982. It should be noted that the +5 o/oo above ambient salinity contour was measured only once during this reporting period, and this is mainly attributed to the high exit velocities at the diffuser ports.

Table 2-1. History of brine plume areal extent data.

Date	Average Bottom Current		Average Brine Pit Salinity	Discharge Rate	Station 39 Bottom Salinity	Areal Extent			
	Speed cm/s	Direction °True	o/oo	Barrels/hr	o/oo	Salinity Contours o/oo	Area km^2	Above Amb. Sal. Cntrs. o/oo	Area km^2
3/22/80	14	200	225	8,125	33.2	35	0.7	+2	0.6
						36	0.4	+3	0.3
3/26/80	17	216	226	9,840	31.9	No Closed Contours			
3/30/80	25	026	229	8,647	32.7	34	0.7	+1	1.1
						35	0.3	+2	0.3
								+3	0.1
3/31/80	16	102	237	8,436	32.8	34	0.5	+1	0.6
						35	0.1	+2	0.2
4/9/80	3	102	247	12,004	34.1	36	5.8	+2	5.3
						37	0.8	+3	0.6
						38	0.1		
4/10/80	13	041	247	12,015	33.3	35	7.4	+2	5.6
						36	2.0	+3	1.0
						37	0.1	+4	0.1
						38	0.02		
5/22/80	9	004	245	12,183	32.0	33	2.7	+1	2.7
						34	0.9	+2	0.9
						35	0.3	+3	0.3
6/13/80	3	160	242	11,386	32.8	34	4.3	+1	4.8
						35	2.1	+2	2.3
						36	1.2	+3	1.3
						37	0.7	+4	0.9
						38	0.2	+5	0.2
7/21/80	11	252	147	18,455	35.0	36	5.6	+1	5.6
7/30/80	13	042	131	21,790	35.8	37	0.3	+1	0.8
8/1/80	4	017	129	27,436	35.5	37	2.6	+1	6.0
								+2	0.4
8/2/80	13	023	163	25.520	35.5	37	7.4	+1	13.1
						38	0.4	+2	3.2
								+3	0.02

Table 2-1. Continued.

Date	Average Bottom Current		Average Brine Pit Salinity	Discharge Rate	Station 39 Bottom Salinity	Areal Extent			
	Speed cm/s	Direction °True	o/oo	Barrels/hr	o/oo	Salinity Contours o/oo	Area km²	Above Amb. Sal. Cntrs. o/oo	Area km²
8/26/80	27	206	216	26,370	34.4	35	6.4	+1	3.5
						36	1.6	+2	0.7
						37	0.4	+3	0.2
9/10/80	13	027	218	21,282	33.7	35	2.3	+1	2.6
						36	0.4	+2	0.8
						37	0.1	+3	0.2
10/1/80	8	029	228	20,415	33.5	35	9.2	+1	10.9
						36	6.7	+2	6.9
						37	3.3	+3	4.4
						38	1.7	+4	2.3
								+5	0.9
10/22/80	15	051	205	28,047	33.2	34	9.2	+1	5.3
						35	2.5	+2	1.4
						36	0.2	+3	0.1
11/6/80	20	025	221	27,738	34.5	36	17.6	+1	
						37	5.5	+2	11.9
						38	0.8	+3	2.3
12/29/80	14	239	250	26,124	34.5	36	12.9	+1	17.9
						37	9.8	+2	10.1
						38	3.0	+3	5.5
						39	1.3	+4	1.9
						40	0.3	+5	0.7
1/28/81	8	227	247	22,320	34.6	36	14.5	+1	17.5
						37	8.1	+2	9.3
						38	2.4	+3	4.4
						39	0.6	+4	1.5
2/25/81	7	023	252	28,188	36.2	37	16.2	+1	15.4
						38	11.7	+2	10.8
						39	8.0	+3	7.7
						40	6.1	+4	5.6
						41	1.6	+5	1.2
3/30/81	15	233	256	27,792	35.1	36	11.6	+1	11.0
						37	5.9	+2	5.4
						38	1.4	+3	1.1
						39	0.4	+4	0.3
						40	0.04	+5	0.04

Table 2-1. Continued.

Date	Average Bottom Current		Average Brine Pit Salinity	Discharge Rate	Station 39 Bottom Salinity	Areal Extent			
	Speed cm/s	Direction °True	o/oo	Barrels/hr	o/oo	Salinity Contours o/oo	Area km^2	Above Amb. Sal. Cntrs. o/oo	Area km^2
4/20/81	18	017	258	28,260	35.6	36	17.0	+1	9.4
						37	7.3	+2	4.6
						38	3.4	+3	1.2
						39	1.1	+4	0.5
						40	0.3	+5	0.3
						41	0.2	+6	0.04
						42	0.05		
5/27/81	36	002	No Data	No Data	35.2	36	14.3	+1	12.5
						37	8.6	+2	7.1
						38	3.7	+3	3.2
						39	1.1	+4	0.5
6/25/81	9	202	249	25,283	35.6	36	19.1	+1	11.6
						37	9.4	+2	6.6
						38	5.8	+3	2.4
						39	0.7	+4	0.2
						40	0.04	+5	0.03
						41	0.02		
8/3/81	15	018	269	26,730	36.2	37	9.9	+1	8.6
						38	5.8	+2	5.0
						39	1.5	+3	0.9
						40	0.4	+4	0.2
8/27/81	21	205	257	25,986	33.2	34	4.9	+1	3.9
						35	1.4	+2	1.1
						36	0.3	+3	0.2
9/15/81	22	003	258	27,315	35.2	36	4.9	+1	3.7
						37	2.3	+2	1.8
						38	0.2	+3	0.1
10/9/81	18	047	263	26,544	34.4	35	17.1	+1	13.2
						36	9.6	+2	7.8
						37	5.1	+3	4.0
						38	3.3	+4	2.0
						39	1.1	+5	0.7
11/5/81	20	240	258	29,976	34.2	35	6.8	+1	4.6
						36	2.1	+2	1.5
						37	0.6	+3	0.4
						38	0.3	+4	0.3
						39	0.2	+5	0.1
						40	0.1	+6	0.1

Table 2-1. Continued.

Date	Average Bottom Current		Average Brine Pit Salinity	Discharge Rate	Station 39 Bottom Salinity	Areal Extent			
	Speed cm/s	Direction °True	o/oo	Barrels/hr	o/oo	Salinity Contours o/oo	Area km^2	Above Amb. Sal. Cntrs. o/oo	Area km^2
1/2/82	13	218	245	27,404	34.5	35	26.2	+1	14.2
						36	5.1	+2	2.2
						37	1.4	+3	0.7
1/24/82	16	204	263	38,851	35.0	36	50.4	+1	50.4
						37	24.5	+2	24.5
						38	9.3	+3	9.3
2/22/82	3	162	203	38,182	35.9	37	20.5	+1	22.9
						38	3.2	+2	3.8
3/31/82	23	239	241	41,590	32.2	33	11.0	+1	9.2
						34	4.0	+2	2.8
						35	0.7	+3	0.4
4/25/82	6	244	256	34,401	33.8	35	12.5	+1	14.3
						36	6.8	+2	7.8
						37	2.4	+3	1.9
						38	0.9	+4	1.0
						39	0.2	+5	0.3
5/10/82	13	156	255	41,863	32.8	35	0.9	+1	7.1
								+2	1.3
6/8/82	13	016	257	36,142	36.3	37	40.3	+1	34.7
						38	19.1	+2	15.0
						39	2.8	+3	1.1
7/15/82	17	233	240	41,883	36.0	37	8.6	+1	8.6
						38	0.4	+2	0.4
8/23/82	11	035	256	41,289	35.6	37	29.9	+1	36.1
						38	11.4	+2	16.9
						39	5.7	+3	7.8
						40	1.0	+4	2.9
9/16/82	12	040	255	41,046	34.7	35	41.0	+1	29.3
						36	26.0	+2	17.7
						37	14.4	+3	6.3
						38	3.5	+4	0.2
						39	0.1		
10/14/82	9	238	255	40,683	33.3	34	13.7	+1	11.5
						35	5.0	+2	2.8
						36	1.2	+3	0.7

Table 2-1. Continued.

Date	Average Bottom Current		Average Brine Pit Salinity	Discharge Rate	Station 39 Bottom Salinity	Areal Extent			
	Speed cm/s	Direction °True	o/oo	Barrels/hr	o/oo	Salinity Contours o/oo	Area km²	Above Amb. Sal. Cntrs. o/oo	Area km²
11/1/82	11	209	254	41,555	34.9	36	5.1	+1	5.1
						37	1.6	+2	2.0
						38	0.6	+3	0.7
12/4/82	13	212	261	41,600	34.3	35	12.7	+1	10.2
						36	6.3	+2	1.3
						37	0.3	+3	0.1
1/11/83	16	037	249	42,208	34.6	36	22.8	+1	33.3
						37	3.4	+2	15.9
						38	0.7	+3	2.0
2/17/83	13	035	232	25,742	32.8	34	6.8	+1	19.5
						35	2.9	+2	6.3
						36	0.2	+3	2.6
						37	0.1	+4	0.1
3/9/83	14	023	225	41,871	34.0	35	0.3	+1	0.3
						36	0.1	+2	0.1
4/10/83	19	022	254	41,023	33.4	35	0.1	+1	5.0
5/4/83	6	015	258	41,813	31.5	32	11.9	+1	9.9
						33	6.7	+2	5.4
						34	3.2	+3	1.7
						35	0.7	+4	0.1
6/8/83	7	177	251	34,161	34.2	35	19.2	+1	14.8
						36	9.1	+2	5.8
						37	1.2	+3	0.8
7/21/83	18	020	241	44,237	34.0	No Closed Contours			
8/11/83	8	086	251	38,306	34.0	35	44.4	+1	40.0
						36	23.2	+2	20.9
						37	2.2	+3	1.9
						38	0.6	+4	0.5

The distribution of the measured areal extent within the +1, +2, +3 and +4 o/oo above ambient salinity contours for the entire postdisposal period is shown in Figure 2-20. The data for the +1 o/oo contour shows the most frequent areal extent was between 5 and 6 km^2. There were four observations in this range out of a total of 44 observations which corresponds to 9.1% relative frequency. In the range of 5 to 20 km^2, a total of 26 measured areas were observed for a relative frequency of 59.1%. The mean areal extent of the +1 o/oo contours is 12.8 km^2. It must be noted that these statistics consider all the data and that the brine discharge rates have changed during the period of these observations. The increases in the discharge rate have tended to increase the areal extent during the last two years. Thus, the mean values are expected to be lower than those obtained using data only after the discharge rate was near one million barrels/day.

The +2 o/oo above ambient salinity contour data show the largest number of observations were for areas in the range of 0.0 to 0.5 km^2. In this range, there were five observations out of a total of 45 for a relative frequency of 11%. Between 0.0 and 8.0 km^2, a total of 35 observations occurred for a relative frequency of 77.8%. The mean areal extent was 5.9 km^2.

The mean areal extent for the +3 and +4 o/oo above ambient contours was 2.0 and 1.3 km^2, respectively. There were a total of 39 and 16 observations for the +3 and +4 o/oo contours. Figure 2-20 shows the largest number of observations, 12, in the range of 0.0 to 0.5 km^2 for a 31% relative frequency for the +3 o/oo contour, and in the case of the +4 o/oo contour, there were 5 observations in the range of 0.2 to 0.4 km^2 for a relative frequency of 31%. The area range of 0.0 to 4.0 km^2

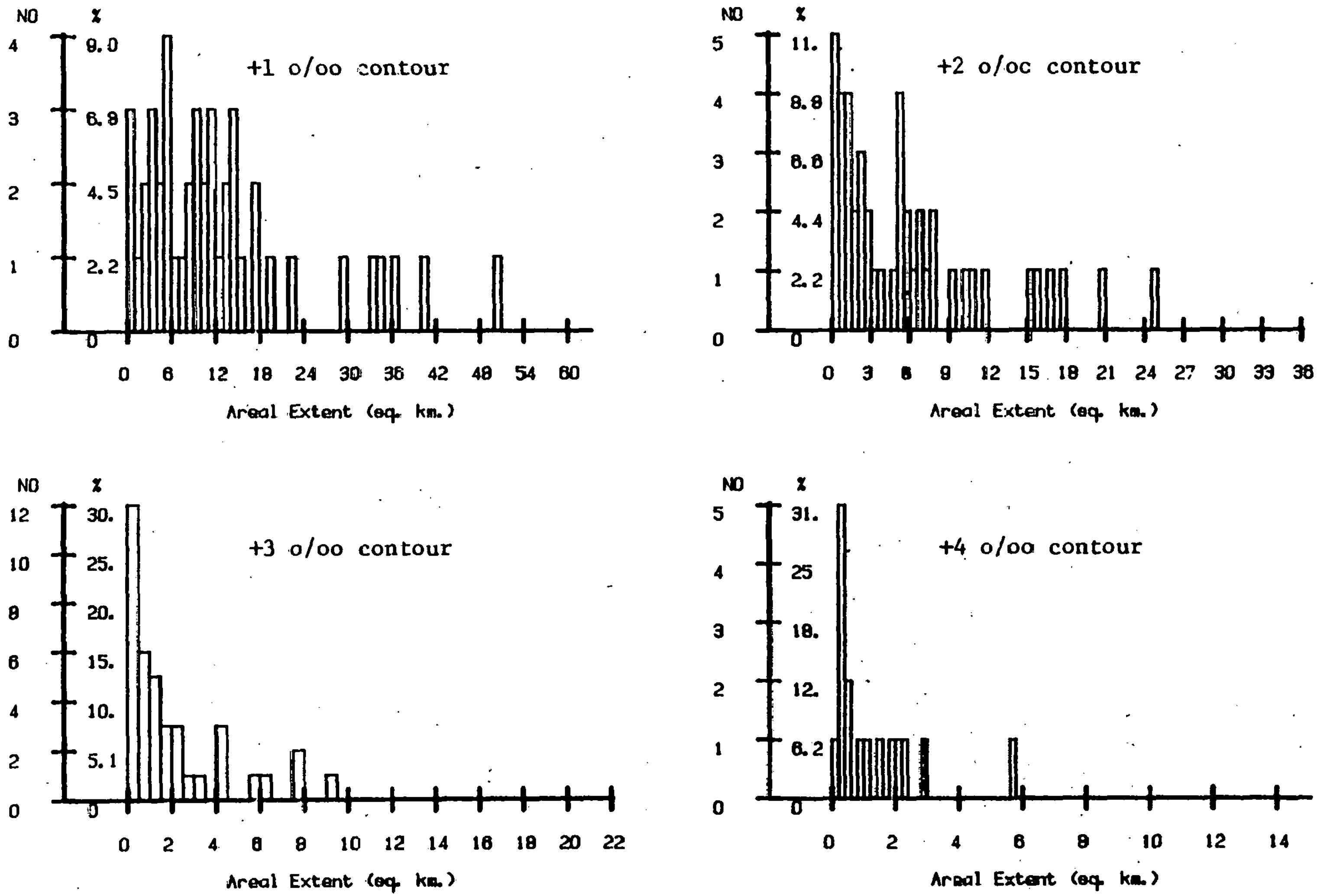


Figure 2-20. Distribution of measured areal extent within above ambient salinity contours for the entire postdisposal period (March 1980 through August 1983). NO is the number of observations and % is the percent relative frequency.

accounted for 31 observations for a relative frequency of 79% in the case of the +3 o/oo contour. For the +4 o/oo contour, the range of 0.0 to 2.0 km^2 accounted for 12 observations for a relative frequency of 75%.

Table 2-2 shows a summary of the maximum measured distances from the center of the diffuser to the above ambient salinity contours which were measured during the entire postdisposal period. It shows the longest distances inshore, offshore, upcoast, downcoast, and the magnitude and direction of the longest distance. The longest distance to the +1 o/oo above ambient contour was 10.5 km from the diffuser in the direction of 159°T or southsoutheast of the diffuser. The longest distance to the +2, +3, +4, +5, and +6 o/oo contours was 7.3, 4.2, 2.9, 1.2, and 0.3 km, respectively. The longest inshore and offshore distance to the +1 o/oo above ambient contour was 3.0 and 10.1 km. In the upcoast and downcoast direction, the longest distance to the +1 o/oo above ambient contour was 6.2 and 3.9 km, respectively. Measurements during this reporting period resulted in the longest upcoast distance to the +1, +2 and +3 contours.

A summary of the measured vertical extent of the brine plume and predicted vertical height of the brine jets is tabulated in Table 2-3. These data were compiled from the vertical salinity profiles measured as near directly over the diffuser as possible during the plume tracks for the entire postdisposal period. For the entire postdisposal period, the measured plume vertical extent ranged between 1.6 and 7.6 m, and the average was 3.8 m. During the period of this annual report, the measured brine vertical extent ranged between 2.0 and 5.6 m with an average of 3.4 m. The profiles measured from March 1980 through August 1982 are illustrated in Randall (1982), Randall and McLellan (1983), and in Appendix B of this report for the period September 1982 through August

Table 2-2. History of the maximum measured distances from the center of the diffuser to the above ambient salinity contours and the largest measured areas inside the above ambient contours.

Contour	Longest Dist. Inshore (325°) km	Longest Dist. Upcoast (055°) km	Longest Dist. Offshore (145°) km	Longest Dist. Downcoast (235°) km	Longest Distance Magnitude km	Longest Distance Direction °T	Maximum Area km^2
+1	3.0 (6/8/82)	6.2 (1/11/83)	10.1 (1/24/82)	3.9 (2/22/82)	10.5 (1/24/82)	159	50.4 (1/24/82)
+2	2.4 (8/3/81)	3.5 (9/16/82)	7.1 (1/24/82)	3.0 (8/23/82) (1/24/82)	7.3 (1/24/82)	154	24.5 (1/24/82)
+3	2.1 (8/23/82)	2.9 (9/16/82)	4.1 (1/24/82)	1.5 (12/29/80)	4.2 (1/24/82)	137	9.3 (1/24/82)
+4	1.0 (2/25/81)	1.8 (2/25/81)	2.8 (1/24/82)	0.7 (12/29/80)	2.9 (1/24/82) (12/29/80)	154 178	5.6 (2/25/81)
+5	0.4 (11/5/81) (12/29/80)	1.1 (10/1/80)	0.6 (12/29/80)	0.3 (10/9/81)	1.2 (10/1/80)	60	1.2 (2/25/81)
+6	0.3 (4/20/81) (11/5/81)	0.1 (4/20/81) (11/5/81)	0.3 (4/20/81) (11/5/81)	0.1 (4/20/81) (11/5/81)	0.3 (4/20/81) (11/5/81)	325 145	0.1 (4/20/81) (11/5/81)

Table 2-3. History of the measured vertical extent of the brine plume and the predicted vertical extent of the brine jets.

Date	Measured Plume Vertical Extent	Predicted Vertical Extent of Brine Jet Equation 2-1		Average Brine Discharge		Average Brine Exit Velocity	Average Ambient Bottom Current
		C = 2.2	C = 1.7	Rate	Salinity		
Month/Day/Year	m	m	m	Barrels/hr	o/oo	m/s	cm/s
3/22/80	No data	3.9	3.3	8125	225	5.3	14
3/26/80	No data	4.4	3.7	9480	226	6.4	17
3/30/80	3.6	4.0	3.4	8647	229	5.6	25
3/31/80	3.6	3.9	3.3	8436	237	5.5	16
4/09/80	2.6	5.0	4.1	12004	247	7.8	3
4/10/80	4.6	5.0	4.1	12015	247	7.8	13
5/22/80	4.3	5.0	4.1	12183	245	7.9	9
6/13/80	3.6	4.8	4.0	11386	242	7.4	3
7/21/80	2.6	5.0	4.2	18455	147	5.8	11
7/30/80		6.1	5.0	21790	131	6.8	13
8/01/80	1.6	7.4	6.0	27436	129	9.8	4
8/02/80	5.6	6.2	5.1	25520	163	8.0	13
8/26/80	7.6	5.5	4.5	26370	216	8.2	27
9/10/80	5.6	4.6	3.9	21282	218	6.7	13
10/01/80	3.6	4.4	3.7	20415	228	6.4	8
10/22/80	5.6	5.9	4.8	28047	205	8.8	15
11/06/80	5.6	5.7	4.7	27738	221	8.7	20
12/29/80	3.6	5.1	4.2	26124	250	8.2	14
1/28/81	5.6	4.6	3.8	22320	247	7.0	8
2/25/81	5.6	5.4	4.5	28188	252	8.8	7
3/30/81	4.8	5.3	4.4	27792	256	8.7	15
4/20/81	3.6	5.4	4.4	28260	258	8.8	18
5/27/81	4.0			No Data			36
6/25/81	7.2	5.0	4.1	25283	249	7.9	9
8/03/81	5.4	5.2	4.3	26780	254	8.4	15
8/27/81	5.2	4.7	3.9	25986	257	7.4	21

Table 2-3. Continued.

Date	Measured Plume Vertical Extent	Predicted Vertical Extent of Brine Jet, Equation 2-1		Average Brine Discharge		Average Brine Exit Velocity	Average Ambient Bottom Current
		C = 2.2	C = 1.7	Rate	Salinity		
Month/Day/Year	m	m	m	Barrels/hr	o/oo	m/s	cm/s
9/15/81	3.0	4.9	4.0	27315	258	7.8	22
10/09/81	1.8	4.7	3.9	26544	263	7.6	18
11/05/81	2.3	5.2	4.3	29976	258	8.5	20
1/02/82	2.3	5.0	4.2	27404	245	7.8	13
1/24/82	2.6	6.4	5.2	38851	263	11.1	16
2/22/82	3.0	7.2	5.8	38182	203	10.9	3
3/31/82	3.5	7.0	5.7	41590	243	11.8	23
4/25/82	2.4	5.8	4.8	34401	256	9.8	6
5/10/82	3.8	6.8	5.6	41863	255	11.9	13
6/08/82	3.0	6.1	5.0	36142	257	10.3	13
7/15/82	1.7	7.1	5.7	41882	240	11.9	17
8/23/82	4.0	6.7	5.5	41288	256	11.8	11
9/16/82	4.5	6.7	5.5	41046	255	11.7	12
10/14/82	3.5	6.7	5.4	40683	255	11.6	9
11/01/82	2.4	6.8	5.5	41555	254	11.8	11
12/04/82	2.5	6.7	5.5	41600	261	11.8	13
1/11/83	2.6	7.0	5.7	42208	249	12.0	16
2/17/83	3.1	4.9	4.1	25742	232	7.3	13
3/09/83	4.4	7.3	5.9	41871	225	11.9	14
4/10/83	3.4	6.8	5.5	41023	254	11.7	19
5/04/83	2.0	6.8	5.5	41813	258	11.9	6
6/08/83	2.3	5.8	4.8	34161	251	9.7	7
7/21/83	4.8	7.3	6.0	44237	241	12.6	18
8/11/83	5.6	6.4	5.2	38306	251	10.9	8

1983.

An empirical equation was used to predict the maximum vertical extent of the brine jets:

$$Z_m = C\ V\ (Dg\Delta\rho/\rho_a)^{1/2} \qquad (2\text{-}1)$$

where Z_m is the maximum vertical extent, D is the exit port diameter, V is the exit velocity, ρ_a is the ambient sea water density, g is the local acceleration of gravity, and $\Delta\rho$ is the difference between the brine density and the sea water density. Laboratory experiments by Tong and Stolzenbach (1979) showed the constant C is 1.7, and field data reported by Randall and McLellan (1983) indicate the value of C is 2.2. These equations were used to estimate the brine jet vertical extent, and the results are also tabulated in Table 2-3. The predicted jet vertical extent using a value of 2.2 for C ranged from 3.9 to 7.4 m and the average was 5.7 m for the entire postdisposal period. During the present reporting period, the predicted jet height ranged between 4.9 and 7.3 m with an average of 6.6 m.

2.5 Acoustical Measurements of the Brine Jets

A Smith Industries Model HE 32 depth sounder aboard the research vessel, EXCELLENCE II was used to measure the vertical height of the brine jets. The vessel passed directly over the diffuser and recorded the brine jets while proceeding on a course parallel to the diffuser. The results on July 15, 1982 from a previous year's report, Randall and McLellan (1983), are shown in Figure 2-21. On this date the average brine discharge rate was 41,882 barrels/hr with an average brine salnity of 240 o/oo. The average vertical extent above the sea floor was 7.6 m.

During the period September 1982 through August 1983, the depth sounder was used to measure the brine jets during plume tracks and

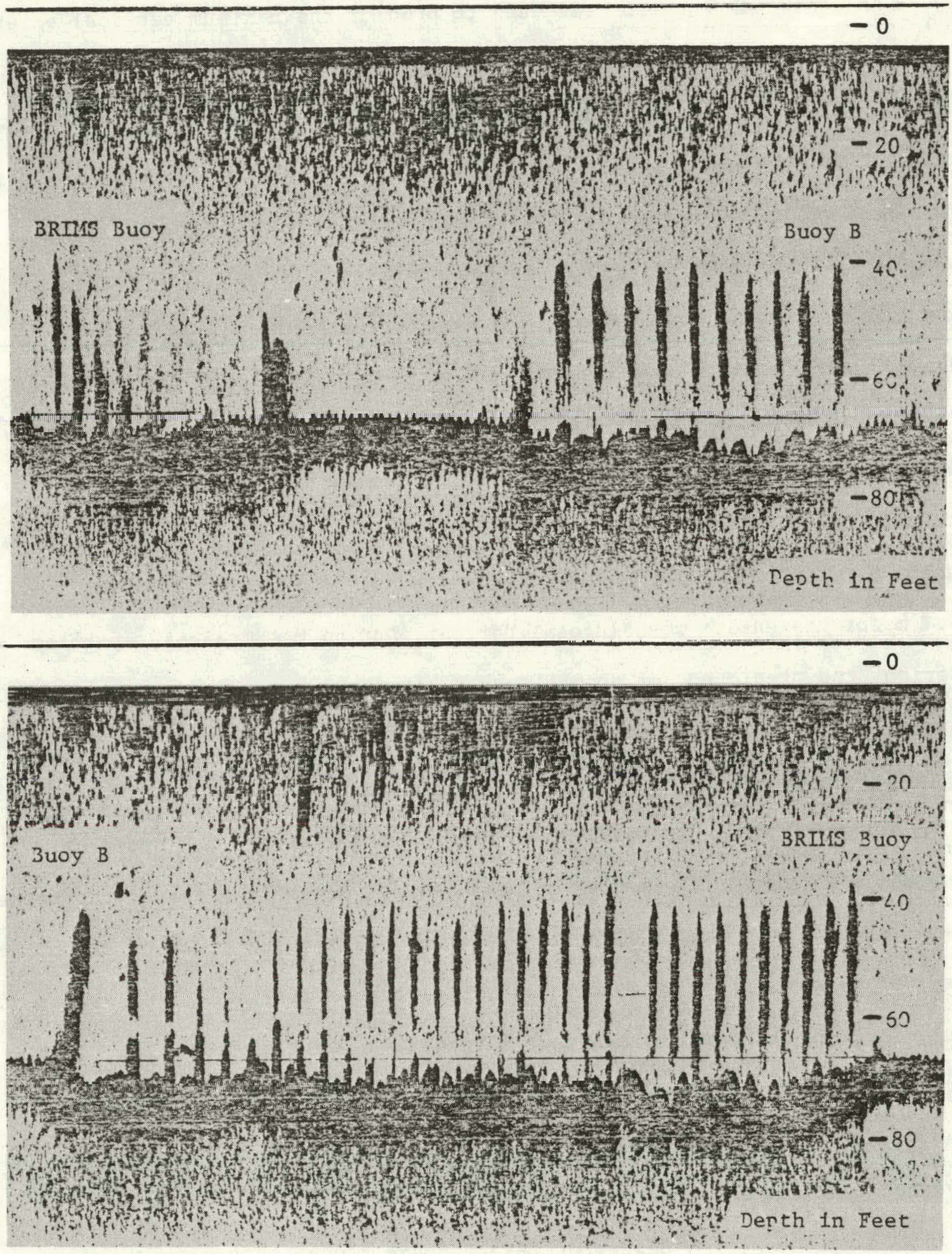
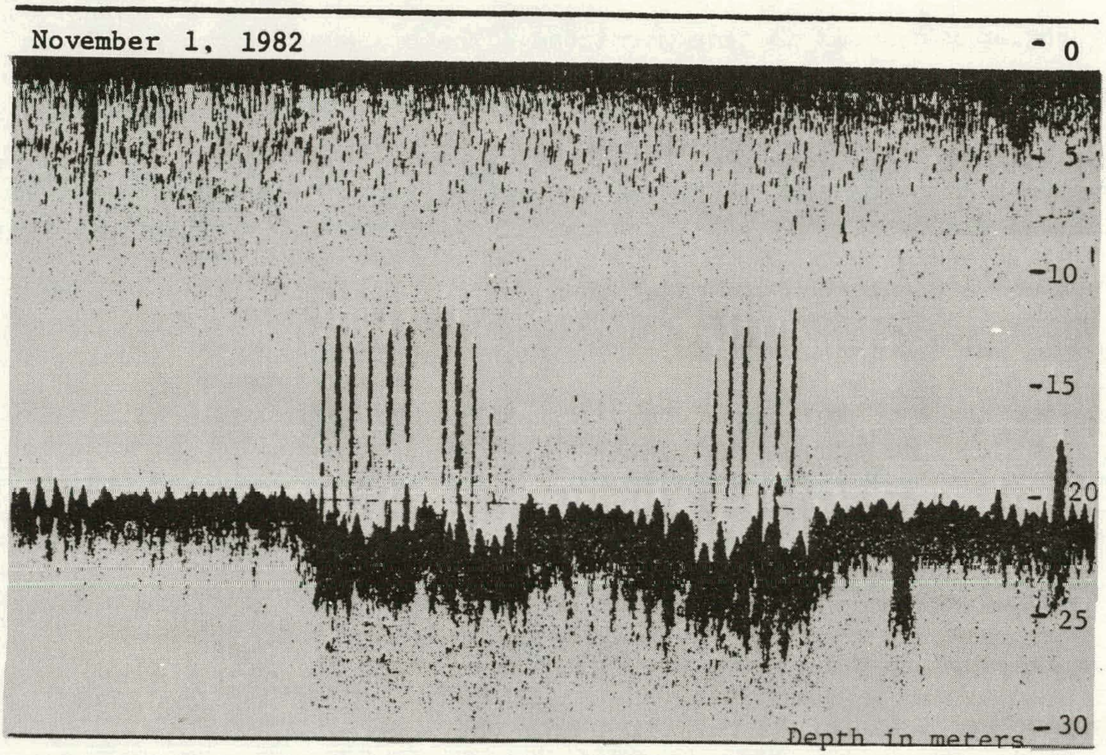


Figure 2-21. Acoustical measurements of brine jets on July 15, 1982 (Randall and McLellan, 1983).

hydrography cruises as time permitted. The brine jet measurements on November 1, 1982 and February 17, 1983 are illustrated in Figure 2-22. The average brine discharge rate on November 1, 1982 was 41,555 barrels/hr and the brine salinity was 254 o/oo. The average vertical height of the jets above the bottom was determined to be 7.6 m while the predicted height was 6.8 m using Equation 2-1 with the coefficient C equaling 2.2. On February 17, 1983 the average brine discharge rate was considerably lower than usual with a rate of 25,742 barrels/hr. The brine jet measurements indicate that the average vertical height was reduced to 5.6 m, and Equation 2-1 predicts a vertical height of 4.9 m. This reduction was expected, and it shows the acoustic measurements can detect the reduced vertical extent resulting from the lower discharge rate.

The brine jet measurements on May 4, 1983 and July 22, 1983 are shown in Figure 2-23. The May 4 measurements were taken when the brine was being discharged at an average rate of 41,813 barrels/hr with a salinity of 258 o/oo. The average measured vertical extent was 7.6 m which was the same as that measured on November 1, 1982 when the discharge and salinity conditions were nearly the same. On July 22, 1983 the average brine discharge rate was 44,264 barrels/hr which was one of the highest rates during the reporting period and the brine salinity was 244 o/oo. The average of vertical height measurements show the jets extended an average of 8.1 m above the sea floor as compared to the 7.3 m predicted value. These results show the acoustical measurements did detect the effect of the increased discharge rate although part of the increased height was due to the less saline, less dense, brine discharge.

These acoustical measurements demonstrate their utility in evaluating the performance of the brine diffuser. A high frequency (greater than 200



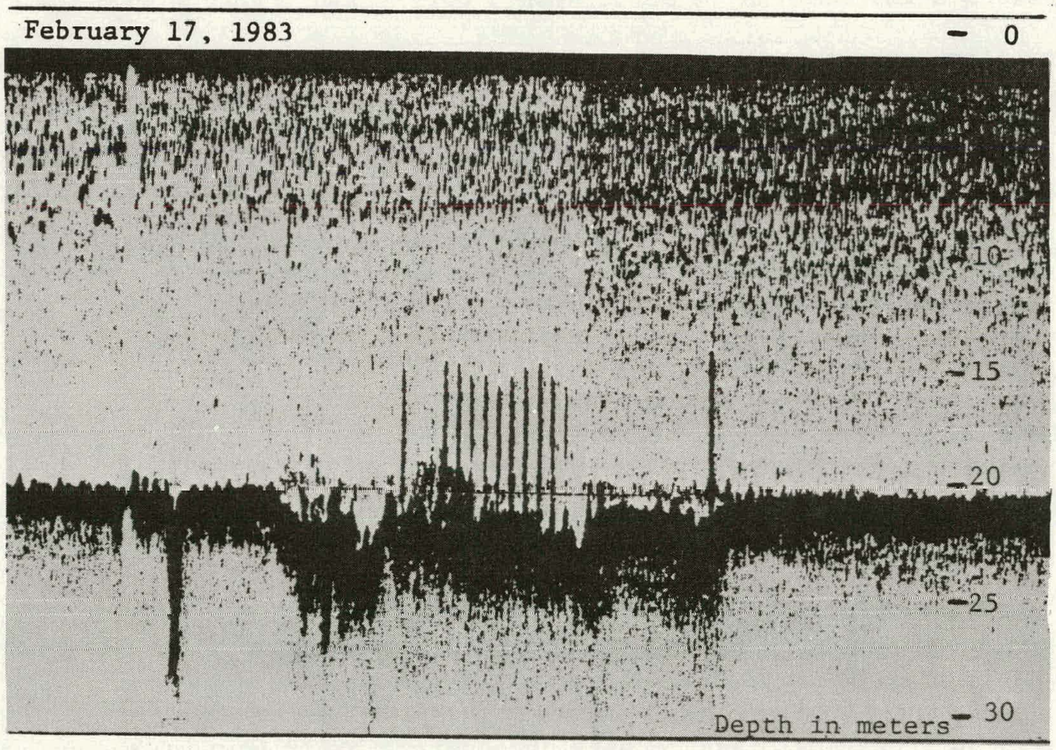


Figure 2-22. Acoustical measurement of brine jets on November 1, 1982 and February 17, 1983.

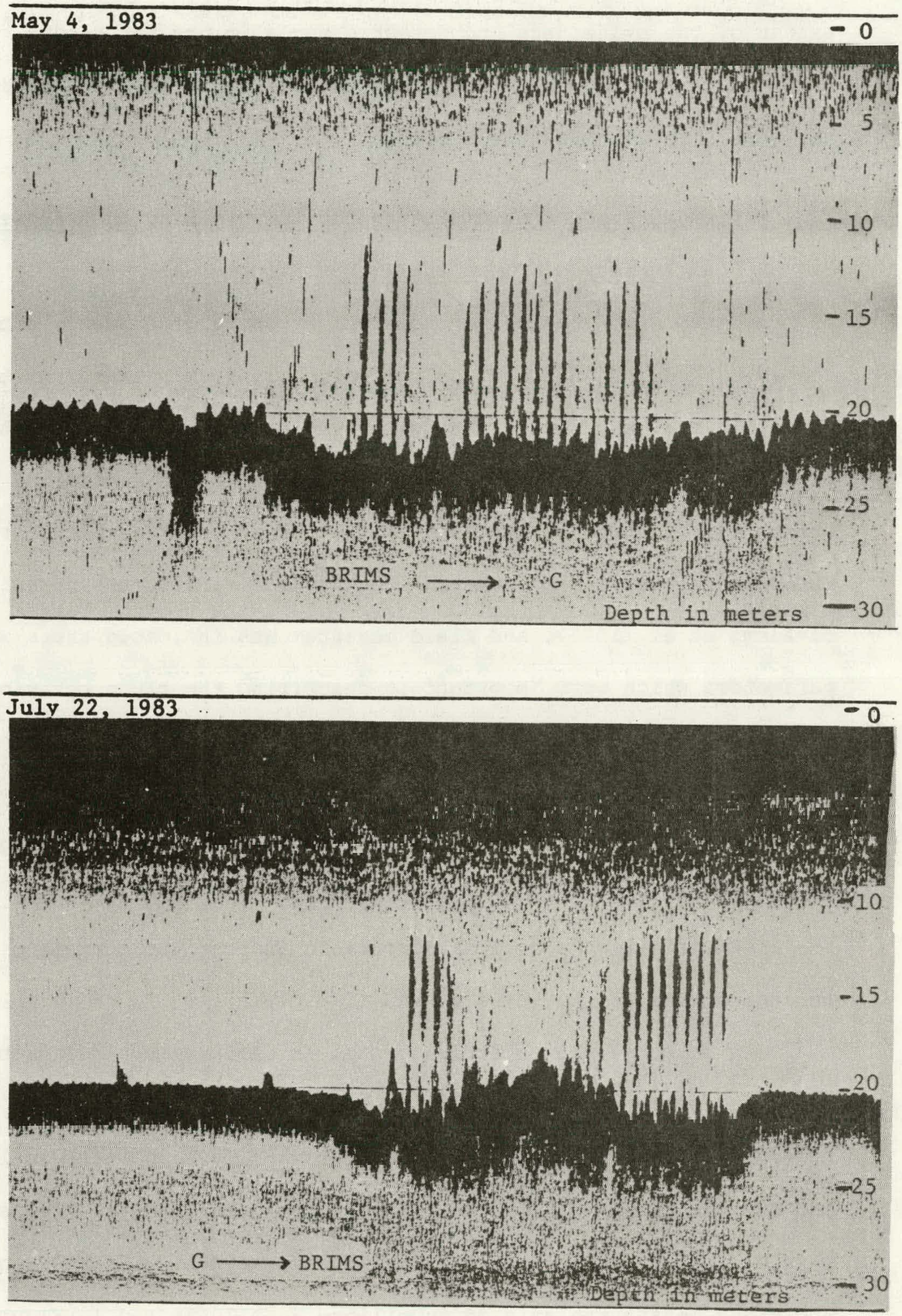


Figure 2-23. Acoustical measurements of brine jets on May 4 and July 22, 1983.

khz) depth sounder and subbottom profiler can easily evaluate the vertical extent of the brine jets and detect changes in the jet height resulting from changes in the discharge characteristics provided the ship can navigate directly over the diffuser.

2.6 Empirical Prediction of Plumes for the Bryan Mound Diffuser

2.6.1 Summary of Plume Prediction Procedures

A method for predicting the areal extent and the above ambient concentration, or dilution, of the brine plume emanating from the Bryan Mound diffuser was needed during periods when the plume was not measured. Such a method would aid investigators interested in predicting the areal extent and dilution of the brine plume during their sampling cruises. Experimental results of Tong and Stolzenbach (1979), the numerical model of Adams et al (1975), and field measurements indicated there were certain parameters which were important in describing the plume behavior. These parameters were: bottom current speed (V_c) and direction, brine salinity (S_b), ambient bottom salinity (S_a), brine exit velocity (V_e), and the brine discharge rate (Q). Therefore, empirical equations using dimensionless groupings of the above parameters were developed to estimate the areal extent, the general dimensions and the above ambient concentrations of the brine plume.

The measured plumes indicate that an ellipse is a reasonable estimate of the above ambient contours. Therefore, empirical equations were determined which related the upstream length (U_i), downstream length (D_i), and maximum width (W_i) of the plume to the dimensionless groups of physical parameters affecting the plume formation. The two lengths and the width define the axes of an ellipse as illustrated in Figure 2-24. The upstream length (U_i) is measured from the center of the diffuser

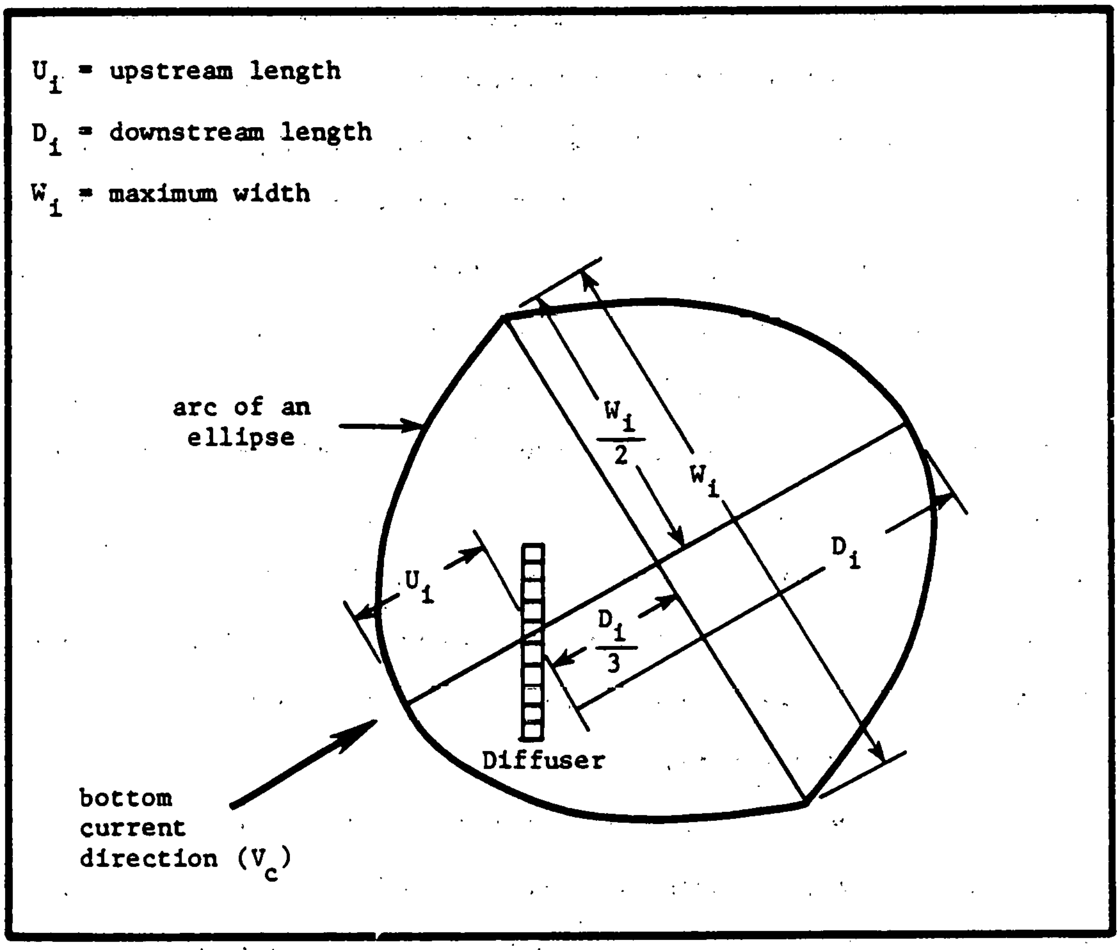


Figure 2-24. Schematic of the ellipse used to predict areal extent of the brine plume.

upstream in the opposite direction of the average bottom current to the desired above ambient salinity contour and is one of the ellipse axes. The downstream length (D_i) is the distance measured in the direction of the bottom current from the center of the diffuser to the desired above ambient contour. The width (W_i) is measured normal to the direction of the bottom current and is bisected by the line extending through the center of the diffuser in the direction of the bottom current. Plume measurements indicate that the maximum width of the plume is usually located approximately 1/3 of the distance downstream of the diffuser, and therefore, the width is displaced a distance $D_i/3$ from the diffuser center. The ends of the lines U_i, D_i, and W_i are then connected with arcs of an ellipse which define the estimated above ambient brine contour.

The empirical relationship which fits the data best is:

$$\begin{matrix} D_i \\ U_i \\ W_i \end{matrix} = M\,(Q/V_c)^{1/2}(S_b/S_a)^e + B \qquad (2\text{-}2)$$

where Q, V_c, S_b, and S_a are the brine discharge rate (m^3/s), average bottom current (m/s), brine salinity and ambient salinity (o/oo), respectively. An empirical equation of similar form,

$$A_i = M\,Q/V_c\,(S_b/S_a)^e + B \qquad (2\text{-}3)$$

was found to be the best fit for predicting the areal extent. The units of the plume dimensions (D_i, U_i, and W_i) are meters and square kilometers for the area (A_i). The measured brine plume data from the Bryan Mound site, the diffuser site C bottom current meter data, and the brine discharge site operating data for the period March 1980 through August

1982 were used to determine the coefficients (M, e, and B) for Equations 2-2 and 2-3. The resulting coefficients are tabulated in Table 2-4.

In addition to the plume dimensions and areal extent, the number of above ambient contours needed to be determined. The above ambient bottom salinity is a function of the brine salinity, ambient bottom salinity, bottom current, port exit velocity, port diameter, brine density, and ambient bottom water density. Laboratory experiments conducted by Tong and Stolzenbach (1979) showed the above ambient bottom salinity could be estimated by

$$\Delta S = 0.5\ \Delta S_m\ V_r\ (F^2)^{-0.67} \qquad (2\text{-}4)$$

where

ΔS = bottom salinity - ambient salinity o/oo

ΔS_m = brine salinity - ambient salinity o/oo

$V_r = V_c/V_e$

V_c = bottom current (m/s)

V_e = jet exit velocity (m/s)

$F = V_c/\left[g(\rho_b - \rho_a/\rho_a)D\right]^{1/2}$

g = 9.81 m/s

ρ_b = brine density (gm/cm^3)

ρ_a = ambient sea water density (gm/cm^3)

D = port inside diameter (m)

This equation shows the above ambient salinity in the immediate vicinity of the diffuser is determined by the exit velocity, bottom current, density ratio, salinity difference, and port diameter.

The brine plume, brine discharge, and physical oceanography current meter data collected from the Bryan Mound and West Hackberry brine disposal operation have been used to determine an empirical relationship

Table 2-4. Coefficients for brine plume prediction equations.

Equation Type	Coefficient M	Coefficient e	Coefficient B	Correlation Coefficient r
Area				
A_1	0.2134E-1	1.8	5.48	0.41
A_2	0.1308E-1	1.8	0.00	0.35
A_3	0.8072E-2	1.8	-0.23	0.41
A_4	0.5682E-2	1.8	-0.63	0.51
A_5	0.1210E-2	1.8	0.00	0.32
A_6	0.1815E-3	1.8	0.00	0.34
Width				
W_1	75.5	1.14	1250.0	0.61
W_2	62.8	1.14	397.0	0.41
W_3	52.2	1.14	0.00	0.49
W_4	40.5	1.14	0.00	0.36
W_5	23.9	1.14	0.00	----
W_6	18.8	1.14	0.00	0.27
Downstream Length				
D_1	110.0	0.5	1436.0	0.29
D_2	96.8	0.5	790.0	0.28
D_3	75.4	0.5	162.0	0.23
D_4	56.6	0.5	88.0	0.21
D_5	29.5	0.5	0.0	0.39
D_6	12.1	0.5	0.0	0.08
Upstream Length				
U_1	36.3	1.0	117.0	0.43
U_2	30.7	1.0	-68.0	0.49
U_3	17.4	1.0	0.0	0.41
U_4	11.9	1.0	0.0	----
U_5	9.08	1.0	0.0	0.25
U_6	4.27	1.0	0.0	0.15

Note: The subscripts indicate the above ambient salinity contour.

similar to Equation 2-4 using linear regression techniques (Randall and McLellan, 1983). The result is

$$\Delta S = .444\, \Delta S_m\, V_r\, (F^2)^{-0.533} \qquad (2\text{-}5)$$

and the correlation coefficient is 0.89. Thus, Equation 2-5 is used to estimate the above ambient bottom salinity, and this value is rounded to the nearest part per thousand in order to determine the number of above ambient salinity contours for the plume prediction.

In summary, the plume prediction procedures require the knowledge of physical data such as bottom currents, brine discharge characteristics (salinity, temperature, flow rate), brine diffuser characteristics (number of open ports, port diameter) and an estimate of the ambient salinity and temperature. The prediction of the plume is for an eight-hour period since this is the approximate time required to measure the plumes. A computer program has been developed which will input the necessary physical data and use these data to compute the plume physical dimensions, areal extent, and above ambient salinity contours for each eight-hour period for which these data are known.

2.6.2 Comparison of Predicted and Measured Plume Contours and Areal Extent

2.6.2.1 Area Extent Comparison

A comparison of the predicted and measured areas within the above ambient salinity contours is illustrated in Figure 2-25. These data show considerable scatter, and thus the empirical equations are only good estimates of the actual areal extent. The data points for this reporting period are identified with a check mark (✓). Some of the reasons for the scatter are the bottom current variability, the brine discharge

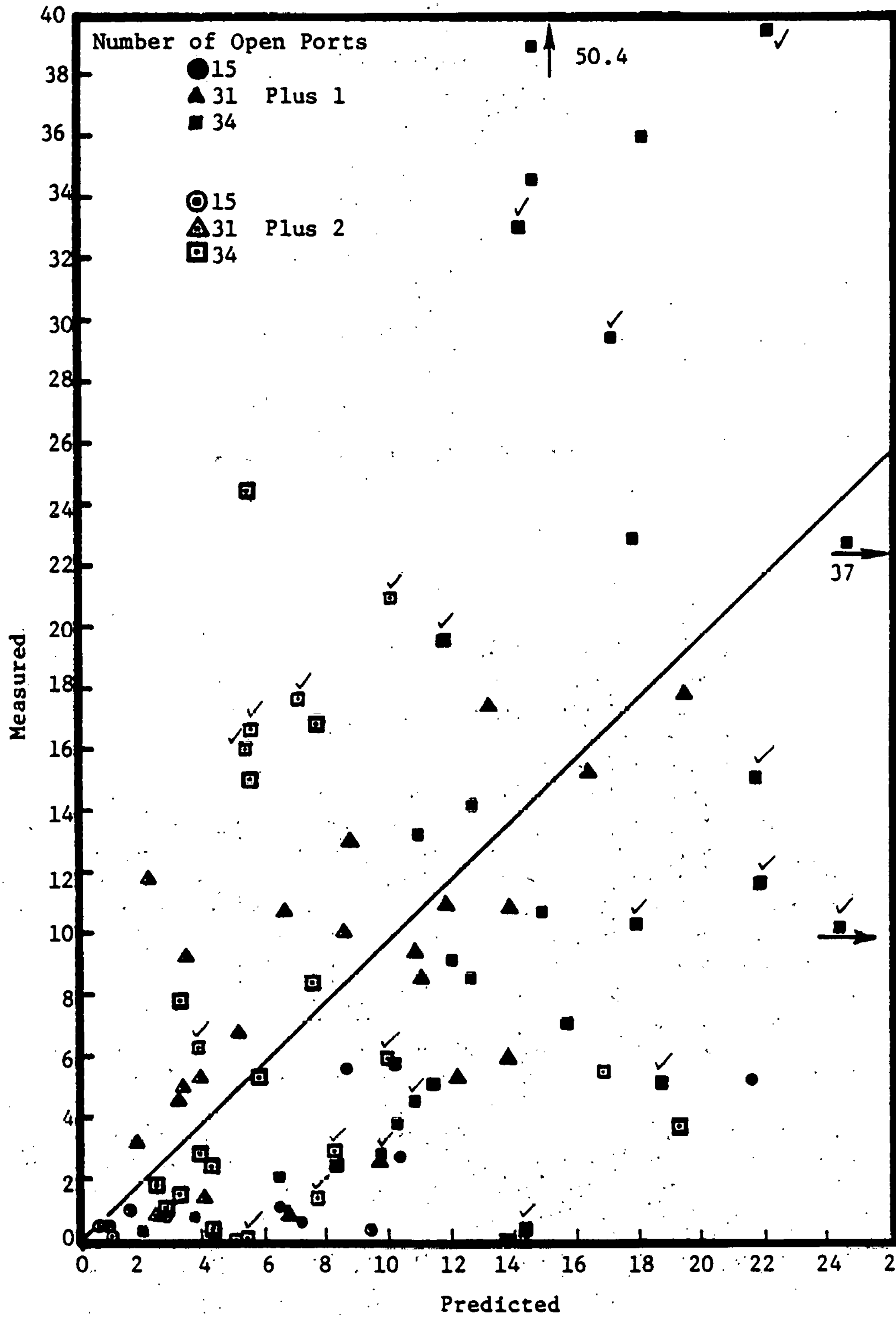


Figure 2-25. Comparison of measured and predicted areal extent inside above ambient salinity contours. The check marks (✓) indicate data for the period September 1982 through August 1983.

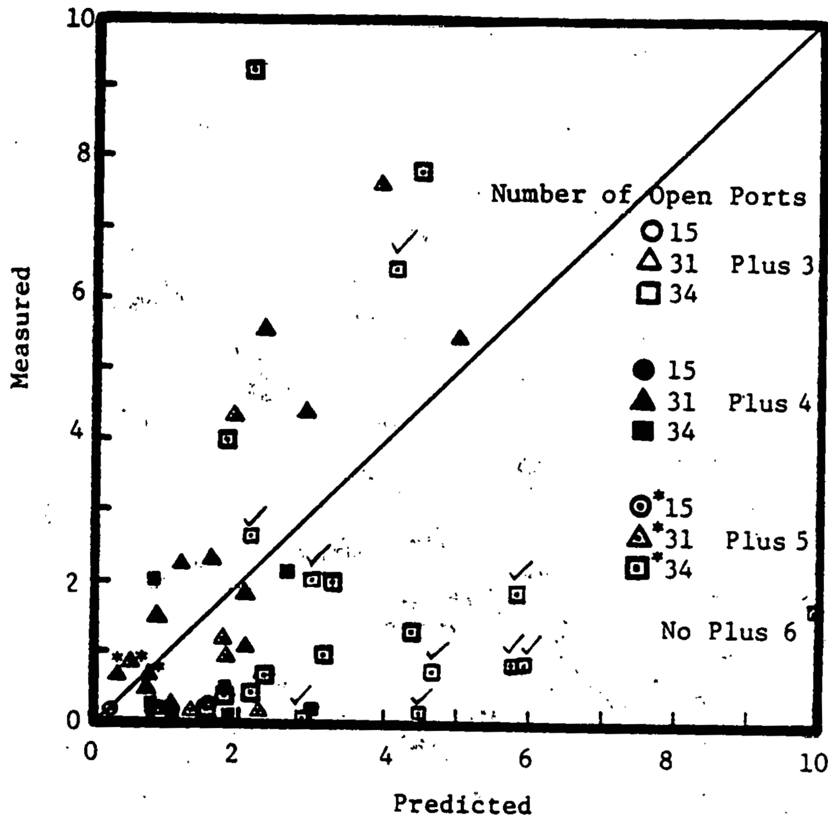


Figure 2-25. Continued.

variability, brine salinity variability, difficulty in determination of ambient salinity and its variability, and the period needed to complete the plume track. The scatter may also indicate that the best dimensionless parameters have not been obtained.

2.6.2.2 Plume Contour Comparison

A comparison of the measured and predicted plume contours is discussed in order to demonstrate the agreement between measured and predicted results for the period September 1982 through August 1983. The first comparison is for October 14, 1982, as shown in Figure 2-26. The measured above ambient contours are shown as solid lines, and the dashed lines are used to illustrate the predicted plume contours. The October 14, 1982 results show the prediction procedure estimated the number of above ambient salinity contours correctly. The agreement between the measured and predicted dimensions for the +1 o/oo contour was very good. For example, the predicted width, downstream length and upstream length was 4.6, 2.8 and 1.3 km, as compared to the measured values of 4.2, 2.8 and 1.0 km, respectively. However, the predictions overestimated the dimensions of the +2 and +3 o/oo contours. The plume direction followed the average bottom current except for the +3 o/oo contour.

Figure 2-27 shows a comparison for the May 4, 1983 plume track. The prediction of the number of above ambient salinity contours was one less than the measured data. In general, predicted plume dimensions and areal extent overestimated the measured results on this date. In the case of the +1 o/oo contour, the predicted area, downstream length, upstream length and width was 32.5 km^2, 3.1, 1.7 and 5.7 km as compared to measured values of 9.9 km^2, 2.0, 1.3 and 3.5 km, respectively. Similar overestimates were obtained for the +2 and +3 o/oo contours.

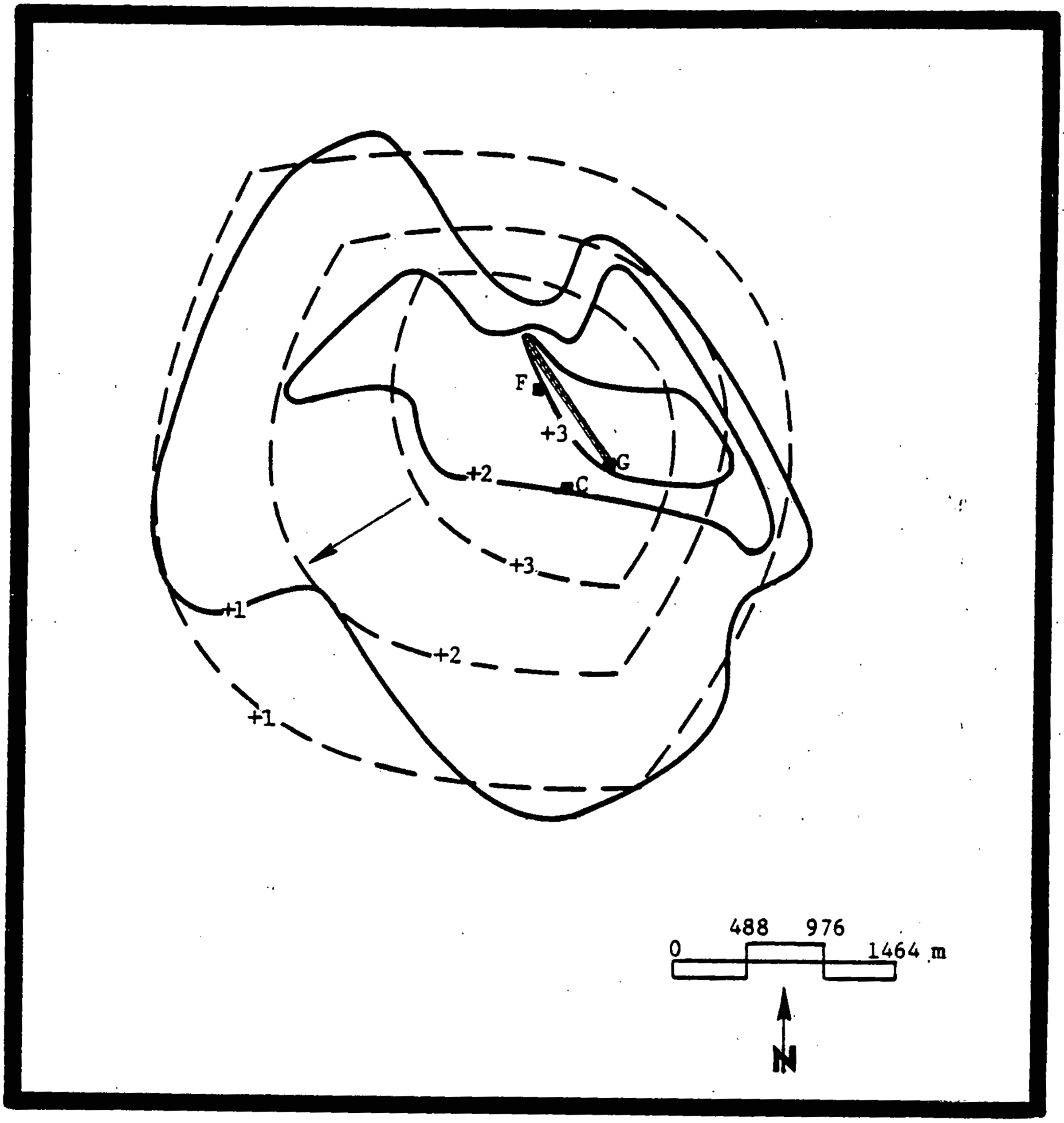


Figure 2-26. Comparison of predicted and measured plume contours for October 14, 1982.

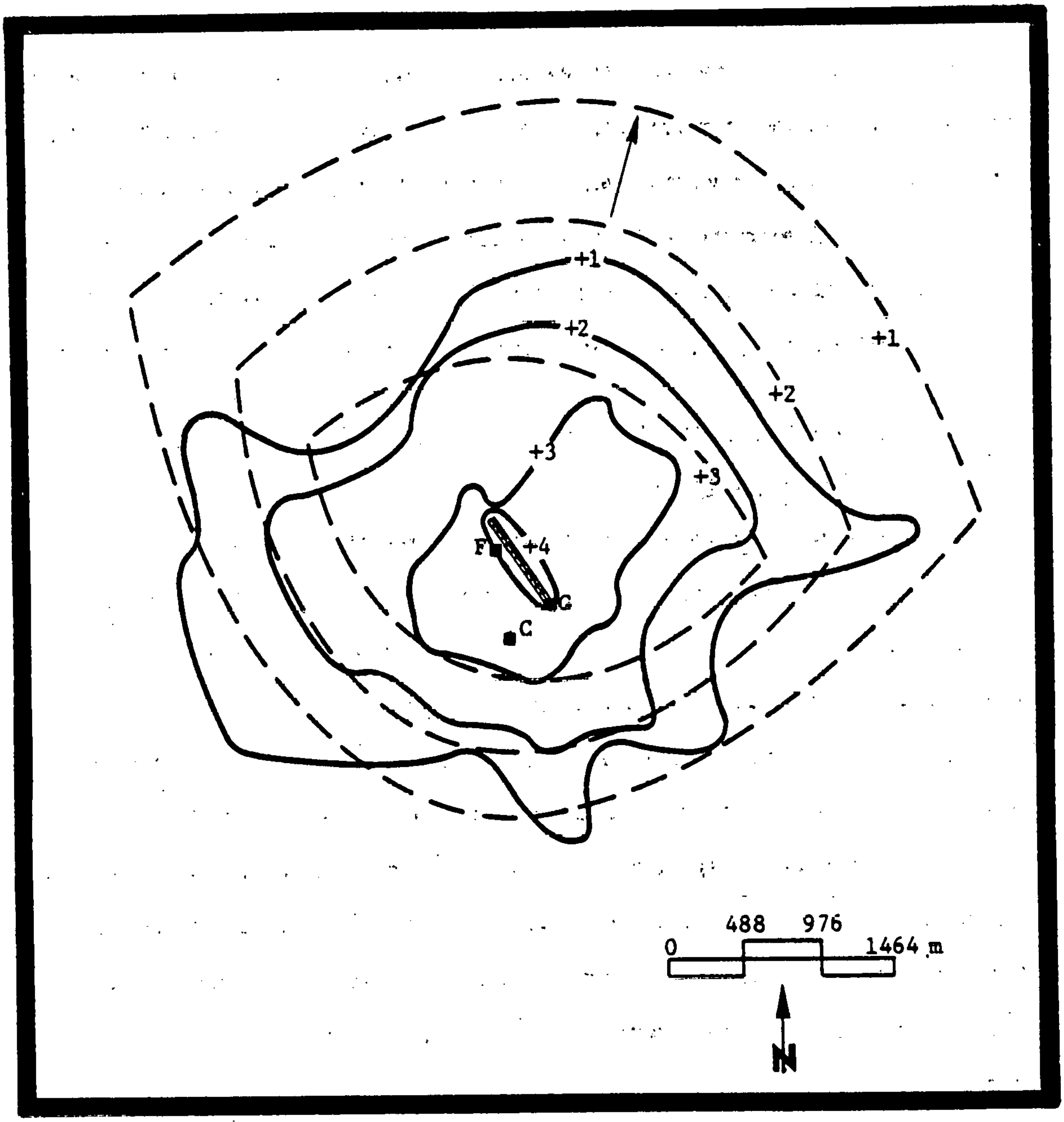


Figure 2-27. Comparison of predicted and measured plume contours for May 4, 1983.

The results of these comparisons and those in a previous report (Randall and McLellan, 1983) show the prediction methods give an excellent estimate of the number of above ambient salinity contours. The estimates of the plume dimensions are not as accurate as desired, but are considered to be reasonable estimates of the plume behavior. The agreement between the average bottom current direction and the apparent plume direction was good. Better agreement between the measured and predicted plume dimensions may be obtained by re-examining the parameters affecting brine dilution and dispersion and then determining new dimensionless parameters and new empirical equations that correlate better with the measured data.

2.6.3 Estimation of Area Exposure Time to Above Ambient Brine Concentrations

The objective of this section is to present results which estimate the percent of time a specific area in the vicinity of the diffuser was exposed to above ambient salinity concentrations. In addition, the maximum distances to the above ambient salinity contours are predicted. The empirical equations described in Section 2.6.1 are necessary for making these estimates as well as the bottom current meter data at site C in the diffuser area (Appendix A) and the brine discharge operating data (Appendix E). These data were compiled for the period September 1982 through August 1983, and the percent area exposure time for the +1, +2, +3, +4, +5, and +6 o/oo above ambient salinity concentrations was computed.

A polar coordinate system with its origin at the center of the diffuser was selected, and the diffuser area was divided into annular area sectors as shown in Figure 2-28. Concentric circles were drawn at intervals of 0.25, 0.75, 1.25, 1.75, 2.25, 3.25, 4.25, 5.25, and 7.25 km,

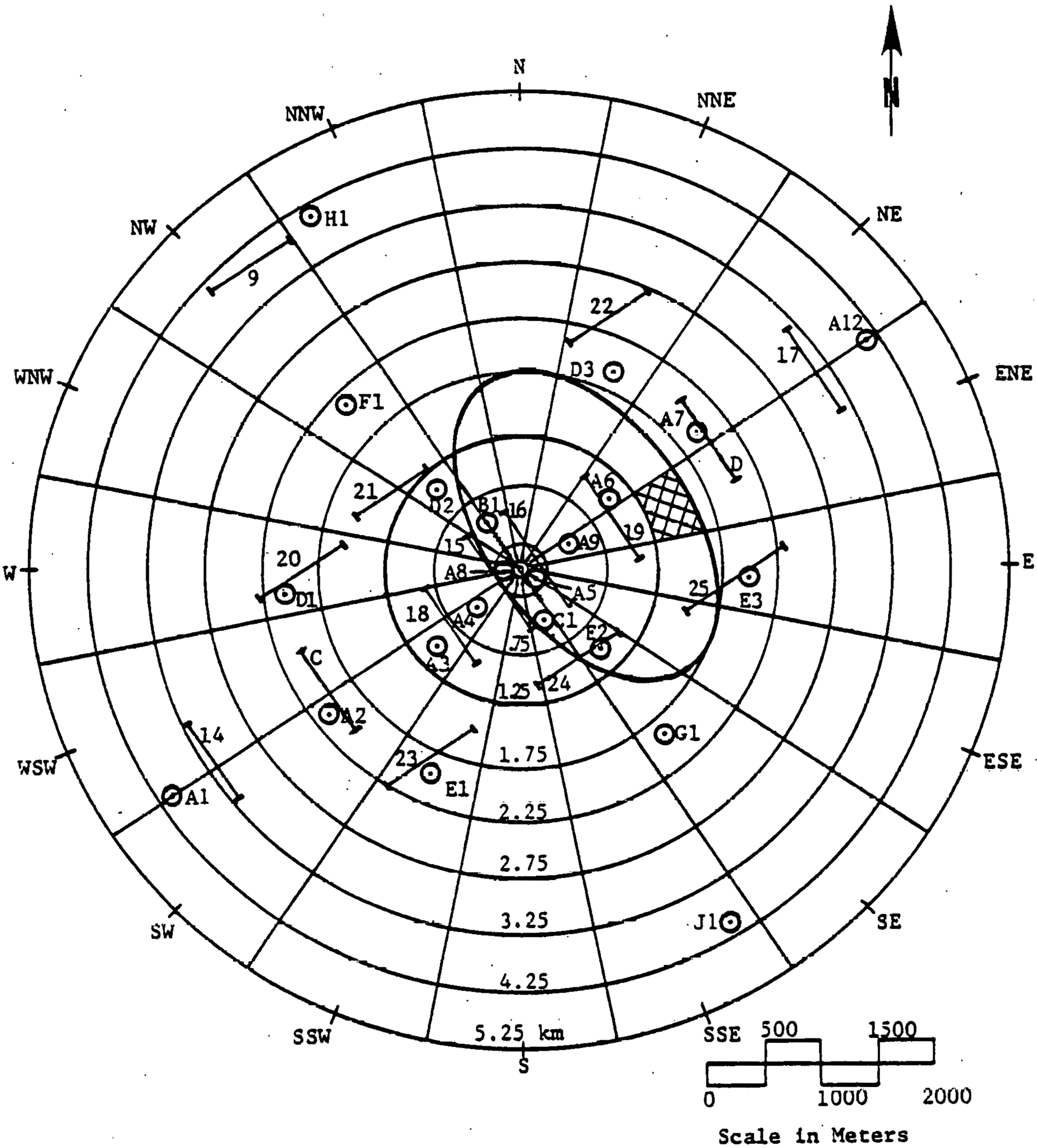


Figure 2-28. Schematic showing division of diffuser area into sectors for use in exposure time computations. The benthic stations are denoted by o and the nekton trawl stations by ———.

and each angular sector represents a total of 22.5°. The center of each sector lay on a compass direction of North, North Northeast, Northeast, etc.

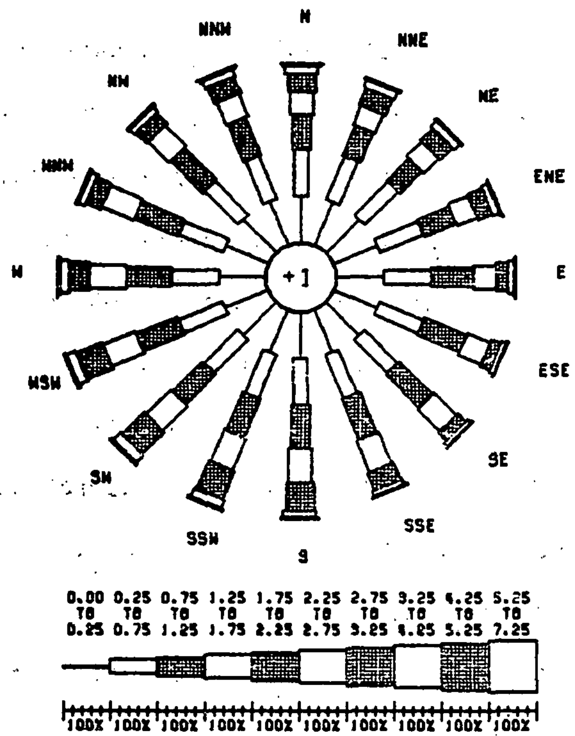
The next step was to compute the predicted plume contours with the equations described in Section 2.6.1. The above ambient plume contours were computed for each eight-hour period of the day for which brine discharge data and bottom current data were available. The predicted downstream length, upstream length and width were used as the axes of an ellipse. The mathematical expression for the ellipse was used to evaluate the distance to the ellipse boundary. Then, the area bounded by the ellipse contour as shown by the cross hatched area in Figure 2-28 was computed. This area was compared with the annular area of the sector. If the cross hatched area was larger than half the annular sector area, then the entire sector area was considered to be within the above ambient ellipse contour. This procedure was completed for the entire ellipse boundary for each above ambient contour.

A computer program was written which computes (1) the eight-hour average current speed and direction; (2) the upstream length, downstream length, and width of the predicted plume; (3) the annular sector areas which are inside the predicted plume contour; (4) the maximum above ambient salinity concentration; and (5) the vertical height of the brine jet. The program makes these computations for each eight-hour period and keeps a record of the areas which were impacted by the plume. After all the available data have been analyzed, the results are presented in the form of a rosette diagram and summary table, a table of maximum distances and a table of the maximum above ambient salinity concentrations. The rosette diagram and summary table were obtained by altering the physical oceanography (Chapter 1) computer programs which produced the current rosettes and joint frequency distribution table of the current meter data.

Figure 2-29 shows the results for the 1 o/oo above ambient area exposure time. The rosette illustrates the percent time of exposure to at least +1 o/oo above ambient salinity in sixteen compass directions. The actual percent exposure time in each annular sector can be determined by the length of the rosette arrow. For example, in the northeast direction the sector which is closest to the diffuser (0.00 to 0.25 km) indicates the +1 o/oo above ambient contour included this sector 100% of the time. The annular sector which is 0.75 to 1.25 km from the diffuser was inside the +1 o/oo contour 66% of the time which is determined by the fact that the cross hatch rectangle is only 66% of the length of the value on the scaled arrow below the rosette. The rosette picture is most useful in getting a quick picture of the preferred directions of the brine plume. In the case of the +1 o/oo contour, the percent time of exposure is shown to be pretty evenly distributed in all directions with a slight reduction in percent exposure in the directions E, ENE, NE, NNE and N.

The table below the rosette diagram has the most information. It gives the values of percent exposure time in each annular sector area. For example, the annular sector northeast of the diffuser and bounded by the distance of 1.25 to 1.75 km is shown to have an exposure time of 45% for the +1 o/oo contour.

The +1 o/oo above ambient exposure time distribution table shows the longest distance for the +1 o/oo above ambient contour is 4.25 km from the diffuser. It shows that the +1 o/oo contour continually enveloped all the area out to 0.75 km from the diffuser. For the distance of 0.75 to 1.25 km the highest percent exposure time was 99% in the WNW direction, and the



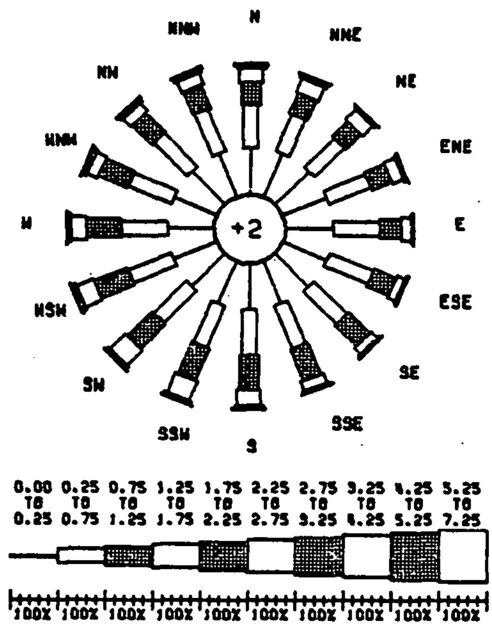
PERIOD: 09/01/82 TO 08/31/83
NO DISCHARGE OR PHYSICAL DATA: 29.67 DAYS

DIR	DISTANCE FROM DIFFUSER (KM)									
	0.00-0.25	0.25-0.75	0.75-1.25	1.25-1.75	1.75-2.25	2.25-2.75	2.75-3.25	3.25-4.25	4.25-5.25	5.25-7.25
E	100	100	90	48	27	11	3	1	0	0
ENE	100	100	73	45	34	14	4	1	0	0
NE	100	100	88	45	37	16	4	0	0	0
NNE	100	100	88	48	38	18	4	0	0	0
N	100	100	74	48	37	17	5	1	0	0
NNW	100	100	86	52	35	16	5	1	0	0
NW	100	100	97	62	32	14	6	0	0	0
WNW	100	100	99	74	34	15	8	0	0	0
W	100	100	97	77	45	18	8	1	0	0
WSW	100	100	94	73	60	20	8	0	0	0
SW	100	100	90	74	68	22	5	0	0	0
SSW	100	100	89	74	68	19	5	0	0	0
S	100	100	91	74	60	14	4	0	0	0
SSE	100	100	95	73	40	11	3	0	0	0
SE	100	100	98	68	23	9	3	0	0	0
ESE	100	100	97	52	22	9	3	0	0	0

Figure 2-29. September 1982 through August 1983 percent exposure time rosette and distribution table for the +1 o/oo above ambient salinity contour.

lowest was 66% in the NE direction. At a distance of 1.25 to 1.75 km, the highest exposure time was 77% in the W direction and the lowest was 44% in the NNE direction. The SW and SSW directions showed the highest percent exposure time (66%) for the distance of 1.75 to 2.25 km and the lowest was 22% in the ESE direction. The maximum percent exposure time for the distance 2.25 to 2.75 km from the diffuser reduced to 22% in the direction SW, and the minimum was 9%, SE and ESE of the diffuser. At the distance 2.75 to 3.25 km, the maximum percent exposure was 6% in the directions of NW, WNW, W and WSW, and the minimum was 3% in the E, ESE, SE and SSE directions. The only exposure for the distance 3.25 to 4.25 km was 1% of the time in the E, ESE, N, NNW and W directions. Thus, the distribution table for the +1 o/oo contour shows the exposure time was generally the least in the SSE to NNE directions and the maximum was spread more generally around from the SSW to NW directions.

The percent exposure time for the +2 o/oo above ambient salinity contour is shown in Figure 2-30. The rosette shows nearly equal distribution in all directions. The distribution table shows the area within 0.25 km of the diffuser center was continually +2 o/oo above the ambient salinity. For the distance of 0.25 to 0.75 km, the highest percent exposure time was 100% in the NW and WNW directions, and the lowest was 86% in the NNE direction. The E, ENE, NE, NNE and N directions showed the lowest percent exposure time between 0.75 and 1.25 km with a value of 46%, and the highest was in the WSW direction with a value of 76%. At a distance of 1.25 to 1.75 km from the diffuser, the highest exposure time was 46% in the SSW direction, and the lowest was 17% in the SE and ESE directions. At the distances of 1.75 to 2.25 km the maximum percent exposure time was 9% in the WNW and WSW directions, and the SE,



PERIOD: 09/01/82 TO 08/31/83
NO DISCHARGE OR PHYSICAL DATA: 29.67 DAYS

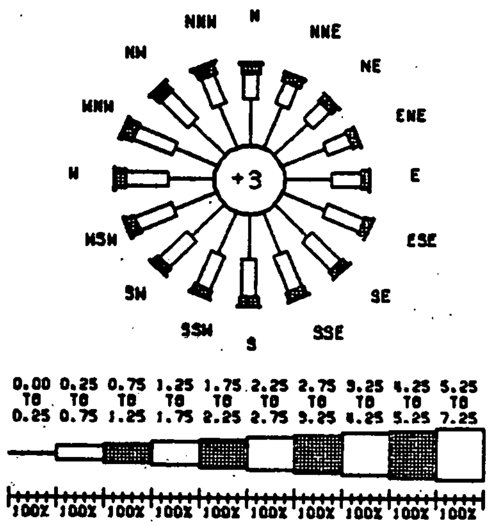
DIR	DISTANCE FROM DIFFUSER (KM)									
	0.00-0.25	0.25-0.75	0.75-1.25	1.25-1.75	1.75-2.25	2.25-2.75	2.75-3.25	3.25-4.25	4.25-5.25	5.25-7.25
E	100	96	48	20	5	1	0	0	0	0
ENE	100	93	48	24	5	1	0	0	0	0
NE	100	87	46	30	6	1	0	0	0	0
NNE	100	86	46	33	7	2	0	0	0	0
N	100	90	48	30	7	2	0	0	0	0
NNW	100	97	52	27	8	3	0	0	0	0
NW	100	100	59	29	7	2	0	0	0	0
WNW	100	100	67	24	9	3	0	0	0	0
W	100	99	74	31	8	3	0	0	0	0
WSW	100	98	78	39	9	2	0	0	0	0
SW	100	97	75	45	7	2	0	0	0	0
SSW	100	97	75	46	6	2	0	0	0	0
S	100	97	74	35	6	2	0	0	0	0
SSE	100	99	73	22	6	1	0	0	0	0
SE	100	99	63	17	5	1	0	0	0	0
ESE	100	99	50	17	5	1	0	0	0	0

Figure 2-30. September 1982 through August 1983 percent exposure time rosette and distribution table for the +2 o/oo above ambient salinity contour.

ESE, E and ENE directions had the minimum value of 5%. The percent exposure time was nearly the same for all directions for the distance 2.25 to 2.75 km with values of approximately 3 to 1%. Thus, the predicted extent of the +2 o/o above ambient contour was 2.75 km in all directions.

The prediction of the percent exposure time for the +3 o/oo above ambient salinity contour is shown in Figure 2-31. The rosette diagram indicates the +3 o/oo contour was generally the same in all directions with a slight decrease in the NNW, N, NNE, NE and ENE directions. The distribution table shows that the area within 0.25 km of the diffuser center was within the +3 o/oo above ambient concentration 99% of the time. The percent exposure time decreased for the distance 0.25 to 0.75 km with a range of 88 to 50%. The maximum value of 88% was in the WNW and W directions. The percent exposure time for the 0.75 to 1.25 distance range was between 33% in the WNW direction and 15% in the SE direction. The extent of the +3 o/oo contour was 1.75 km and the percent exposure time for the distance of 1.25 to 1.75 km was 2 to 5% in all directions.

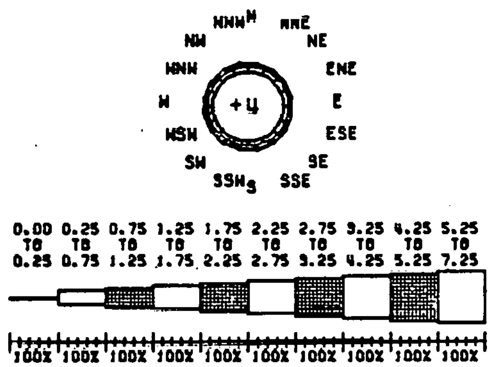
The percent exposure times for the +4 and +5 o/oo above ambient salinity contours are illustrated in Figures 2-32 and 2-33, respectively. A +6 o/oo above ambient contour was not predicted during the period from September 1, 1982 through August 31, 1983. The rosette diagrams indicate the exposure time for these contours was the same in all directions. Figure 2-32 shows the percent exposure time for the +4 o/oo above ambient concentration was 10 to 11% in the 0 to 0.25 km range, 5 to 8% in the 0.25 to 0.75 km range, and 1 to 2% in the 0.75 to 1.25 km range. For the +5 o/oo above ambient concentration, Figure 2-33 shows the percent exposure time was 1% within 0.25 km of the diffuser in all directions, and 0.25 km was the maximum extent of this contour.



PERIOD: 09/01/82 TO 08/31/83
NO DISCHARGE OR PHYSICAL DATA: 29.67 DAYS

	DISTANCE FROM DIFFUSER (KM)									
DIR	0.00-0.25	0.25-0.75	0.75-1.25	1.25-1.75	1.75-2.25	2.25-2.75	2.75-3.25	3.25-4.25	4.25-5.25	5.25-7.25
E	99	82	16	2	0	0	0	0	0	0
ENE	99	53	17	3	0	0	0	0	0	0
NE	99	50	17	3	0	0	0	0	0	0
NNE	99	50	18	4	0	0	0	0	0	0
N	99	58	19	4	0	0	0	0	0	0
NNW	99	66	21	4	1	0	0	0	0	0
NW	99	79	22	4	0	0	0	0	0	0
WNW	99	88	23	5	0	0	0	0	0	0
W	99	88	21	4	0	0	0	0	0	0
WSW	99	82	20	4	0	0	0	0	0	0
SW	99	79	17	4	0	0	0	0	0	0
SSW	99	78	18	3	0	0	0	0	0	0
S	99	78	19	3	0	0	0	0	0	0
SSE	99	83	18	3	0	0	0	0	0	0
SE	99	87	15	3	0	0	0	0	0	0
ESE	99	82	16	3	0	0	0	0	0	0

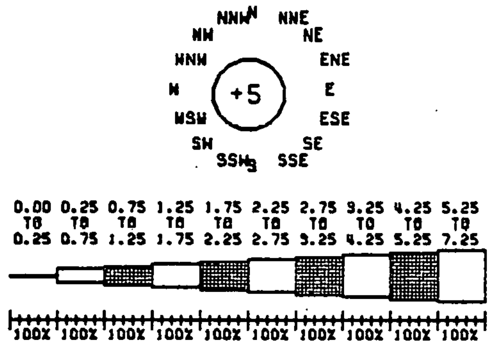
Figure 2-31. September 1982 through August 1983 percent exposure time rosette and distribution table for the +3 o/oo above ambient salinity contour.



PERIOD: 09/01/82 TO 08/31/83
NO DISCHARGE OR PHYSICAL DATA: 29.67 DAYS

DIR	DISTANCE FROM DIFFUSER (KM)									
	0.00-0.25	0.25-0.75	0.75-1.25	1.25-1.75	1.75-2.25	2.25-2.75	2.75-3.25	3.25-4.25	4.25-5.25	5.25-7.25
E	11	5	1	0	0	0	0	0	0	0
ENE	10	5	2	0	0	0	0	0	0	0
NE	10	5	2	0	0	0	0	0	0	0
NNE	10	5	2	0	0	0	0	0	0	0
N	10	5	2	0	0	0	0	0	0	0
NNW	11	6	2	0	0	0	0	0	0	0
NW	11	7	2	0	0	0	0	0	0	0
WNW	11	7	2	0	0	0	0	0	0	0
W	11	7	2	0	0	0	0	0	0	0
WSW	11	7	2	0	0	0	0	0	0	0
SW	10	7	2	0	0	0	0	0	0	0
SSW	10	7	2	0	0	0	0	0	0	0
S	10	7	2	0	0	0	0	0	0	0
SSE	11	8	2	0	0	0	0	0	0	0
SE	11	7	2	0	0	0	0	0	0	0
ESE	11	8	1	0	0	0	0	0	0	0

Figure 2-32. September 1982 through August 1983 percent exposure time rosette and distribution table for the +4 o/oo above ambient salinity contour.



PERIOD: 09/01/82 TO 08/31/83
NO DISCHARGE OR PHYSICAL DATA: 29.67 DAYS

	DISTANCE FROM DIFFUSER (KM)									
DIR	0.00-0.25	0.25-0.75	0.75-1.25	1.25-1.75	1.75-2.25	2.25-2.75	2.75-3.25	3.25-4.25	4.25-5.25	5.25-7.25
E	1	0	0	0	0	0	0	0	0	0
ENE	1	0	0	0	0	0	0	0	0	0
NE	1	0	0	0	0	0	0	0	0	0
NNE	1	0	0	0	0	0	0	0	0	0
N	1	0	0	0	0	0	0	0	0	0
NNW	1	0	0	0	0	0	0	0	0	0
NW	1	0	0	0	0	0	0	0	0	0
WNW	1	0	0	0	0	0	0	0	0	0
W	1	0	0	0	0	0	0	0	0	0
WSW	1	0	0	0	0	0	0	0	0	0
SW	1	0	0	0	0	0	0	0	0	0
SSW	1	0	0	0	0	0	0	0	0	0
S	1	0	0	0	0	0	0	0	0	0
SSE	1	0	0	0	0	0	0	0	0	0
SE	1	0	0	0	0	0	0	0	0	0
ESE	1	0	0	0	0	0	0	0	0	0

Figure 2-33. September 1982 through August 1983 percent exposure time rosette and distribution table for the +5 o/oo above ambient salinity contour.

During the September 1982 through August 1983 postdisposal period, the percent exposure time to above ambient salinity was predicted on 335.33 days, and 29.67 days were not evaluated because either brine discharge or bottom current data were unavailable. In summary, the results indicate that the percent exposure time was almost evenly distributed in all directions with a slight increase in the W to S direction. A summary of the maximum predicted areas within and distances from the diffuser center to the above ambient salinity contours are tabulated in Table 2-5. It is shown that the maximum predicted distances upcoast, downcoast, inshore and offshore for the +1, +2, +3, +4, and +5 o/oo above ambient salinity contours were nearly the same in each direction with values of 4.0, 3.0, 2.1, 1.6 and 0.7 km. The maximum predicted area inside the same contours was 62.6, 35.0, 21.4, 14.6 and 2.0 km^2, respectively. Equation 2-5 was used to predict the above ambient salinities, and Table 2-6 is a summary of the maximum values. The highest predicted above ambient salinities were 5.2, 5.1 and 4.8 o/oo on June 1, 1983; 4.6 o/oo on August 23, August 22 and February 17, 1983; 4.5 o/oo on April 19 and March 17, 1983; and 4.4 o/oo on March 17, February 17 and June 13, 1983. The main reason for the high above ambient salinities was a low discharge rate between 25,742 and 31,168 barrels/hr on these dates, respectively.

2.6.4 Temporal Variation and Frequency Distribution of Predicted Areal Extent Data

The plume prediction data for evaluating the exposure to above ambient bottom salinity discussed in the previous section is used to illustrate the temporal variation and distribution of the predicted areal extent data from September 1982 through August 1983. The temporal

Table 2-5. Summary of the maximum areas and predicted distances from the center of the Bryan Mound diffuser to the above ambient salinity contours for the period September 1982 through August 1983 (29.67 days were not evaluated because of no brine discharge or bottom current data).

Maximum Predicted Values	Above Ambient Bottom Salinity Contours (o/oo)				
	+1	+2	+3	+4	+5
Downcoast (km) 235°T	11/29/82 4.1	11/29/82 3.0	05/06/83 2.3	05/06/83 1.8	08/22/83 0.8
Upcoast (km) 055°T	01/22/83 3.9	01/22/83 2.9	07/22/83 2.0	12/06/83 1.5	06/11/83 0.6
Inshore (km) 325°T	11/28/82 4.0	11/28/82 3.0	01/22/83 2.1	09/17/82 1.5	06/01/83 0.7
Offshore (km) 145°T	11/29/82 4.0	11/29/82 3.0	09/26/82 2.1	09/26/82 1.6	06/01/83 0.8
Area (km^2)	05/06/83 62.6	05/06/83 35.0	05/06/83 21.4	05/06/83 14.6	06/01/83 2.0

Table 2-6. Summary of the maximum predicted above ambient salinity computed from Equation 2-5 for the Bryan Mound diffuser for the period September 1982 through August 1983 (29.67 days were not evaluated because there was no brine discharge or bottom current data).

Maximum Predicted Above Ambient Salinity from Equation 2-5 (o/oo)	Date
5.2	6/01/83
5.1	6/01/83
4.8	6/01/83
4.6	8/23/83
	8/22/83
	2/17/83
4.5	4/19/83
	3/17/83
4.4	3/17/83
	2/17/83
	6/13/83

variation of the areal extent inside the respective above ambient salinity contours is illustrated in Figure 2-34. This figure shows large fluctuations in areal extent with values for the +1 o/oo contour greater than 50 km^2 occurring in September and November 1982 and in January, February, April, May, June, July and August 1983. These large areal extents were of short duration (~8 hours). The maximum predicted area was 62.6 km^2 in May 1983. The results show that above ambient contours of +1, +2 and +3 o/oo were generally always present and that +4 o/oo contours were occasionally present. Very few instances of +5 o/oo contours were predicted, and they occurred in February, June and August 1983. The existence of these contours is attributed to low brine discharge rates mentioned previously. The elimination of the higher (+5 and +6 o/oo) above ambient contours follows the trend reported in the previous report (Randall and McLellan, 1983) which was observed after the brine discharge rate was increased to near one million barrels/day and the resulting jet exit velocities reached values near 12 m/s.

The distribution of the predicted areal extent data is plotted as a histogram in Figure 2-35. The ordinate is the number of observations and percent relative frequency, and the abscissa shows the areal extent. The areal extent increments are 1.0, 0.5, 0.5 and 0.2 km^2 for the +1, +2, +3 and +4 o/oo contours, respectively. The data for the +1 o/oo contour show the highest number of observations (110) was between 11 and 12 km^2. There were a total of 1003 observations and 720 observations (71.8% relative frequency) were areas between 10 and 20 km^2. The mean predicted areal extent was 17.3 km^2 and the standard deviation was 8.7 km^2.

For the +2 o/oo contour, the highest number of observations in one 0.5 km^2 area increment was 96 observations for the area between 3.5 and 4

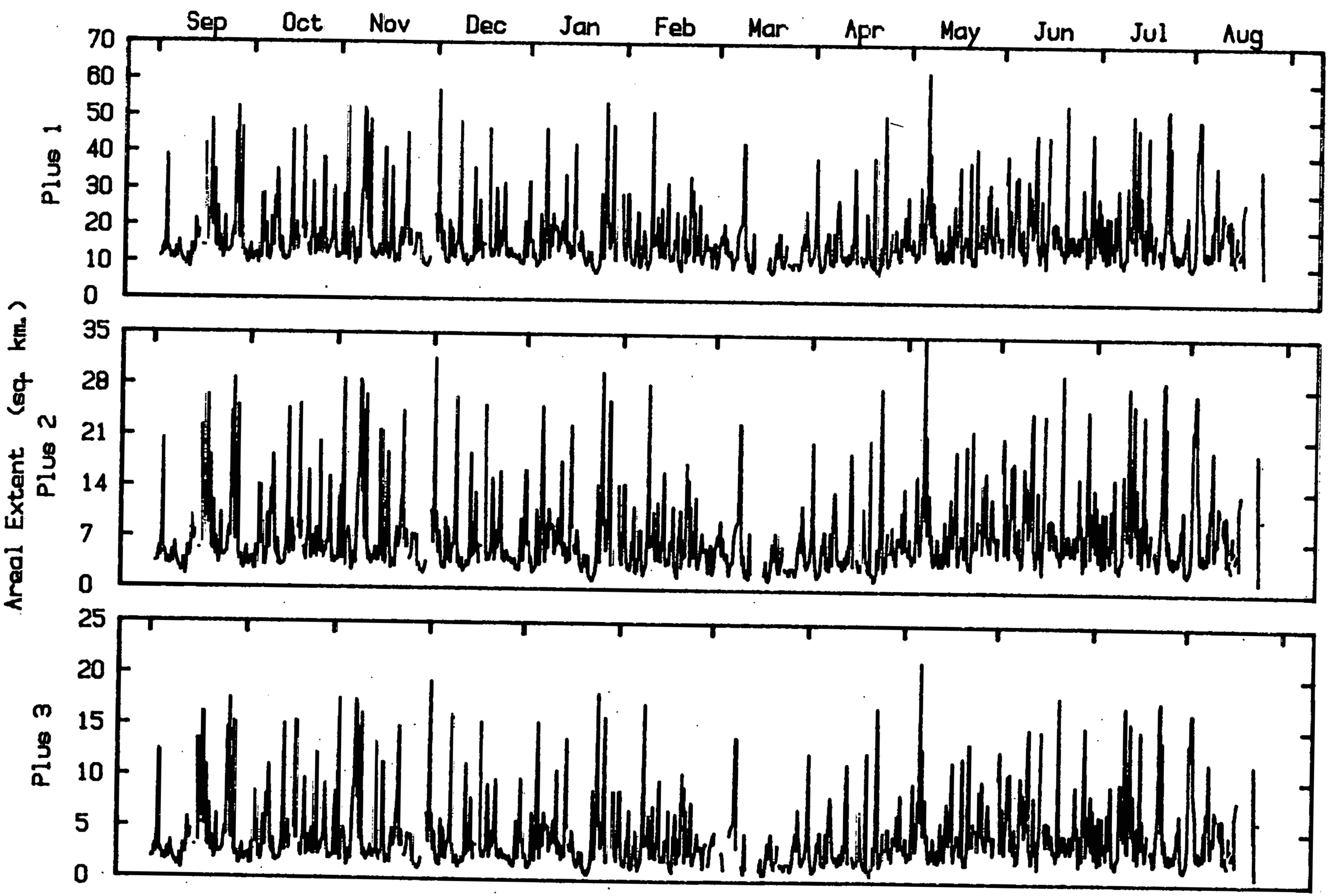


Figure 2-34. Temporal variation of predicted areal extent for above ambient salinity contours.

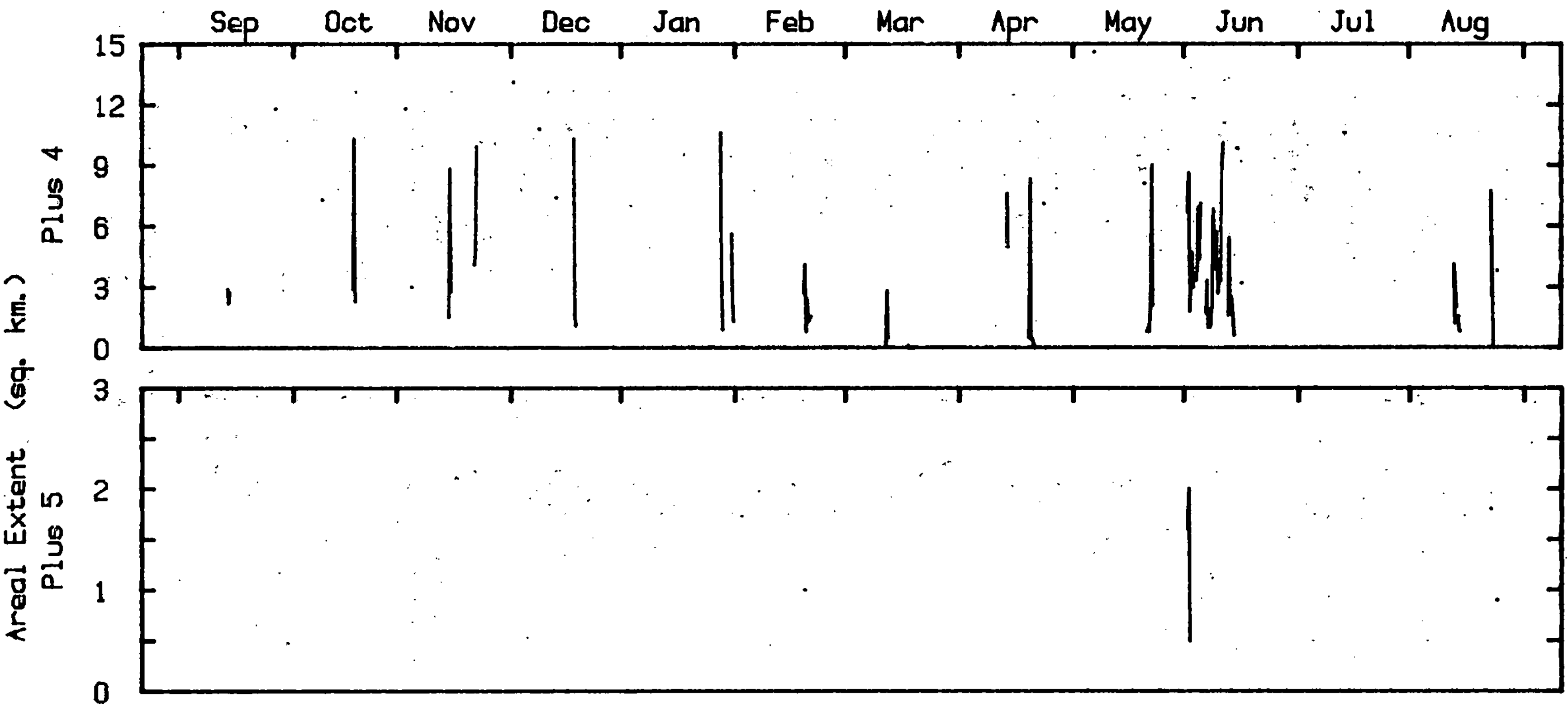


Figure 2-34. Continued.

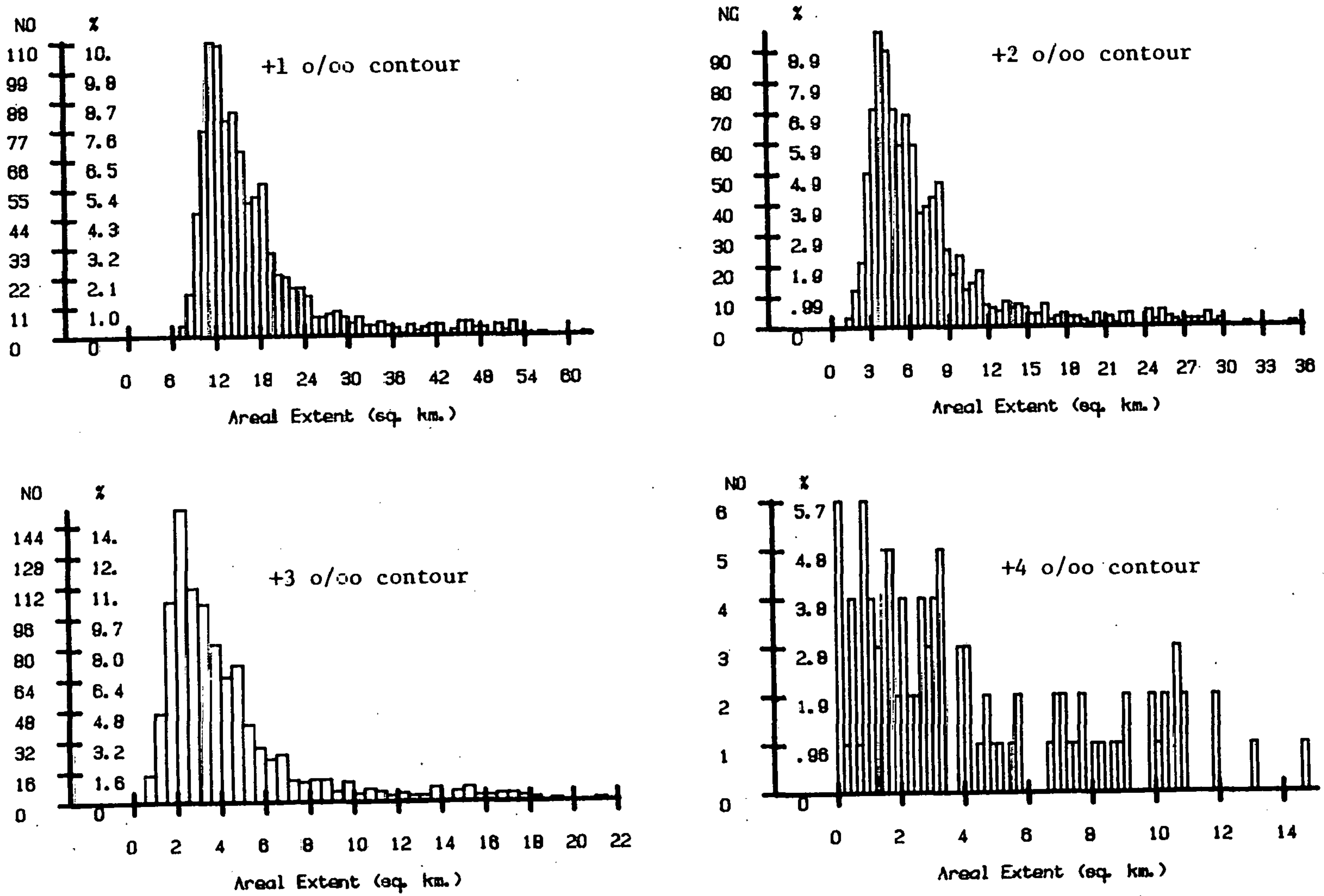


Figure 2-35. Distribution of predicted areal extent within above ambient salinity contours for the period September 1982 through August 1983. NO is the number of observations and % is the percent relative frequency.

km^2. The +2 o/oo areal extent between 2 and 10 km^2 account for 816 out of 1003 observations which is a relative frequency of 81.4%. The mean predicted areal extent inside the +2 o/oo contour was 7.3 km^2 and the standard deviation was 5.3 km^2.

For the case of the +3 o/oo above ambient salinity contours, the area extent increment between 2.0 and 2.5 km^2 had the greatest number of observations (152) which was a percent relative frequency of 15.4%. The total number of observations was 988 which is lower than the 1003 value for the +1 and +2 o/oo contours because a +3 o/oo contour was not always predicted. The increment between 1.0 and 5.0 km^2 accounted for 734 observations for a percent relative frequency of 74.3%. The mean predicted areal coverage inside the +3 o/oo contour was 4.3 km^2 with a standard deviation of 3.3 km^2.

Figure 2-35 also shows the predicted distribution of the +4 o/oo areal coverage. There was a total of 104 observations with a +4 o/oo contour. The area increments of 0.0 to 0.2 km^2 and 0.8 to 1.0 km^2 had the largest number of observations with 6 each. The area increment between 0.0 and 6.0 km^2 accounted for 75 observations for a percent relative frequency of 71.7%. The mean predicted areal coverage inside the +4 o/oo contour was 4.2 km^2 with a standard deviation of 3.6 km^2

2.7 Summary of Results

A conductivity, temperature, and depth (CTD) sensor was towed on a predetermined search course through the expected brine plume area. The sensor continuously measured conductivity, which was converted to salinity, at a distance of 25 cm above the sea floor. These data were used to construct isohaline and above ambient salinity contour plots which indicate the areal coverage of the plume and the magnitude of the excess salinity concentration. In addition, vertical salinity profiles were measured in the vicinity of the diffuser to evaluate the vertical extent of the brine plume, and acoustical measurements were made to evaluate the vertical extent of the brine jets.

Brine plume measurements were conducted once a month during the study period. During the plume tracks in September, October, and November 1982, the brine discharge rate was 41,046; 40,683; and 41,555 barrels/hr while the brine salinity was 255, 255 and 254 o/oo, respectively. The largest areal extent for the +1 o/oo above ambient contour was 29.3 km^2 on September 16. The highest above ambient contour measured during these three months was +5 o/oo on September 16, and it encompassed an area of 0.1 km^2. The maximum salinity was 40.6 o/oo which was the highest measured salinity on the plume tracks during the present study period. This value was 5.9 o/oo higher than the largest ambient salinity of 34.7 o/oo. This was the second highest measured bottom salinity since brine disposal began. The highest value was 42.5 o/oo on April 20, 1981.

The daily average brine discharge rate during the December 1982, January 1983, and February 1983 plume measurements was 41,600; 42,208 and 25,742 barrels/hr, and the brine salinity was 261, 249 and 232 o/oo, respectively. The largest measured areal extent occurred on January 11 when the +1 o/oo contour covered an area of 33.3 km^2. The highest above ambient contour measured during these three months was +4 o/oo on February 17, and this contour enclosed an area of 0.1 km^2. The highest salinity occurred on the January 11 plume track when a value of 38.2 o/oo, which was 3.8 o/oo above the ambient salinity, was measured.

The March, April, and May plume tracks were conducted when the brine discharge rate was 41,871; 41,023 and 41,813 barrels/hr, and the brine salinity was 225, 254 and 258 o/oo, respectively. The area measured inside the +1 o/oo above ambient salinity contour was 0.3, 5.0 and 9.9 km^2, respectively. The highest above ambient contour was +4 o/oo which enclosed an area of 0.1 km^2 around the diffuser. The very small area on March 9, 1983 was mainly attributed to the low brine salinity.

The 1983 June and August plume measurements were conducted when the discharge rate and brine salinity were 34,161 barrels/hr at 251 o/oo and 38,306 barrels/hr at 251 o/oo, respectively. The areal extent of the +1o/oo above ambient contour was 14.8 and 40.0 km^2. The August 11 areal extent was the largest measured during the reporting period and the second largest since brine disposal began. The large areal extent is attributed to a combination of low bottom current, isohaline condition of the receiving waters, and the low brine exit velocity. The largest areal extent was 50.4 km^2 on January 24, 1982 during a previous reporting period. The highest above ambient contours were +3 o/oo on June 8 and +4 o/oo on August 11 within which the areal extent was 0.8 and 0.5 km^2, respectively. A salinity of 38.5 o/oo was measured near the diffuser on August 11. The July 21, 1983 plume measurements provided no closed contours. This was caused by the strong halocline in the bottom waters, the strong bottom currents (18 cm/s) and the low brine salinity (241 o/oo).

All of the plume tracks conducted since the beginning of discharge on March 10, 1980 were considered in order to evaluate the maximum distance to the above ambient contours. The longest measured distance to the +1 o/oo above ambient contour was still 10.5 km south southeast of the diffuser which was measured on January 24, 1982 during the previous reporting period. The longest measured distance to the +2, +3, +4, +5, and +6 o/oo contours remained unchanged at 7.3, 4.2, 2.9, 1.2, and 0.3 km, respectively. The highest measured inshore, offshore, upcoast, and downcoast distances for the +1 o/oo contour were 3.0, 10.1, 6.2, and 3.9 km, respectively. Only the upcoast value of 6.2 km increased from the previous studies.

The distribution of the measured areal extent data for the entire postdisposal period indicate the areal extent within the +1 o/oo contour was between 5.0 and 20.0 km^2 for 59.1% of the measurements and for the +2 o/oo contour it was between 0.0 and 8.0 km^2 for 77.8% of the measurements. The +3 o/oo areal extent was between 0.0 and 4.0 km^2 for 79% of the time when a +3 o/oo contour was measured. For the +4 o/oo contour, the range of 0.0 to 2.0 km^2 accounted for 75% of the time when the +4 o/oo contour was measured. The mean measured areal extent for the entire postdisposal period was 12.8, 5.9, 2.0, 1.3, 0.4 and 0.1 km^2 for the +1, +2, +3, +4, +5 and +6 o/oo contours, respectively. These mean values were computed using data when some of the discharge rates were lower than the present one million barrels/day rate.

During this study as well as the previous studies (Randall, 1982; Randall and McLellan, 1983), the bottom temperature data collected during the plume tracks did not indicate that a significant thermal plume was present. The bottom temperatures in the plume area varied less than 1°C from ambient conditions.

The vertical extent of the brine plume was determined by measuring vertical salinity profiles directly over and in the immediate vicinity of the diffuser. During the period from September 1981 through January 21, 1982, 34 ports were open, and the average port exit velocity during the plume tracks was 7.8 m/s. The highest measured vertical extent was 3.0 m on September 15, 1981, and the average measured vertical extent was 2.4 m. The average measured values were approximately 60% of the calculated values for the height of the brine jet. The port exit velocity was increased for the period January 22, 1982 through August 31, 1983. The average exit velocity for the plume tracks during this period was 11.2 m/s. At the higher exit velocity, the highest measured vertical extents were 4.8 m on July 24, 1983 and 5.6 m on August 11, 1983, and the average measured vertical extent was 3.3 m. The vertical profile measurements during this period were about 50% of the predicted jet height values. Vertical profile measurements were also taken in the immediate and far field as well as the near field, and these showed the bottom salinity and usually the vertical extent decreased with distance from the diffuser.

Acoustic measurements using a 200 khz depth sounder show the average vertical extent of the brine jets varied between 5.6 and 8.1 m above the natural sea floor. The 5.6 m value occurred when the discharge was reduced to 25,742 barrels/hr on February 17, 1983. The 8.1 m vertical extent occurred when the discharge rate was 44,264 barrels/hr which was one of the highest values during this reporting period. The acoustical measurements demonstrate their utility in evaluating the performance of the brine diffuser.

The plume prediction techniques developed in previous reports were used to estimate the percent of time a specific area in the vicinity of the diffuser was exposed to above ambient salinity conditions during the September 1982 through August 1983 study period. The empirical equations for evaluating the width, upstream length, and downstream length of the brine plume, the bottom current meter data in the diffuser area, and the brine discharge data were used for this computation. The results show that the percent exposure time was almost evenly distributed in all directions. There was a slight favoring of the west to south directions, and the least percent of exposure time was usually in the east to north direction. The maximum predicted distance of the +1, +2, +3, +4 and +5 o/oo contours was 4.1, 3.0, 2.3, 1.8 and 0.8 km from the center of the diffuser. The maximum predicted areal extent was 62.6, 35.0, 21.4, 14.6, 2.0 and 2.0 km^2 for the +1, +2, +3, +4, and +5 o/oo above ambient salinity contours. The maximum predicted above ambient salinity was 5.2 o/oo.

The empirical prediction techniques for this reporting period indicated there were no +6 o/oo contours and only a few instances of the +5 o/oo contour. The +4 o/oo was occasionally present, and the +1, +2 and +3 o/oo contours were generally always present. The mean values of the predicted areal extents were 17.3, 7.3, 4.3 and 4.2 km^2 for the +1, +2, +3 and +4 o/oo above ambient salinity contours. The area frequency distribution shows the +1 o/oo areal extent was between 10 and 20 km^2 71.8% of the time, the +2 o/oo areal extent was between 2 and 10 km^2 81.4% of the time, the +3 o/oo areal extent was between 1.0 and 5.0 km^2 74.3% of the time, and the +4 o/oo areal extent was between 0.0 and 6.0 km^2 71.7% of the time this contour was present.

2.8 Conclusions and Recommendations

The plume tracking system consisting of a towing sled and underwater CTD sensor, and a microcomputer data logger continues to be an excellent system for measuring the excess salinity concentration and the areal extent of the near bottom brine plume.

During the period from September 1982 through August 1983, the highest bottom salinity measured during plume tracks was 40.6 o/oo which was measured in the immediate vicinity of the diffuser on September 16, 1982 when the ambient bottom salinity was 34.7 o/oo. The highest above ambient salinity contour measured during the year was +5 o/oo which occurred on September 16, 1982. The +4 o/oo contour was found on September 16, 1982, February 17, 1983, May 4, 1983 and August 11, 1983. The largest areal extent within the +1 o/oo contour was 40.0 km^2 which occurred on August 11, 1983. The maximum measured horizontal extent of the brine plume based upon the distance from the diffuser center to the +1 o/oo above ambient salinity contour was 7.4 km northeast of the diffuser on January 11, 1983.

The bottom temperatures measured in the plume area varied less than 1°C from ambient conditions, and thus it was concluded that no significant thermal plume was present during plume tracks.

The maximum vertical extent of the brine plume was measured on August 11, 1983 as 5.6 m above the sea floor directly over the diffuser. The average plume vertical extent during the study period was 3.0 m when the average exit velocity was 11.2 m/s. These results were approximately 50% of the predicted vertical extent of the brine jets. Acoustic measurements of the brine jets indicated the average jet vertical height varied between 5.6 and 8.1 m when the average exit velocity was 7.3 and 12.6 m/s, respectively. Vertical profile measurements in the intermediate and far field indicate that bottom salinity, and usually the plume vertical extent, decreased with increasing distance up and downstream of the diffuser.

The empirical prediction of plume contours was used in conjunction with physical oceanographic data at the diffuser site and the brine discharge data to evaluate the percent time a particular annular sector of the sea floor was exposed to above ambient salinity conditions. The results show the percent exposure time was almost evenly distributed in all directions. The west and south directions were slightly favored and the east to north directions were least favored. The maximum predicted extent of the +1, +2, +3, +4 and +5 o/oo contours was 4.1, 3.0, 2.3, 1.8 and 0.8 km from the diffuser, respectively. The mean predicted areal extent for the +1, +2, +3 and +4 o/oo contours was 17.3, 7.3, 4.3 and 4.2 km^2, respectively.

The number of above ambient salinity contours which were +5 o/oo above ambient have remained significantly reduced since the exit velocity was increased to near 12 m/s. Thus, the increased exit velocity has increased the dilution efficiency of the diffuser.

The areal extent of the +1 o/oo above ambient contour has increased with representative values of 40.0, 33.3 and 29.3 km^2 since the exit velocity, has remained near 12 m/s. In comparison, representative large areas at the lower exit velocity (8 m/s) were 17.9, 17.5, and 15.4 km^2.

The brine plume measurement data indicate the brine diffuser in its present configuration and discharge rate is diluting the brine from near 263 o/oo to near 5 o/oo above the ambient salinity, and the plume salinity is further reduced to 1 o/oo above ambient within 11 km of the diffuser by advection and diffusion.

It is recommended that subbottom profiler and side scan sonar measurements of the Bryan Mound diffuser be conducted on a one-time basis to evaluate their capability of evaluating the brine jet operating characteristics.

It is recommended that the empirical prediction technique be reevaluated to obtain better agreement between predicted and measured data. Salinity stratification and exit velocity should be considered as additional parameters.

Monthly plume measurements are recommended in order to continue collection of data at various environmental conditions which have not been observed to date. More measurements at low currents (<6 cm/s) and for stratified conditions are needed. New information has been obtained each year. For example, this reporting period revealed the effects of a strong halocline in the bottom waters.

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CHAPTER 3

WATER AND SEDIMENT QUALITY

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3.1 Introduction

Prior to commencement of brine discharge from the Bryan Mound site of the Strategic Petroleum Reserve on March 10, 1980, a number of concerns were raised about the environmental impact of brine disposal in coastal waters upon water and sediment quality. Among these were the effect of the brine discharge upon bottom water salinities, temperatures, dissolved oxygen and major ion balance. In addition, there was concern that toxic substances, such as heavy metals and synthetic organic compounds, contained in the Brazos River leach water or the salt dome could lead to changes in their concentrations in water, biota and sediments near the brine diffuser with adverse effects.

Previous monitoring studies conducted at the Bryan Mound diffuser site by Texas A&M University have provided answers to most of these concerns (Slowey and Jeffrey, 1981, 1982 and 1983). However, several concerns still remained. Among these were whether several metals as well as hydrocarbons associated with the brine or stored oil were being transported to the offshore diffuser area sufficiently to impact upon this area. Also of concern was the question as to what extent the brine influenced ionic imbalance, especially in sediment pore waters.

This report contains results of the past year's monitoring carried out between September 1, 1982 and August 31, 1983 in an attempt to answer these concerns. Toward this end, water samples were collected quarterly at fourteen (14) stations shown in Figure 3-1. Twelve (12) stations were located offshore in the vicinity of the diffuser and the remaining two (2) stations were located onshore at the brine pond (BP) and the Brazos River (BR) Raw Water Intake Structure. Station designators and coordinates are given in Table 3-1. Water samples for routine analyses were collected at three depths (surface, middepth, and bottom) at the 12 offshore stations and at one depth at the 2 onshore stations. Samples were collected during November 1982, February 1983, May 1983, and August 1983. Parameters measured in these samples included: salinity, temperature, pH, oil and grease, dissolved heavy metals (Cd, Cr, Cu, Hg, Zn, Pb, Al, Fe, Ni), and dissolved bulk ions (Ca^{++}, Mg^{++}, Na^{+}, K^{+}, Cl^{-}, SO_4^{--}).

Quarterly sediment samples were collected at the 12 offshore stations during the same months as for the water samples. Parameters measured in these samples included: oil and grease, Eh/pH, heavy metals (Cd, Cr, Cu, Hg, Zn, Pb, Al, Fe, Ni), pore water (Ca^{++}, Mg^{++}, Na^{+}, K^{+}, Cl^{-}, SO_4^{--}, and total dissolved solids), and percent sand, silt and clay.

In addition to the routine water and sediment sampling and analyses, a special semi-annual high molecular hydrocarbon sampling and analysis program was carried out. Samples for the determination of high molecular weight hydrocarbons (HMWH) were collected in the months of February 1983 and August 1983 from the water column at the brine pond (BP) and the Brazos River (BR), and from the surface and bottom of the water column and the sediments at offshore station D14.

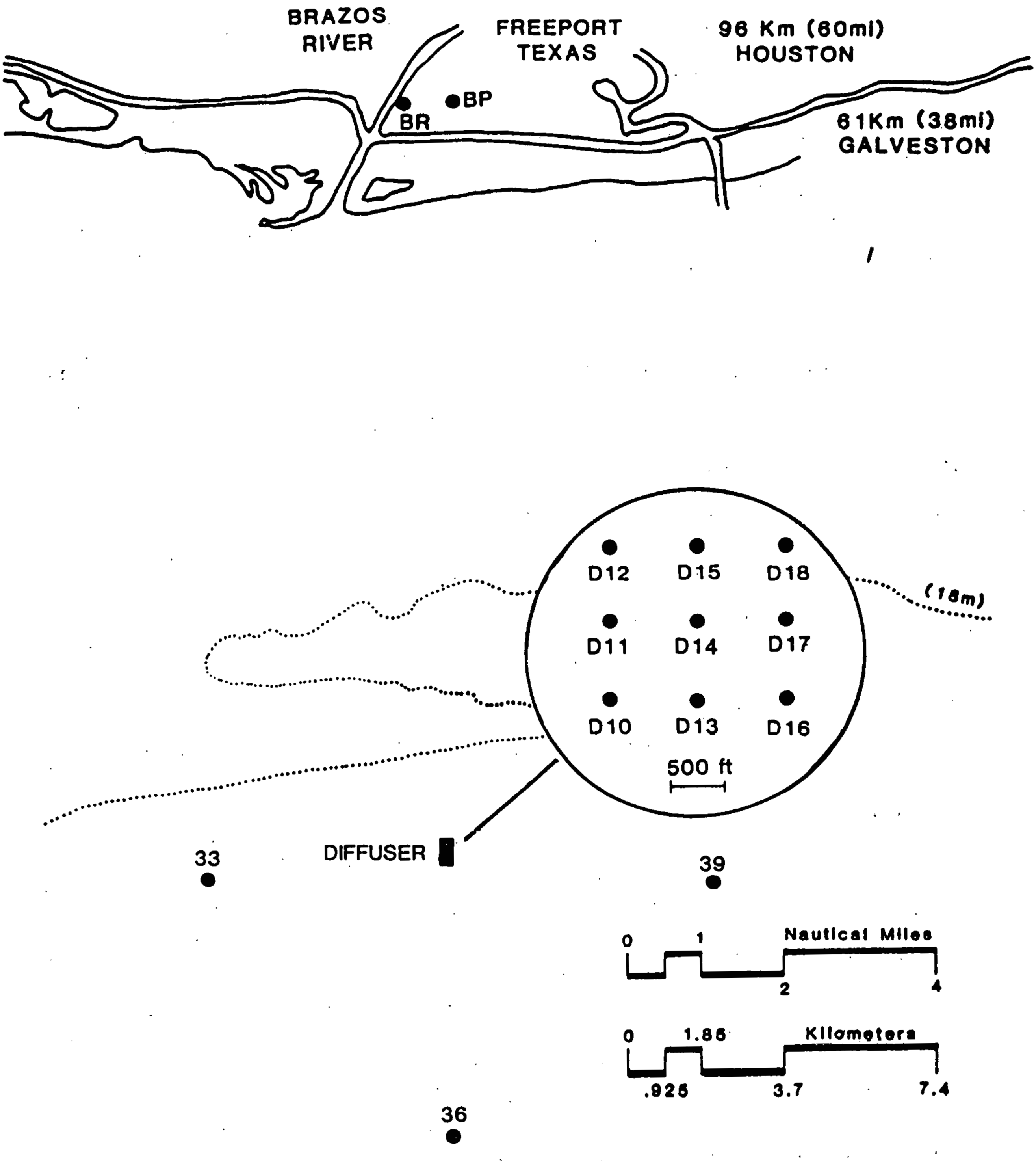


Figure 3-1. Water and sediment quality stations at Bryan Mound.

Table 3-1. Station designators and coordinates for the water and sediment quality stations at Bryan Mound.

Station	North Latitude	West Longitude
33	28°42'18"	95°17'42"
36	28°41'24"	95°11'27"
39	28°47'00"	95°10'24"
D10	28°44'04"	95°14'34"
D11	28°44'07"	95°14'37"
D12	28°44'11"	95°14'40"
D13	28°44'06"	95°14'30"
D14	28°44'10"	95°14'33"
D15	28°44'13"	95°14'35"
D16	28°44'08"	95°14'25"
D17	28°44'12"	95°14'28"
D18	28°44'16"	95°14'31"

3.2 Sampling and Analytical Methods

Sample collection and analytical procedures used in these studies are presented in detail in the Field and Laboratory Procedures Manual (Hann, Giammona and Randall, 1983). Analytical methods used were based upon those contained in the American Public Health Association's Standard Methods for the Examination of Water and Wastewater, 14th edition, 1975, or in the Environmental Protection Agency's Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020 of March 1979 where possible. Laboratory quality assurance was based upon procedures contained in the Handbook for Analytical Quality Control in Water and Wastewater Laboratories (EPA, 1979).

3.2.1 Field Sampling

Water samples were collected at all stations using 5-liter Niskin water samplers suspended on stainless steel wire. Also at each station, the following parameters were measured in situ using a Hydrolab 8000 probe system: conductivity, temperature, pH, depth and dissolved oxygen. The probe system was calibrated according to manufacturer's instructions prior to each cruise.

At each station and depth, water samples collected in the Niskin samplers were split into appropriate fractions and transferred to other containers for preservation, storage and transfer to the laboratory for subsequent analysis. Samples for heavy metal, major ion, and oil and grease analyses were preserved for shipment back to the laboratory by placing them in the dark at 4°C.

Sediment samples were collected at each station using a precleaned stainless steel 25 x 25 cm box corer. The upper 5 cm of sediment was sampled through the top opening of the sampler. Samples used for general sediment quality and heavy metal analyses were taken from the center surface area using an acid-cleaned plastic spatula and placed into clean conventional polyethylene freezer cartons. These cartons were filled to the top, sealed, and immediately cooled using blue ice packs and kept cold until they arrived in the laboratory.

For quality control and aid in data interpretation, a minimum of 10% of all water samples were collected and analyzed in duplicate. All sediment samples were collected and analyzed in duplicate.

Hydrocarbon water samples were collected biannually using either a special precleaned PVC pump and tubing system or a precleaned 30-liter PVC Niskin bottle. Samples were stored in precleaned 20-liter glass carboys for return to the laboratory. Sediment samples for hydrocarbon analyses were collected using a precleaned stainless steel box corer. These samples were stored in specially cleaned glass jars with teflon-lined caps and frozen until analysis.

3.2.2 Laboratory and Analytical Procedures

Upon return to the laboratory, all water and sediment samples requiring refrigeration are stored at 4°C until time of analyses. Water samples for metal analyses were preserved by addition of 5 ml of trace metal grade nitric acid per liter sample after filtration through 0.45 um pore size membrane filters.

Analyses of general water and pore water quality parameters were made in accordance with the following methods. Chloride (Cl) was determined by the mercuric nitrate titration method while sulfates (SO_4) were determined by the barium sulfate turbidimetric method, both after appropriate dilution.

Those organic compounds lumped together and referred to under the general term "oil and grease" were measured using the freon extraction, infrared spectrophotometric method.

Samples collected for salinity measurements were analyzed in the laboratory by conductance using a Grundy Model 6230N benchtop salinometer according to manufacturer's instructions. The salinometer was standardized against standard I.A.P.S.O. seawater.

All heavy metals in the water column and major cations in both the water column and pore waters were measured by atomic absorption spectrophotometry (AAS). The major cations (sodium, potassium, calcium, and magnesium) were determined by direct flame aspiration after appropriate dilution and treatment. Mercury (Hg) was analyzed using the cold method of AAS. The remaining heavy metals were determined by chelation and extraction into methyl isobutyl ketone. The metals contained in the extract were then measured by direct AAS.

Water samples for high molecular weight hydrocarbon were extracted directly from the large glass carboys using methylene chloride. The extracts were combined, reduced in volume and fractionated using silica gel chromatography into four fractions. Each fraction was analyzed by gas chromatography.

Immediately upon return to the laboratory, pH and oxidation-reduction potential (Eh) of sediment samples were made using a standard laboratory mv/pH meter. Sediment samples were then divided into appropriate fractions for analyses required. Pore waters were obtained and used for major cation and anion analyses.

Heavy metal analyses were also performed on 1N HNO_3 extracts obtained from the sediments.

For high molecular weight hydrocarbon analysis, sediment samples were thawed, mixed, transferred to a Soxhlet apparatus and extracted with a series of solvents. These extracts were then fractionated by silica gel chromotography into four fractions and analyzed by gas chromatography.

3.3 Results

3.3.1 General Water Quality

The general water quality parameters measured on a quarterly basis included salinity, temperature, pH, and oil and grease. Results of these analyses for the four quarterly sampling periods, November 16, 1982, February 22, 1983, May 23, 1983 and August 29, 1983 are presented in Appendix Tables C-1 through C-4. More intensive or monthly analyses for salinity, temperature, and dissolved oxygen were conducted as part of the CTD/DO studies and are presented as part of Chapter 1.

Of the remaining two parameters, only oil and grease appears of interest. Oil and grease levels were below the detection limit of 0.5 mg/l except for the February 22 sampling period. Values at that time ranged fom 0.5 mg/l to 16 mg/l. Elevated levels were found at both the diffuser stations and control stations. The mean value for diffuser stations was 7.3 mg/l and for control stations, 7.5 mg/l. Levels of oil and grease near 10 mg/l have been observed over the area in some of the previous years during early spring and appear associated with either runoff or plankton blooms that occur at this time of year. The elevated levels in February 1982 similarly appear related to processes outside the diffuser area.

3.3.2 Major Ions in Water Column

Results of major ion analyses for the quarterly sampling periods are presented in Appendix Tables C-1 through C-4.

Any change in major ions as a result of brine discharge should be detected in the bottom waters. For evaluation purposes, mean values of the major ions in the bottom waters were calculated for the downcoast intermediate diffuser stations (D10, D11 and D12--set 1 in the tabulated data), the near field diffuser stations (D13, D14 and D15--set 2), the upcoast intermediate diffuser stations (D16, D17 and D18--set 3) and the control or ambient stations (33, 36 and 39--set 4). A comparison of these mean values plus standard deviations and range of values for the quarterly sample dates are presented in Table 3-2.

According to Bauer (1971), when comparing chemical data with limited degrees of freedom the two-tailed "t" test is used to compare the difference between two averages both of which have a degree of uncertainty. This approach was used to establish whether any of the three diffuser area sets individually were significantly different from the controls at the 95% confidence level. During the first three quarters, the only major ion that was significantly different at the diffuser area stations was calcium which was higher at two of the diffuser sets in November 1982. In November, salinity was also higher significantly at the intermediate upcoast diffuser stations (set 3). In February and May, salinity was significantly higher at all diffuser station sets relative to ambient.

More interesting were the results for the last quarter samples collected on August 29, 1983, about one and a half weeks after Hurricane Alicia. On that date, a number of ions were significantly lower in the area of the diffuser than at the controls. We have no explanation for this observation at this time. It is possible that low salinity bottom water was moving through the area at the time of sampling and that two of

Table 3-2. Mean major ion values for bottom waters at the diffuser, intermediate field diffuser and control stations.

SET1=(D10,D11,D12) SET2=(D13,D14,D15) SET3=(D16,D17,D18) SET4=(33,36,39)

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
DATE=16 NOV 82 SET=1					
SAL	3	34.867	0.808	34.000	35.600
NA	3	10.400	0.500	9.900	10.900
K	3	0.395	0.006	0.389	0.399
CA	3	0.407	0.006	0.400	0.410
MG	3	1.237	0.035	1.200	1.270
CL	3	19.900	0.458	19.400	20.300
SO4	3	2.333	0.126	2.200	2.450
DATE=16 NOV 82 SET=2					
SAL	3	34.767	0.751	34.000	35.500
NA	3	10.300	0.458	9.800	10.700
K	3	0.397	0.001	0.396	0.398
CA	3	0.410	0.000	0.410	0.410
MG	3	1.210	0.026	1.190	1.240
CL	3	19.467	0.306	19.200	19.800
SO4	3	2.417	0.104	2.300	2.500
DATE=16 NOV 82 SET=3					
SAL	3	34.567	0.289	34.400	34.900
NA	3	10.367	0.058	10.300	10.400
K	3	0.397	0.004	0.394	0.402
CA	3	0.410	0.010	0.400	0.420
MG	3	1.240	0.020	1.220	1.260
CL	3	19.533	0.252	19.300	19.800
SO4	3	2.410	0.066	2.350	2.480
DATE=16 NOV 82 SET=4					
SAL	3	34.033	0.115	33.900	34.100
NA	3	10.333	0.493	10.000	10.900
K	3	0.389	0.008	0.380	0.394
CA	3	0.393	0.006	0.390	0.400
MG	3	1.283	0.110	1.210	1.410
CL	3	19.633	0.404	19.200	20.000
SO4	3	2.350	0.180	2.160	2.500
DATE=22 FEB 83 SET=1					
SAL	3	34.700	0.458	34.200	35.100
NA	3	9.467	0.153	9.300	9.600
K	3	0.374	0.009	0.364	0.382
CA	3	0.390	0.000	0.380	0.800
MG	3	1.207	0.042	1.160	1.240
CL	3	18.267	0.115	18.200	18.400
SO4	3	1.757	0.172	1.620	1.950
DATE=22 FEB 83 SET=2					
SAL	3	34.967	0.153	34.800	35.100
NA	3	9.733	0.306	9.400	10.000
K	3	0.368	0.004	0.364	0.371
CA	3	0.387	0.006	0.380	0.390
MG	3	1.167	0.012	1.160	1.180
CL	3	18.733	0.473	18.200	19.100
SO4	3	1.040	0.085	1.850	2.020
DATE=22 FEB 83 SET=3					
SAL	3	34.100	0.200	33.900	34.300
NA	3	9.800	0.265	9.600	10.100
K	3	0.368	0.000	0.368	0.368
CA	3	0.383	0.006	0.380	0.390
MG	3	1.173	0.012	1.160	1.180
CL	3	19.000	0.520	18.400	19.300
SO4	3	2.000	0.020	1.980	2.020
DATE=22 FEB 83 SET=4					
SAL	3	32.433	0.252	32.200	32.700
NA	3	9.400	0.200	9.200	9.600
K	3	0.369	0.004	0.364	0.371
CA	3	0.390	0.000	0.390	0.390
MG	3	1.170	0.026	1.150	1.200
CL	3	18.367	0.351	18.000	18.700
SO4	3	1.957	0.040	1.920	2.000

Table 3-2. Continued.

SET1=(D10,D11,D12) SET2=(D13,D14,D15) SET3=(D16,D17,D18) SET4=(33,36,39)

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
DATE=23 MAY 83 SET=1					
SAL	3	35.200	0.173	35.000	35.300
NA	3	10.367	0.503	9.900	10.900
K	3	0.360	0.012	0.346	0.367
CA	3	0.400	0.017	0.380	0.410
MG	3	1.343	0.058	1.310	1.410
CL	3	18.867	0.153	18.700	19.000
SO4	3	2.473	0.040	2.450	2.520
DATE=23 MAY 83 SET=2					
SAL	3	36.533	0.503	36.000	37.000
NA	3	10.267	0.379	10.000	10.700
K	3	0.370	0.002	0.367	0.371
CA	3	0.407	0.006	0.400	0.410
MG	3	1.227	0.029	1.210	1.260
CL	3	19.433	0.635	18.700	19.800
SO4	3	2.713	0.210	2.500	2.920
DATE=23 MAY 83 SET=3					
SAL	3	35.733	0.709	35.100	36.500
NA	3	10.300	0.608	9.600	10.700
K	3	0.366	0.002	0.363	0.367
CA	3	0.400	0.000	0.400	0.400
MG	3	1.223	0.064	1.150	1.260
CL	3	18.833	1.365	17.900	20.400
SO4	3	2.510	0.155	2.350	2.660
DATE=23 MAY 83 SET=4					
SAL	3	32.900	0.854	32.000	33.700
NA	3	9.667	0.208	9.500	9.900
K	3	0.364	0.009	0.354	0.371
CA	3	0.407	0.006	0.400	0.410
MG	3	1.243	0.058	1.210	1.310
CL	3	18.333	0.404	17.900	18.700
SO4	3	2.623	0.075	2.550	2.700
DATE=29 AUG 83 SET=1					
SAL	3	30.000	0.458	29.600	30.500
NA	3	8.867	0.153	8.700	9.000
K	3	0.336	0.001	0.335	0.337
CA	3	0.343	0.006	0.340	0.350
MG	3	1.023	0.006	1.020	1.030
CL	3	16.533	0.289	16.200	16.700
SO4	3	2.287	0.058	2.220	2.320
DATE=29 AUG 83 SET=2					
SAL	3	30.067	0.666	29.500	30.800
NA	3	8.633	0.252	8.400	8.900
K	3	0.331	0.005	0.326	0.336
CA	3	0.337	0.006	0.330	0.340
MG	3	1.010	0.017	1.000	1.030
CL	3	16.200	0.458	15.800	16.700
SO4	3	2.410	0.036	2.380	2.450
DATE=29 AUG 83 SET=3					
SAL	3	29.633	0.289	29.300	29.800
NA	3	8.500	0.100	8.400	8.600
K	3	0.329	0.003	0.326	0.331
CA	3	0.343	0.006	0.340	0.350
MG	3	1.030	0.017	1.010	1.040
CL	3	16.233	0.153	16.100	16.400
SO4	3	2.387	0.012	2.380	2.400
DATE=29 AUG 83 SET=4					
SAL	3	32.133	1.498	30.900	33.800
NA	3	9.467	0.473	9.100	10.000
K	3	0.360	0.016	0.348	0.379
CA	3	0.370	0.017	0.360	0.390
MG	3	1.103	0.051	1.060	1.160
CL	3	18.300	0.693	17.500	18.700
SO4	3	2.657	0.129	2.550	2.800

the control stations were outside of this type water thereby biasing results for the controls at that time. One problem with quarterly sampling is that short-term events may be missed or only partially observed. Secondly, it is difficult to determine meaningful standard deviations for a specific sample period since only three stations are measured for each station set. This latter problem accounts for the fact that some diffuser station sets had higher means but were not significantly different statistically from ambient compared to other station sets that may have had lower means but were statistically different.

As previously stated, concern was raised early in the SPR project about the potential adverse effects of ionic imbalance or changes in the ratios of one major ion to another. Such imbalance was expected since the relative proportions of the major ions in seawater and the salt dome brine are different. The ratios for some of these ions in typical seawater (35 o/oo) are:

$$Na/K = 27.8$$

$$Ca/Mg = 0.32$$

$$SO_4/Cl = 0.140$$

Based upon major ion analyses of the Bryan Mound brine for the past year as presented in Table 3-3, these same ratios for the brine were:

$$Na/K = 170$$

$$Ca/Mg = 4.04$$

$$SO_4/Cl = 0.011$$

From these two sets of ratios, it can be seen that differences between the two salt waters are an order of magnitude. The Na/K and Ca/Mg ratios in the receiving waters would tend to increase and SO_4/Cl decrease as a result of brine discharge. Ion ratios for all samples are presented in

Table 3-3. Major ions in Brazos River water and Bryan Mound brine. Concentrations are in g/l.

Major	11/17/82		2/21/83		5/24/83		8/30/83	
Ion	BR	BP	BR	BP	BR	BP	BR	BP
Na^{+}	3.5	108.7	0.8	100.0	0.34	104.0	1.7	106.0
K^{+}	0.14	0.66	0.03	0.61	0.02	0.54	0.06	0.66
Ca^{++}	0.01	0.93	<0.01	0.85	<0.01	0.84	<0.01	0.94
Mg^{++}	0.37	0.23	0.08	0.21	0.04	0.2	0.15	0.22
Cl^{-}	5.5	175.4	1.22	161.5	0.54	166.2	2.7	170.0
SO_4^{--}	0.84	1.99	0.19	1.83	0.09	1.70	0.38	2.05
S o/oo *	9	265	2	244	1	252	4	256

BR - Brazos River Intake

BP - Brine Pond Discharge

* From POSSI data

Appendix Table C-5 while a comparison of the mean ion ratios for the bottom waters is presented in Table 3-4. Based upon the two-tailed "t" test, significant differences at the 95% confidence level were found only twice during the year for any of the ratios. The SO_4/Cl ratio at diffuser set 1 on May 23 was lower than ambient and the Na/K ratio at diffuser set 2 on August 29 was lower than ambient.

Overall, during this report period brine discharge had little if any effect upon major ion levels or ions ratios in the water column.

3.3.3 Heavy Metals in Water Column

Heavy metal analyses of water samples for the past year are presented in Appendix Tables C-1 through C-4. Throughout the year, metal levels were generally low and at levels expected based upon predischarge and previous postdischarge data. A few high values were observed for a single sample only, although not necessarily the same sample for any given metal. Several metals (Hg, Ni, Cr, Cd) were usually below detection limits and exceeded the detection limit for only a few samples. Lead (Pb) was also usually below the detection limit of 1 $\mu g/l$. However, Pb levels near the diffuser on November 16, 1982 ranged from <1 to 6 $\mu g/l$. Highest values were observed at the downcoast intermediate diffuser stations (D10, D11 and D12). Physical oceanographic observations for the period sampled indicate currents were in that direction and suggests the Pb could have come from the diffuser. Results of metal analyses of brine taken at the brine pond, presented in Table 3-5, indicate elevated Pb levels occurred in the brine relative to the Brazos River leach water on November 17. This suggests the potential existed for Pb in the brine to impact on waters near the diffuser. It should, however, be pointed out that elevated Pb levels existed in the brine at all four sample dates and Pb

Table 3-4. Mean major ratios for bottom waters at Bryan Mound diffuser and control stations.

SET1=D10,D11,D12 SET2=D13,D14,D15 SET3=D16,D17,D18 SET4=33,36,39

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
DATE=16 NOV 82 SET=1					
RNAK	3	26.301	0.990	25.450	27.387
RCAMG	3	0.329	0.013	0.315	0.342
RSO4CL	3	0.117	0.006	0.110	0.121
DATE=16 NOV 82 SET=2					
RNAK	3	25.921	1.084	24.747	26.884
RCAMG	3	0.339	0.007	0.331	0.345
RSO4CL	3	0.124	0.005	0.119	0.128
DATE=16 NOV 82 SET=3					
RNAK	3	26.093	0.414	25.622	26.396
RCAMG	3	0.331	0.013	0.317	0.344
RSO4CL	3	0.123	0.004	0.121	0.128
DATE=16 NOV 82 SET=4					
RNAK	3	26.588	1.822	25.381	28.684
RCAMG	3	0.308	0.028	0.277	0.331
RSO4CL	3	0.120	0.011	0.109	0.130
DATE=22 FEB 83 SET=1					
RNAK	3	25.338	0.209	25.131	25.549
RCAMG	3	0.323	0.011	0.315	0.336
RSO4CL	3	0.096	0.010	0.089	0.107
DATE=22 FEB 83 SET=2					
RNAK	3	26.471	0.677	25.824	27.174
RCAMG	3	0.331	0.004	0.328	0.336
RSO4CL	3	0.104	0.006	0.097	0.107
DATE=22 FEB 83 SET=3					
RNAK	3	26.630	0.719	26.087	27.446
RCAMG	3	0.327	0.004	0.322	0.331
RSO4CL	3	0.105	0.002	0.104	0.108
DATE=22 FEB 83 SET=4					
RNAK	3	25.496	0.331	25.275	25.876
RCAMG	3	0.333	0.007	0.325	0.339
RSO4CL	3	0.107	0.002	0.104	0.109

Table 3-4. Continued.

SET1=D10,D11,D12 SET2=D13,D14,D15 SET3=D16,D17,D18 SET4=33,36,39

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
DATE=23 MAY 83 SET=1					
RNAK	3	28.848	2.363	26.975	31.503
RCAMG	3	0.298	0.025	0.270	0.313
RSO4CL	3	0.131	0.003	0.129	0.135
DATE=23 MAY 83 SET=2					
RNAK	3	27.772	0.968	26.954	28.841
RCAMG	3	0.332	0.007	0.325	0.339
RSO4CL	3	0.140	0.007	0.134	0.147
DATE=23 MAY 83 SET=3					
RNAK	3	28.161	1.492	26.446	29.155
RCAMG	3	0.328	0.018	0.317	0.348
RSO4CL	3	0.134	0.017	0.115	0.149
DATE=23 MAY 83 SET=4					
RNAK	3	26.576	1.204	25.876	27.966
RCAMG	3	0.328	0.019	0.305	0.339
RSO4CL	3	0.143	0.003	0.140	0.147
DATE=29 AUG 83 SET=1					
RNAK	3	26.388	0.408	25.970	26.786
RCAMG	3	0.336	0.007	0.330	0.343
RSO4CL	3	0.138	0.001	0.137	0.139
DATE=29 AUG 83 SET=2					
RNAK	3	26.053	0.383	25.767	26.488
RCAMG	3	0.333	0.006	0.330	0.340
RSO4CL	3	0.149	0.005	0.143	0.152
DATE=29 AUG 83 SET=3					
RNAK	3	25.837	0.398	25.378	26.074
RCAMG	3	0.333	0.006	0.327	0.337
RSO4CL	3	0.147	0.002	0.145	0.148
DATE=29 AUG 83 SET=4					
RNAK	3	26.269	0.118	26.149	26.385
RCAMG	3	0.335	0.005	0.330	0.340
RSO4CL	3	0.145	0.005	0.140	0.150

Table 3-5. Metal content of Brazos River water and Bryan Mound brine. Concentrations are in $\mu g/l$.

Metal	11/17/82		2/21/83		5/24/83		8/30/83	
Content	BR	BP	BR	BP	BR	BP	BR	BP
Al	<1	<5	10	8	--	--	--	--
Cd	<0.5	0.8	<0.5	<0.5	<0.5	1.1	<0.5	0.9
Cr	4	5	4	3	23	5	3	4
Cu	2	2	3	1	<0.5	<0.5	0.5	0.5
Fe	600	215	2200	30	2300	3200	41	990
Hg	<0.2	<0.2	<0.2	<0.2	<0.1	<0.2	0.3	<0.2
Ni	7	21	7	21	7	<1	2	<1
Pb	2	27	3	9	1.4	25	<0.5	26
Zn	57	98	48	64	32	39	12	45

BR - Brazos River Intake

BP - Brine Pond Discharge

was not detected in waters near the diffuser on three of the four sampling periods suggesting adequate dilution occurred. In addition, the highest Pb levels observed in offshore waters on November 16 were located at the surface. It is not possible to explain this observation if the diffuser were the only source of the Pb. Lead introduced from the diffuser should have remained in the bottom waters.

Offshore, highest levels for iron (Fe) were observed in November 1982 and for copper (Cu), zinc (Zn) and nickel (Ni) in August 1983. The latter were observed after the passage of Hurricane Alicia. All three metals were highest at the downcoast intermediate diffuser stations and at the downcoast control station (33). Since Cu and Ni were very low in the brine at that time, as indicated in Table 3-5, it would appear that increased levels of these metals were not due to brine discharge although currents in the area were downcoast. Results of the metal analyses for the past year have been summarized as ranges and are presented in Table 3-6 along with previously observed ranges and EPA recommended criteria for marine aquatic life (EPA, 1980). From this table, it can be seen that metal levels at the diffuser area were about the same as for control stations and were essentially no higher than previously observed levels including those during the predischarge period. Also, levels were below the EPA criteria levels for the past year with the exception of nickel for one sample and copper for four samples which exceeded the 24-hour criteria and the possible exception of Hg whose detection limit was above the 24-hour average value allowed. Mercury (Hg) as well as the other metals did not exceed the maximum value limit during this report period. Furthermore, since samples used in this study are grab samples rather than 24-hour composites, the 24-hour criteria level does not appear to be

Table 3-6. Range of soluble metal values observed in waters at Bryan Mound diffuser and control stations (in $\mu g/l$).

Present Period			Previous Results			EPA Criteria for Marine Aquatic Life		
	Diffuser Area	Controls		Diffuser Area	Controls		Max. Allowed	24-Hour Ave.
Al	<0.5 - 5	<0.5 - 1	Al	<0.3 - 23.5	<0.3 - 16.7	Al	--	--
Cd	<0.1 - 1.8	<0.1 - 1.4	Cd	<0.5 - 3.5	<0.5 - 2.4	Cd	59	4.5
Cr	<1	<1	Cr	<1 - 4 (7)*	<1 - 5	Cr	1260	18
Cu	0.5 - 9.1(12.3)*	0.5 - 6.5	Cu	0.5 - 11.6	0.5 - 9.5	Cu	23	4
Fe	1 - 30	1 - 15	Fe	<2 - 58	1 -21	Fe	--	--
Hg	<0.1	<0.1	Hg	<0.1 - 0.7 (4)*	<0.1 - 0.4	Hg	3.7	0.025
Ni	1 - 11	1 - 5	Ni	<5 - 6	<5 - 11	Ni	140	7.1
Pb	<1 - 6	<1 - 2	Pb	<1 - 5	<1 - 11	Pb	50**	--
Zn	1 - 42	1 - 34	Zn	<1 - 29 (87)*	<1 - 73	Zn	170	58

( )* Represents a single value above listed range.

** No criteria listed, old proposed EPA value (1973).

applicable.

3.3.4 General Sediment Quality

General sediment quality parameters that were measured during the past year included pH, Eh, and oil and grease. Results of the individual analyses are contained in Appendix Tables C-6 through C-9. As discussed later under major ion results, for the purpose of evaluating brine discharge effects upon sediments, stations D10 through D18 are considered as the diffuser and stations 33, 36 and 39 as the controls.

As indicated in Figure 3-2, oil and grease concentrations in the sediments continued at the lower levels observed in mid 1982. The highest value, 170 mg/kg, was observed in late August 1983 at station D14 located in the middle of the diffuser. However, the second highest of 159 mg/kg was located at control station 36, also in August. Mean oil and grease levels at the diffuser were essentially the same as observed for ambient during the preceding two years. Highest mean oil and grease values during the past year were in November 1982. Natural variability of oil and grease in the sediments is considerable and it is difficult to ascertain effects of the brine discharge on this parameter on a quarterly basis.

Most notable in sediment quality during the past year was the fact that after steadily declining for over two years, the redox potential (Eh) increased to a positive value at all stations in May 1983 (see Figure 3-3). This was the first indication of sufficient oxygenation of sediments since late 1980. Unfortunately, the Eh values returned to negative values again in late August following Hurricane Alicia in mid-August and hypoxic conditions in early summer. Although reasons for the sudden increase and subsequent decrease in Eh are not known at this time, there appears to be a significant relationship between the Eh and

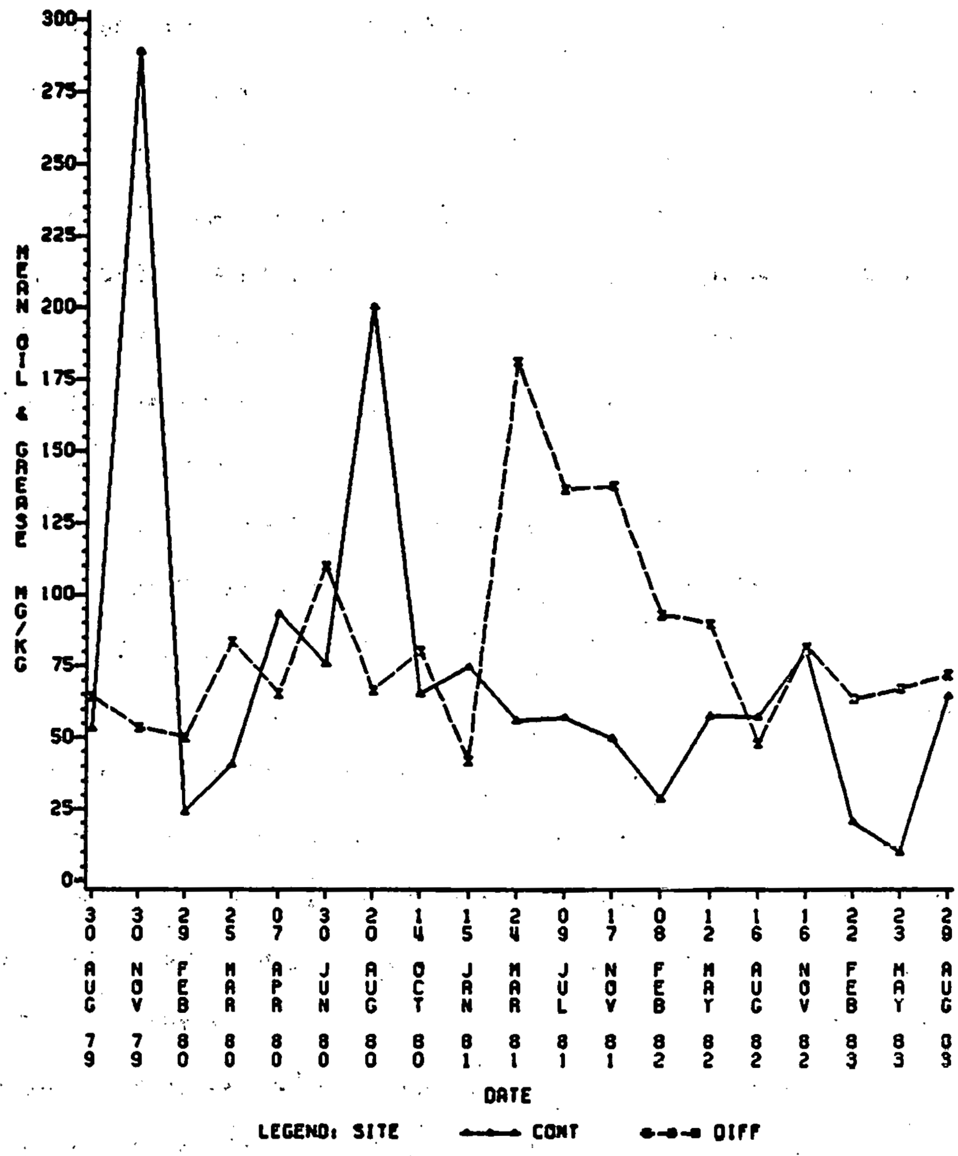


Figure 3-2. Mean sediment oil and grease values for the diffuser area and control stations.

benthic organisms. This is discussed in more detail in Chapter 5 of this report.

Mean pH values since the start of the monitoring program have remained essentially the same (Figure 3-4).

3.3.5 Major Ions in Sediment Pore Water

Results of major ion analyses of sediment pore waters are also presented in Appendix Tables C-6 through C-9. The mean values for the major ions and total dissolved solids (TDS) in pore water from sediment samples taken from the near field (diffuser) and downcoast and upcoast intermediate diffuser fields are compared to those from ambient stations in Table 3-7. These indicate that elevated TDS, Na^+ and Cl^- levels compared to ambient occurred at both the near and intermediate diffuser stations (sets 1, 2 and 3). The similarity of values observed for the near and intermediate diffuser stations suggest that the effects of brine discharge upon major ions in the sediment extends to at least the intermediate stations located 152 m from the diffuser itself and that, for all practical purposes, all nine diffuser area stations can be considered together in evaluating the effects at the diffuser. Therefore, stations D10 through D18 are considered as being at the diffuser in graphical presentations of sediment data.

The mean total dissolved solids in pore waters located at all diffuser area stations and at the ambient or control stations for the past year are combined with those of previous report periods and are shown in Figure 3-5. During the past year, mean values at the diffuser area ranged from 2.1 to 2.5 g/l over ambient. The highest single value was 40.5 g/l. Since salinity (o/oo) is equal to 0.9012 TDS, this represented a salinity of 36.5 o/oo, considerably lower than the 56.1 o/oo observed in May of

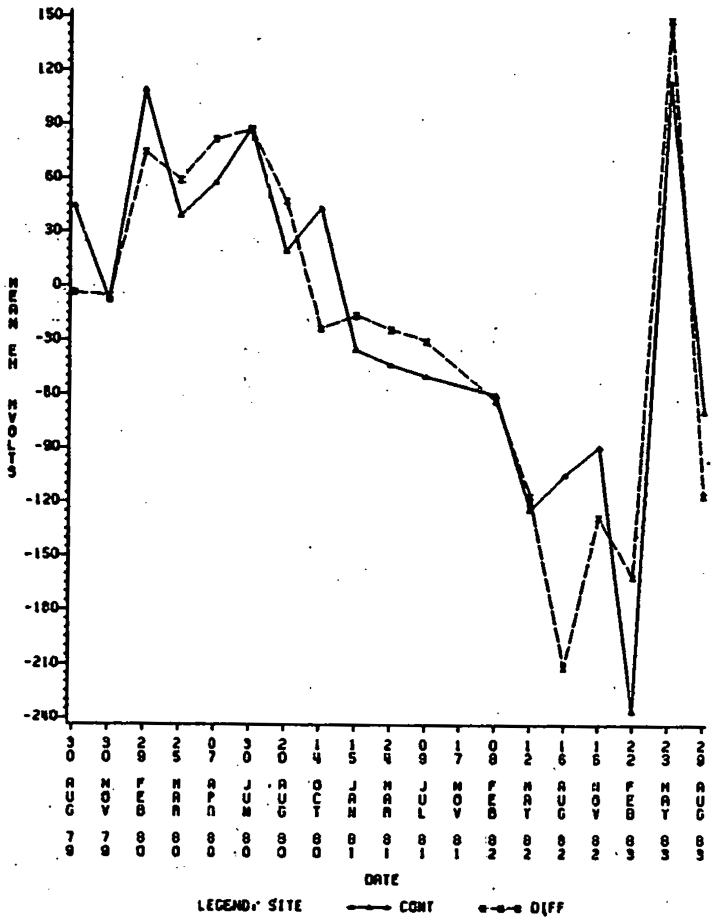


Figure 3-3. Sediment Eh values for diffuser area and control stations.

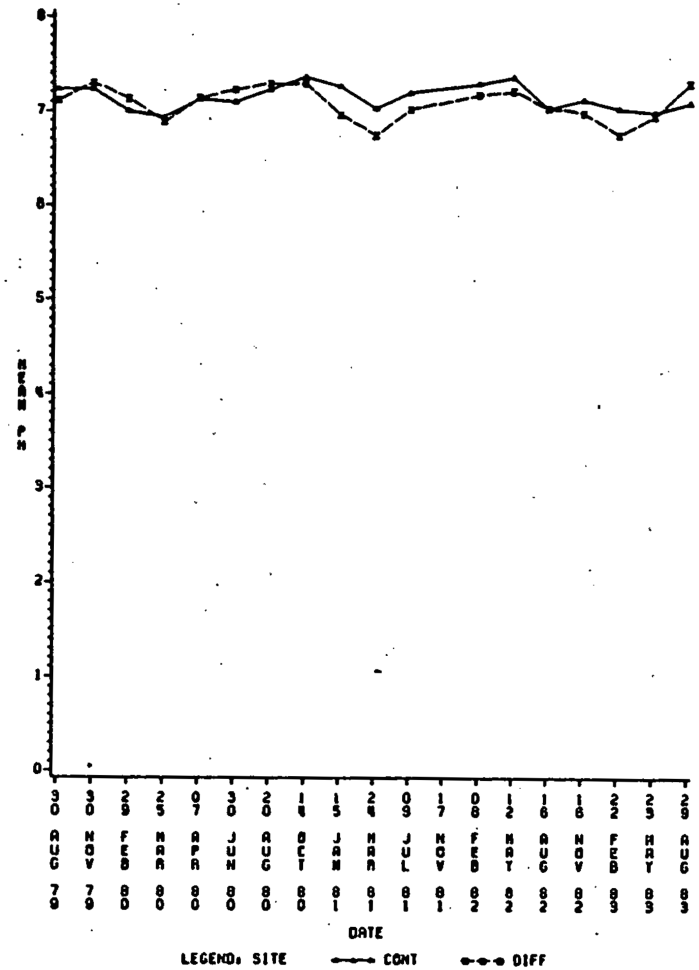


Figure 3-4. Sediment pH values for diffuser area and control stations.

Table 3-7. Mean major ion values for sediment pore waters at Bryan Mound diffuser and control stations.

SET1=(D10,D11,D12) SET2=(D13,D14,D15) SET3=(D16,D17,D18) SET4=(33,36,39)

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
DATE=16 NOV 82 SET=1					
TDS	3	38.233	0.351	37.900	38.600
NA	3	10.700	0.300	10.400	11.000
K	3	0.350	0.000	0.350	0.350
CA	3	0.400	0.000	0.400	0.400
MG	3	1.300	0.035	1.280	1.340
CL	3	20.367	0.503	19.900	20.900
SO4	3	2.507	0.042	2.460	2.540
DATE=16 NOV 82 SET=2					
TDS	3	36.633	1.518	35.000	38.000
NA	3	10.367	0.306	10.100	10.700
K	3	0.343	0.006	0.340	0.350
CA	3	0.383	0.012	0.370	0.390
MG	3	1.210	0.020	1.190	1.230
CL	3	19.733	0.666	19.000	20.300
SO4	3	2.183	0.040	2.140	2.220
DATE=16 NOV 82 SET=3					
TDS	3	39.200	0.436	38.700	39.500
NA	3	10.800	0.000	10.800	10.800
K	3	0.340	0.017	0.320	0.350
CA	3	0.400	0.010	0.390	0.410
MG	3	1.270	0.046	1.220	1.310
CL	3	20.433	0.231	20.300	20.700
SO4	3	2.140	0.035	2.120	2.180
DATE=16 NOV 82 SET=4					
TDS	3	35.867	0.379	35.600	36.300
NA	3	9.967	0.153	9.800	10.100
K	3	0.360	0.010	0.350	0.370
CA	3	0.393	0.006	0.390	0.400
MG	3	1.280	0.044	1.230	1.310
CL	3	18.933	0.306	18.600	19.200
SO4	3	2.240	0.017	2.220	2.250
DATE=22 FEB 83 SET=1					
TDS	3	39.433	0.153	39.300	39.600
NA	3	10.867	0.252	10.600	11.100
K	3	0.347	0.006	0.340	0.350
CA	3	0.380	0.010	0.370	0.390
MG	3	1.227	0.025	1.200	1.250
CL	3	20.100	0.200	19.900	20.300
SO4	3	2.257	0.129	2.150	2.400
DATE=22 FEB 83 SET=2					
TDS	3	39.800	0.557	39.200	40.300
NA	3	10.800	0.458	10.300	11.200
K	3	0.370	0.026	0.350	0.400
CA	3	0.390	0.010	0.380	0.400
MG	3	1.263	0.091	1.160	1.330
CL	3	19.900	0.529	19.300	20.300
SO4	3	2.347	0.090	2.290	2.450
DATE=22 FEB 83 SET=3					
TDS	3	39.733	0.666	39.300	40.500
NA	3	10.967	0.115	10.900	11.100
K	3	0.367	0.023	0.340	0.380
CA	3	0.390	0.000	0.390	0.390
MG	3	1.227	0.049	1.170	1.260
CL	3	20.233	0.231	20.100	20.500
SO4	3	2.313	0.090	2.220	2.400
DATE=22 FEB 83 SET=4					
TDS	3	37.100	0.800	36.300	37.900
NA	3	10.167	0.153	10.000	10.300
K	3	0.380	0.010	0.370	0.390
CA	3	0.383	0.006	0.380	0.390
MG	3	1.247	0.031	1.220	1.280
CL	3	18.800	0.458	18.400	19.300
SO4	3	2.283	0.153	2.150	2.450

Table 3-7. Continued.

SET1=(D10,D11,D12) SET2=(D13,D14,D15) SET3=(D16,D17,D18) SET4=(33,36,39)

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
DATE=23 MAY 83 SET=1					
TDS	3	38.667	1.050	37.600	39.700
NA	3	10.867	0.153	10.700	11.000
K	3	0.373	0.006	0.370	0.380
CA	3	0.393	0.012	0.380	0.400
MG	3	1.217	0.021	1.200	1.240
CL	3	19.300	0.700	18.500	19.800
SO4	3	2.450	0.100	2.350	2.550
DATE=23 MAY 83 SET=2					
TDS	3	39.200	0.721	38.400	39.800
NA	3	10.633	0.208	10.400	10.800
K	3	0.367	0.012	0.360	0.380
CA	3	0.380	0.017	0.360	0.390
MG	3	1.180	0.026	1.150	1.200
CL	3	19.800	0.000	19.800	19.800
SO4	3	2.460	0.151	2.300	2.600
DATE=23 MAY 83 SET=3					
TDS	3	38.300	0.866	37.800	39.300
NA	3	10.733	0.231	10.600	11.000
K	3	0.357	0.006	0.350	0.360
CA	3	0.377	0.015	0.360	0.390
MG	3	1.233	0.012	1.220	1.240
CL	3	19.867	0.208	19.700	20.100
SO4	3	2.470	0.061	2.400	2.510
DATE=23 MAY 83 SET=4					
TDS	3	36.400	0.872	35.800	37.400
NA	3	9.800	0.173	9.600	9.900
K	3	0.353	0.029	0.320	0.370
CA	3	0.370	0.026	0.340	0.390
MG	3	1.223	0.029	1.190	1.240
CL	3	18.633	0.252	18.400	18.900
SO4	3	2.567	0.058	2.500	2.600
DATE=29 AUG 83 SET=1					
TDS	3	38.667	1.050	37.600	39.700
NA	3	10.033	0.208	9.800	10.200
K	3	0.353	0.012	0.340	0.360
CA	3	0.407	0.012	0.400	0.420
MG	3	1.160	0.010	1.150	1.170
CL	3	18.867	0.586	18.200	19.300
SO4	3	2.617	0.076	2.550	2.700
DATE=29 AUG 83 SET=2					
TDS	3	39.567	1.069	38.400	40.500
NA	3	10.367	0.058	10.300	10.400
K	3	0.377	0.012	0.370	0.390
CA	3	0.430	0.026	0.400	0.450
MG	3	1.170	0.017	1.150	1.180
CL	3	19.267	0.513	18.700	19.700
SO4	3	2.750	0.132	2.600	2.850
DATE=29 AUG 83 SET=3					
TDS	3	38.300	0.866	37.800	39.300
NA	3	10.167	0.351	9.800	10.500
K	3	0.353	0.012	0.340	0.360
CA	3	0.397	0.006	0.390	0.400
MG	3	1.153	0.015	1.140	1.170
CL	3	18.733	0.493	18.400	19.300
SO4	3	2.760	0.069	2.680	2.800
DATE=29 AUG 83 SET=4					
TDS	3	36.400	0.872	35.800	37.400
NA	3	9.333	0.404	9.100	9.800
K	3	0.337	0.025	0.310	0.360
CA	3	0.407	0.012	0.400	0.420
MG	3	1.177	0.025	1.150	1.200
CL	3	17.767	0.569	17.300	18.400
SO4	3	2.800	0.000	2.800	2.800

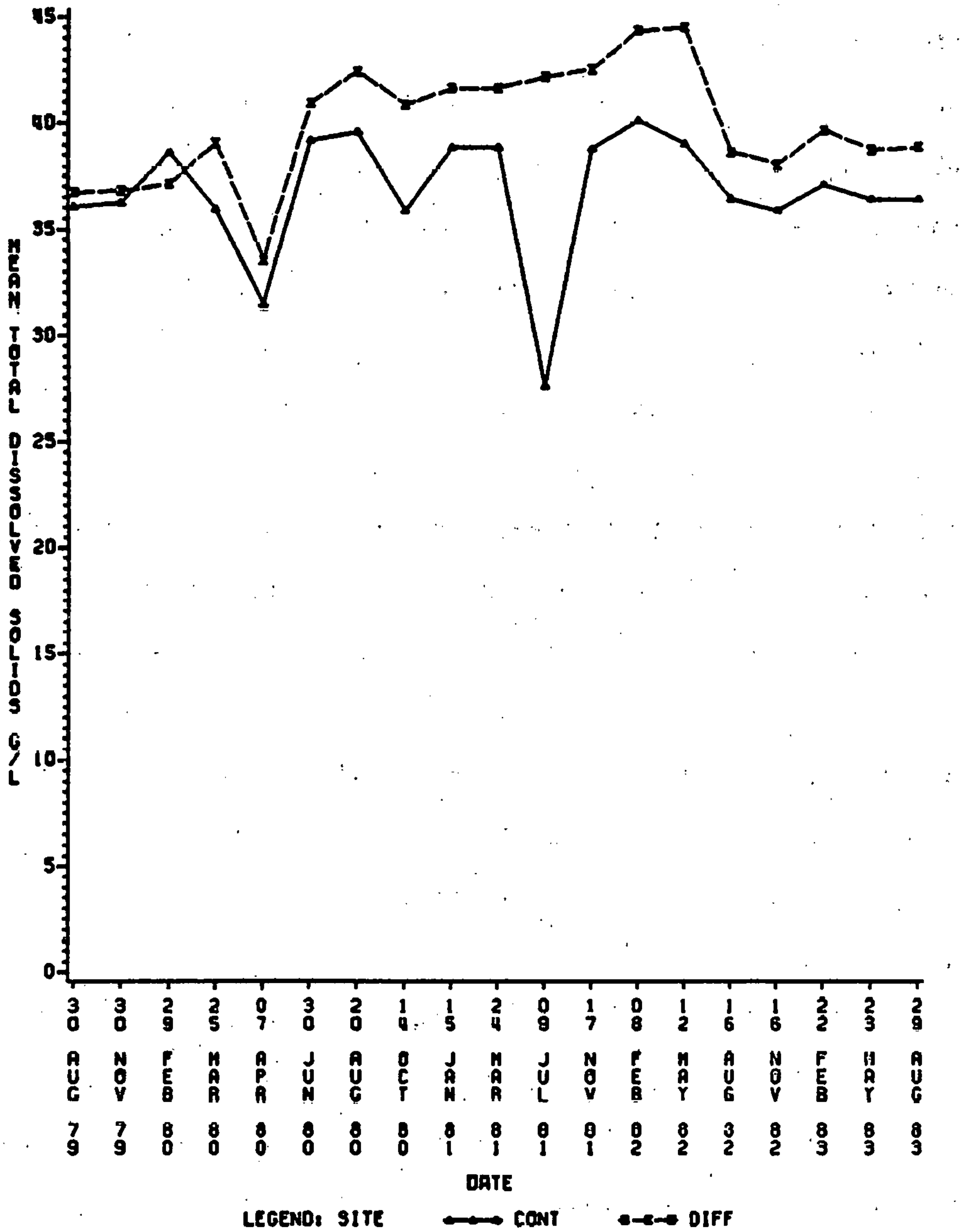


Figure 3-5. Total dissolved solids in sediment pore water at diffuser area and control stations.

1982. Based upon "t" test results, total dissolved solids were significantly higher at most diffuser stations during the year.

Comparison of mean Na and Cl values for the diffuser area and controls since 1979 are presented in Figures 3-6 and 3-7. These indicate the levels to which Na and Cl ions have been increased as a result of brine discharge. It should be noted that since brine discharge has stabilized, the earlier trend toward increased Na^{+} and Cl^{-} with time at the diffuser relative to ambient has ceased and that the differential between values for diffuser and ambient has remained constant over the past year.

Comparison of mean values for the other major ions (K^{++}, Ca^{++}, Mg^{++} and SO_4^{--}) between diffuser and control stations are presented in Figures 3-8, 3-9, 3-10 and 3-11. These indicate little difference in values for these ions between diffuser and ambient sediment pore waters.

Table 3-8 gives the mean ion ratios (Na/K, Ca/Ng and SO_4/Cl) for the sediment pore waters. These indicate that the elevated Na and Cl observed at the diffuser versus ambient have produced significant increases in the Na/K ratio and decreases in the SO_4/Cl at the diffuser during part of the year. Differences in the Ca/Mg ratio were not significant at any time during the year.

During June 1982, a special expanded twenty-station grid was sampled to determine the extent of elevated pore water salinities. At that time, pore water salinities of more than 2 o/oo over ambient extended two nautical miles from the diffuser. In June 1983, nineteen of these stations were resampled. Results, presented in Figure 3-12, show pore water salinity elevations were much less extensive than the preceding year. This suggests major ion changes have probably been restricted to the

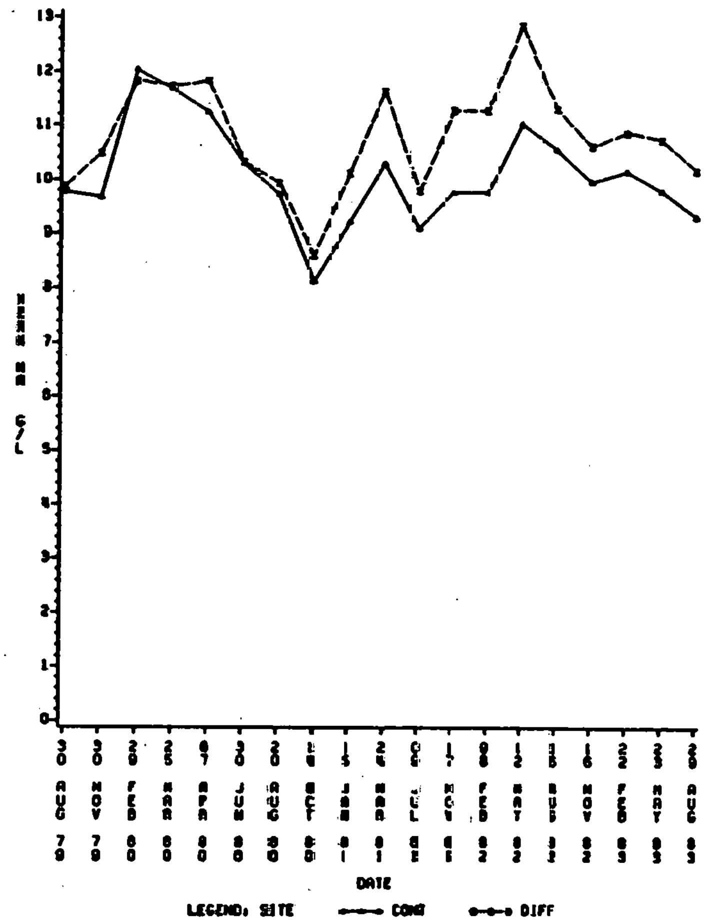


Figure 3-6. Mean sodium in sediment pore waters at diffuser area and control stations.

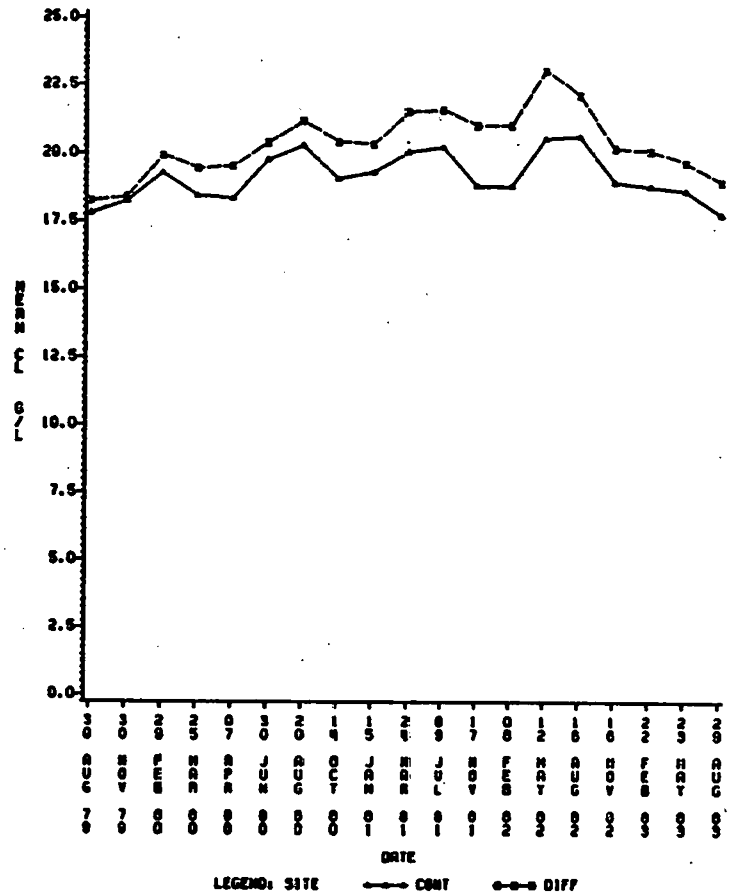


Figure 3-7. Mean chloride in sediment pore waters at diffuser area and control stations.

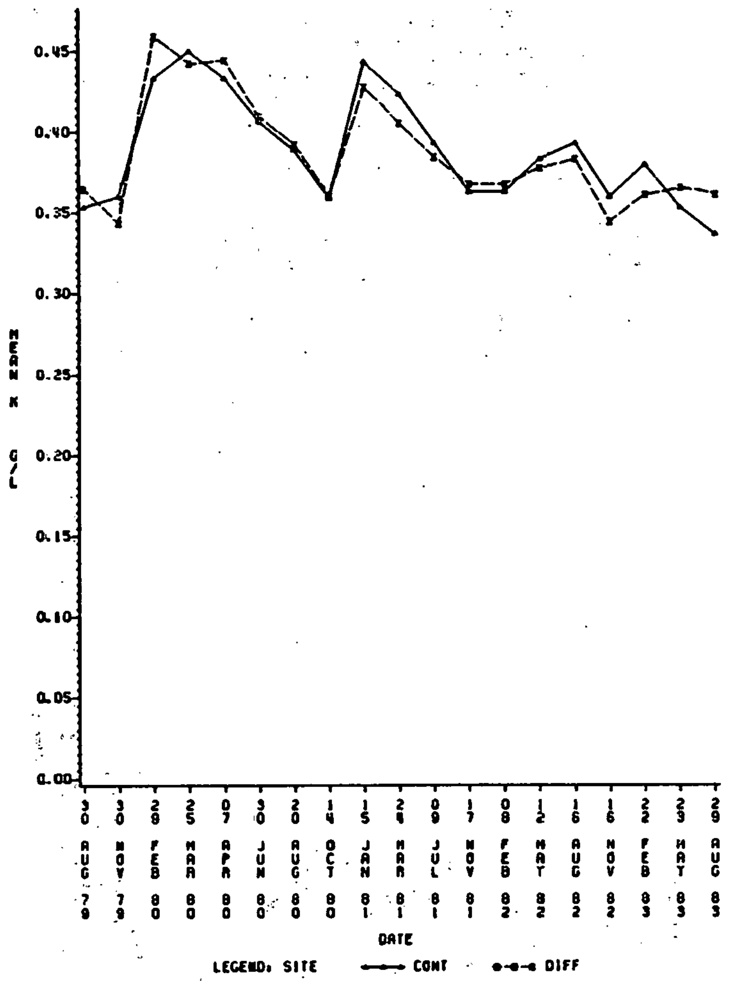


Figure 3-8. Mean potassium in sediment pore waters at diffuser area and control stations.

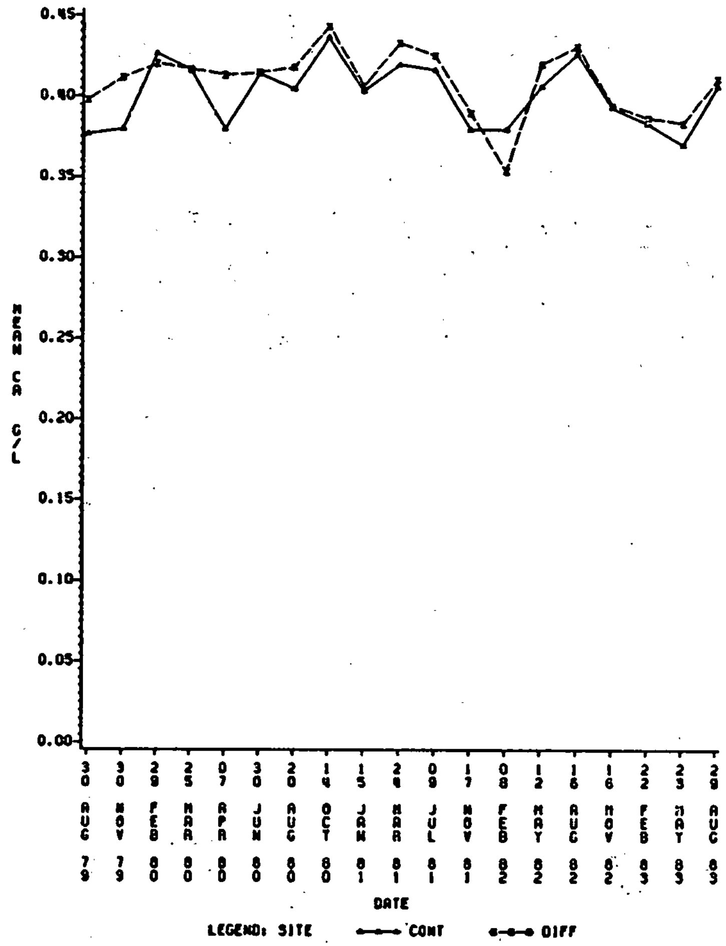


Figure 3-9. Mean calcium in sediment pore waters at diffuser area and control stations.

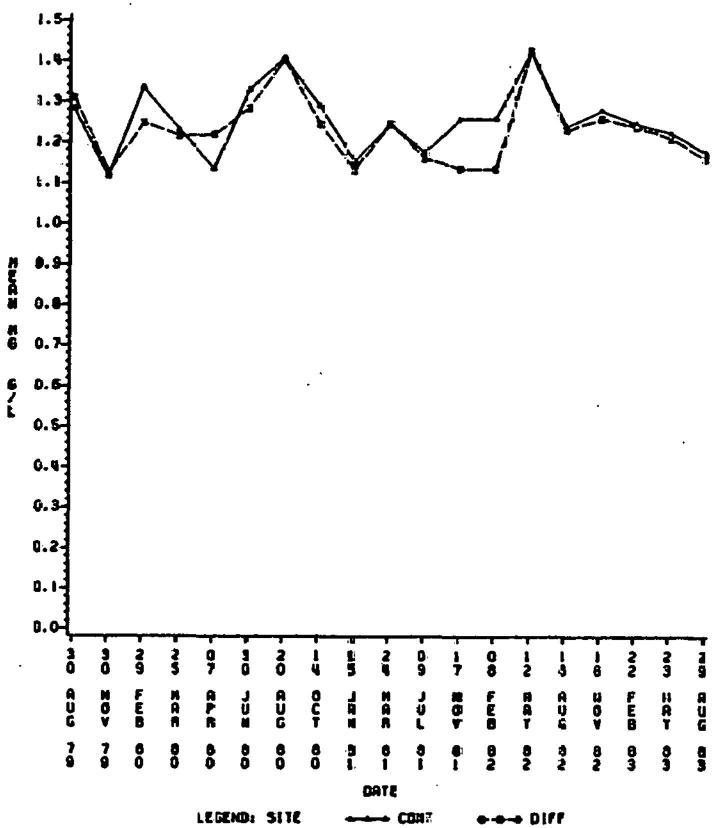


Figure 3-10. Mean magnesium in sediment pore waters at diffuser area and control stations.

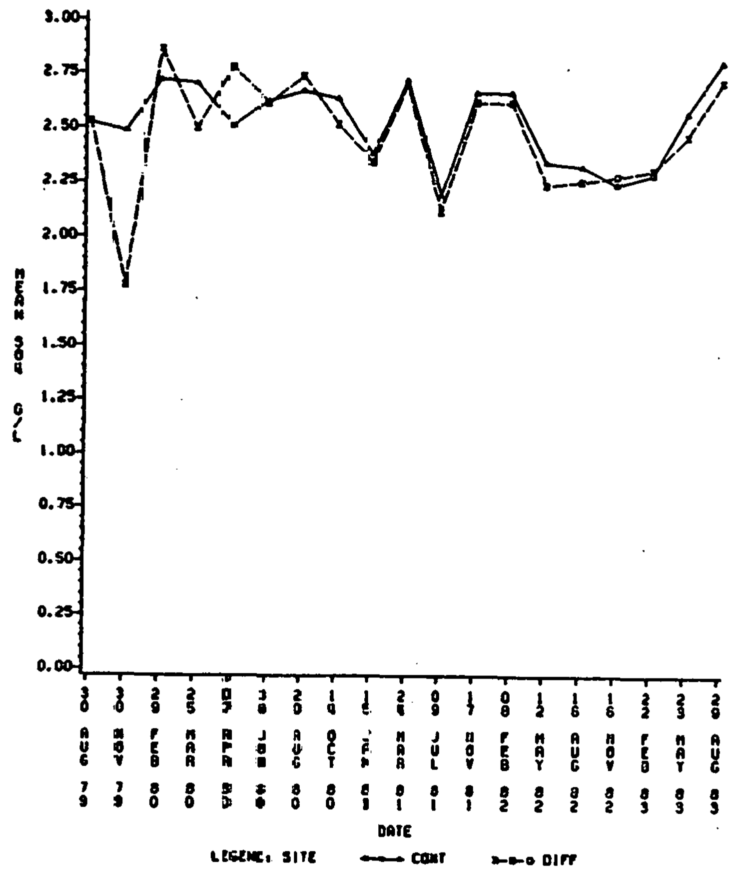


Figure 3-11. Mean sulfate in sediment pore waters at diffuser area and control stations.

Table 3-8. Mean ion ratios Na/K, Ca/Mg, and SO_4/Cl in waters and sediment pore waters at Bryan Mound.

SET1=D10,D11,D12 SET2=D13,D14,D15 SET3=D16,D17,D18 SET4=33,36,39

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
DATE=16 NOV 82 SET=1					
RNAK	3	30.571	0.857	29.714	31.429
RCAMG	3	0.308	0.008	0.299	0.313
RSO4CL	3	0.123	0.005	0.118	0.127
DATE=16 NOV 82 SET=2					
RNAK	3	30.202	1.108	29.429	31.471
RCAMG	3	0.317	0.006	0.311	0.322
RSO4CL	3	0.111	0.004	0.108	0.115
DATE=16 NOV 82 SET=3					
RNAK	3	31.821	1.670	30.857	33.750
RCAMG	3	0.315	0.004	0.313	0.320
RSO4CL	3	0.105	0.003	0.102	0.107
DATE=16 NOV 82 SET=4					
RNAK	3	27.694	0.578	27.027	28.056
RCAMG	3	0.307	0.010	0.298	0.317
RSO4CL	3	0.118	0.001	0.117	0.119
DATE=22 FEB 83 SET=1					
RNAK	3	31.345	0.321	31.143	31.714
RCAMG	3	0.310	0.007	0.304	0.317
RSO4CL	3	0.112	0.007	0.107	0.121
DATE=22 FEB 83 SET=2					
RNAK	3	29.251	1.666	28.000	31.143
RCAMG	3	0.310	0.017	0.293	0.328
RSO4CL	3	0.118	0.004	0.113	0.122
DATE=22 FEB 83 SET=3					
RNAK	3	29.985	1.816	28.684	32.059
RCAMG	3	0.318	0.013	0.310	0.333
RSO4CL	3	0.114	0.003	0.110	0.117
DATE=22 FEB 83 SET=4					
RNAK	3	26.765	0.697	26.316	27.568
RCAMG	3	0.308	0.004	0.305	0.311
RSO4CL	3	0.122	0.010	0.111	0.131

Table 3-8. Continued.

SET1=D10,D11,D12 SET2=D13,D14,D15 SET3=D16,D17,D18 SET4=33,36,39

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
DATE=23 MAY 83 SET=1					
RNAK	3	29.111	0.549	28.684	29.730
RCAMG	3	0.323	0.010	0.314	0.333
RSO4CL	3	0.127	0.003	0.124	0.130
DATE=23 MAY 83 SET=2					
RNAK	3	29.011	0.659	28.421	29.722
RCAMG	3	0.322	0.020	0.300	0.339
RSO4CL	3	0.124	0.008	0.116	0.131
DATE=23 MAY 83 SET=3					
RNAK	3	30.106	1.146	29.444	31.429
RCAMG	3	0.305	0.013	0.290	0.315
RSO4CL	3	0.124	0.004	0.119	0.127
DATE=23 MAY 83 SET=4					
RNAK	3	27.880	2.679	25.946	30.938
RCAMG	3	0.302	0.015	0.286	0.315
RSO4CL	3	0.138	0.005	0.132	0.141
DATE=29 AUG 83 SET=1					
RNAK	3	28.404	0.389	28.056	28.824
RCAMG	3	0.351	0.007	0.345	0.355
RSO4CL	3	0.139	0.002	0.136	0.140
DATE=29 AUG 83 SET=2					
RNAK	0	27.542	0.980	26.410	28.108
RCAMG	3	0.367	0.017	0.348	0.381
RSO4CL	3	0.143	0.004	0.139	0.147
DATE=29 AUG 83 SET=3					
RNAK	3	28.775	0.419	28.333	29.167
RCAMG	3	0.344	0.003	0.342	0.348
RSO4CL	3	0.147	0.003	0.145	0.151
DATE=29 AUG 83 SET=4					
RNAK	3	27.781	1.382	26.765	29.355
RCAMG	3	0.346	0.006	0.339	0.350
RSO4CL	3	0.158	0.005	0.152	0.162

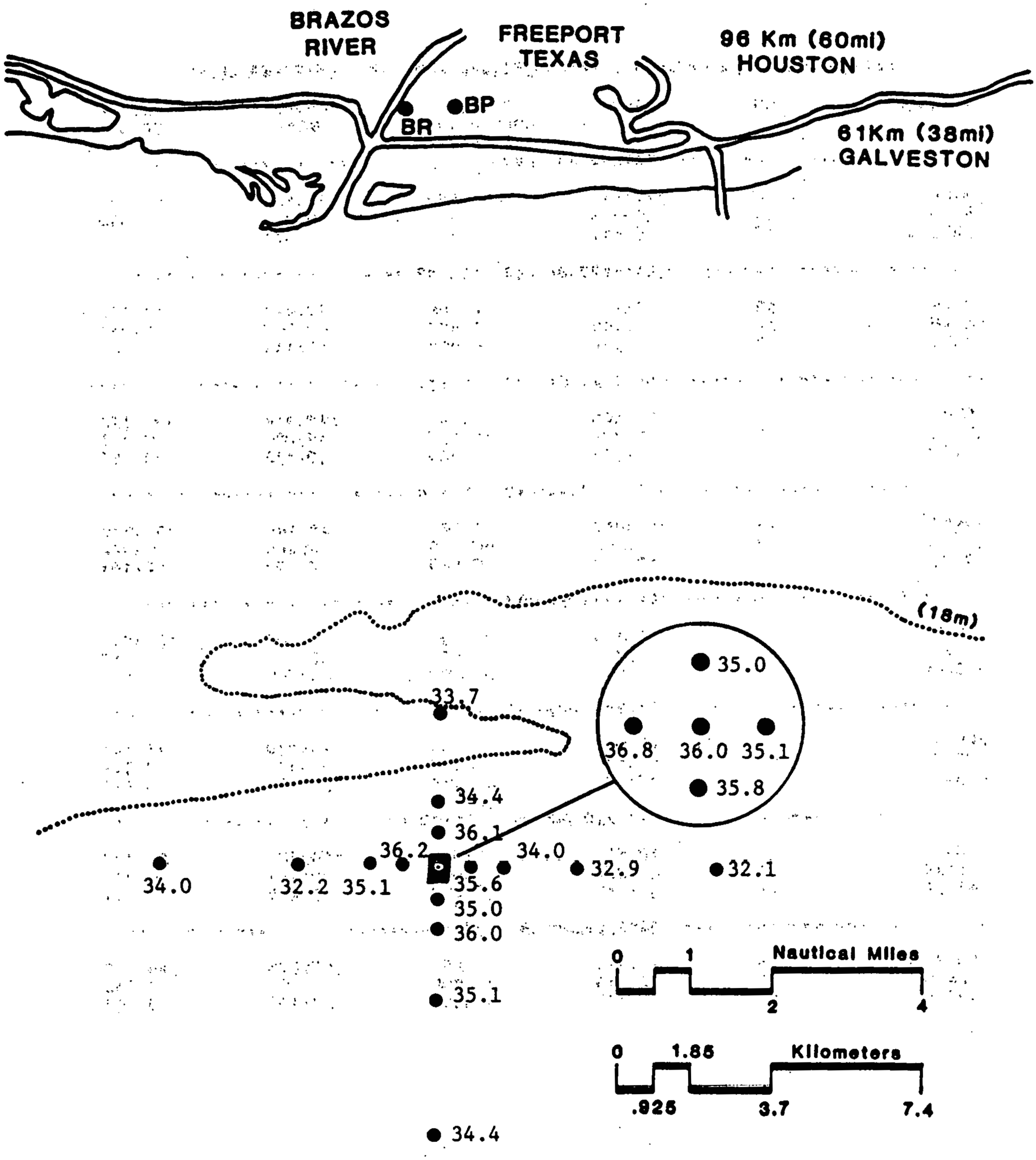


Figure 3-12. Mean salinity values in sediment pore waters for the diffuser area and control stations (June 1983).

immediate diffuser area for the past year.

3.3.6 Heavy Metals in Sediments

In addition to the major ions, heavy metal analyses of 1 H HNO_3 leachate from quarterly sediment samples were carried out along with determination of the total mercury in the sediments. The complete results are given in Appendix Tables C-6 through C-9. Although some differences occur from station to station with time, they do not appear important in terms of diffuser stations versus control stations and indicate no effects of brine discharge on sediment metals at this time with the possible exception of lead. The reason for differences in leachable metals at a given station from one sample period to another lies in the nature of the sediments in this area. Sediments in the area are primarily sand to clayey sand with patches of sandy clay or silty sand. As indicated in Figure 3-13, size distribution shifts occur at many of the stations from one sample date to another. Since leachability of the metals is related to surface area and therefore particle size, these shifts in particle size lead to the different metal concentrations in leachate for a given station.

Mean levels of each metal at the diffuser area stations and at ambient or control stations during the part year are presented in Table 3-9. Although mean lead values for the diffuser exceeded control values only twice during the year, the overall trend with time has been toward a greater increase with time at the diffuser relative to ambient. This can be seen in Figure 3-14 where the slope for diffuser stations is greater ($\simeq$ 2X) than for control stations. Since lead levels in the brine have consistently been elevated relative to the Brazos River leach water (see Table 3-5) there remains a good possibility that the lead increase is

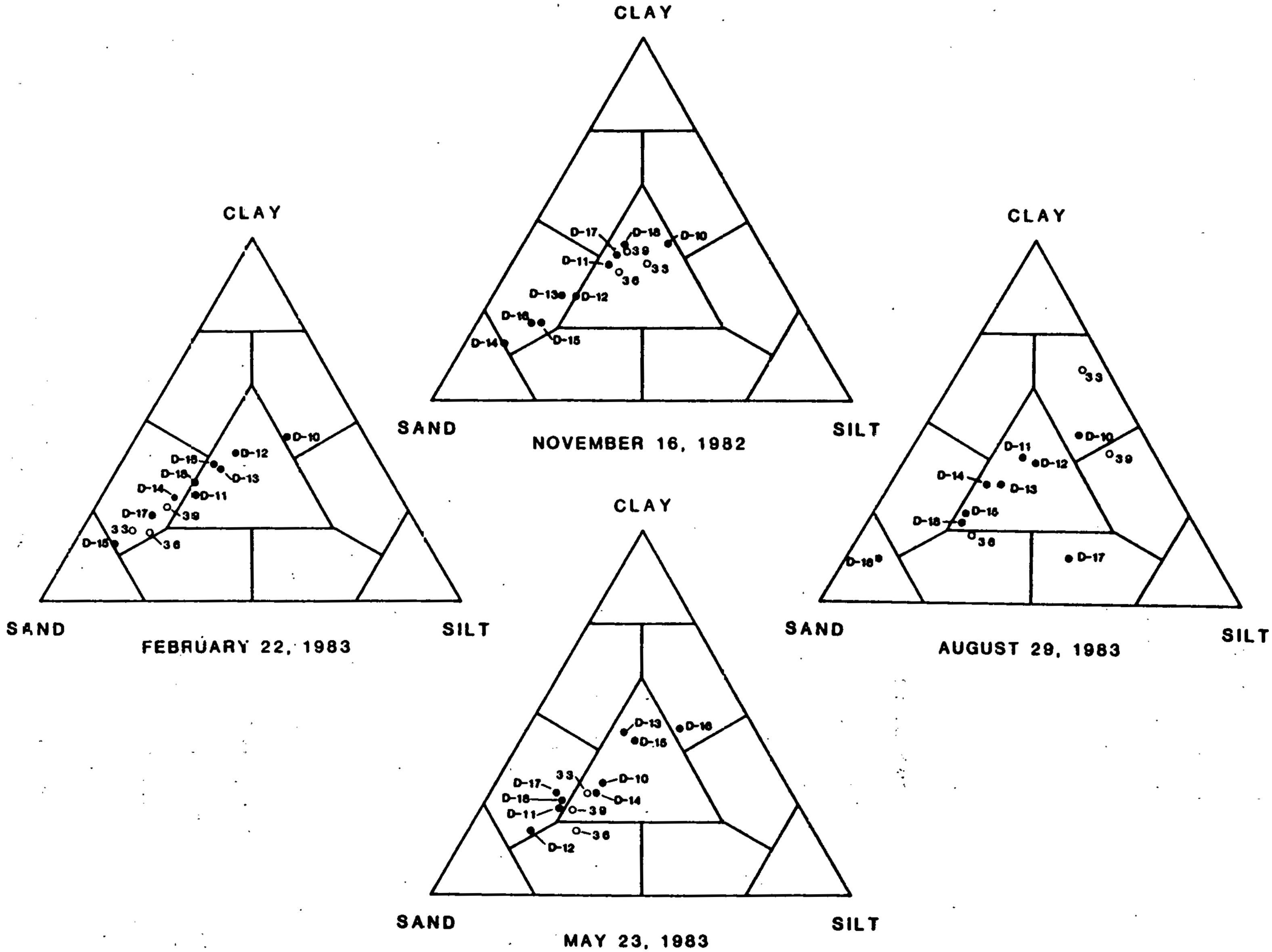


Figure 3-13. Shepard diagrams showing % sand, silt and clay for Bryan Mound area sediments.

Table 3-9. Mean sediment metal levels. Concentrations are in $\mu g/l$.

Metal	11/16/82		2/22/83		5/23/83		8/29/83	
Content	Dif.	Cont.	Dif.	Cont.	Dif.	Cont.	Dif.	Cont.
Al	611	857	957	888	1338	1307	1083	1195
Cd	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.04
Cu	2.9	3.9	2.9	2.6	1.3	2.0	3.7	4.5
Cr	1.1	1.4	1.9	1.9	2.2	2.2	2.5	2.8
Fe	1846	2188	2779	3129	4016	4094	3856	3965
Ni	1.3	2.1	2.3	2.3	3.8	3.3	2.8	2.8
Pb	8.1	8.8	9.5	7.9	7.7	6.3	8.3	8.5
Zn	10.5	13.6	15.9	16.8	18.6	20.4	18.3	19.8
Hg	0.039	0.037	0.042	0.039	0.027	0.024	0.028	0.025

Dif. = Diffuser

Cont. = Controls

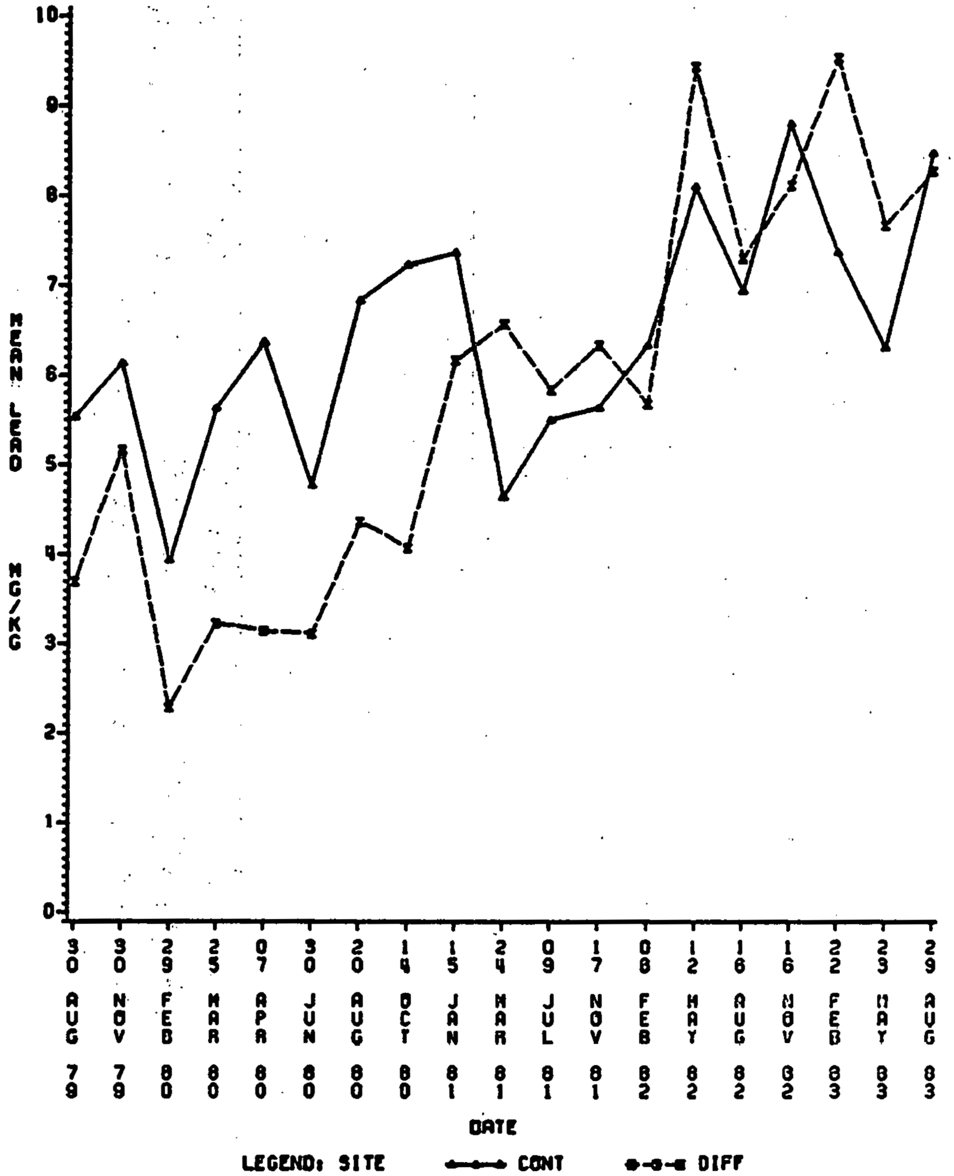


Figure 3-14. Mean lead in sediment extracts for the diffuser area and control stations.

related to brine discharge. This should not be unexpected since many lead compounds are relatively insoluble and would accumulate in the sediments rather than migrate away from the diffuser via the water column. Although metal accumulation can occur near the diffuser as a result of brine discharge, results for nickel shown in Figure 3-15 suggest that once the source is removed, the levels may return to normal. It was during the first year of brine discharge (1980 to 1981) that the greatest elevation of nickel in the brine was observed. Once the discharge levels diminished, nickel concentration in diffuser area sediments also decreased. Whether elevated nickel levels at the diffuser actually resulted from brine discharge could never be established since levels at control stations during early periods of monitoring were both higher and more variable than ever encountered at the diffuser.

Results for the remaining metals being monitored are presented in Figures 3-16 through 3-22. These indicate that natural concentrations and variability of the metals are as great at control stations as at the diffuser.

The tendency for diffuser area sediments to be lower in metals initially and to increase in metals toward ambient levels with time results from the fact that activities associated with trenching and burying of the diffuser pipe caused the finer grained sedimentary material to be suspended and carried away from the diffuser area relative to the coarse grain sands. This is reflected in the lower initial levels for some metals. With time, it appears that more fine grain material has returned to the area and metal levels near the diffuser have approached, if not exceeded, ambient. This pattern is especially evident for Al (Figure 3-16), Cr (Figure 3-18), Fe (Figure 3-20) and Zn (Figure 3-22).

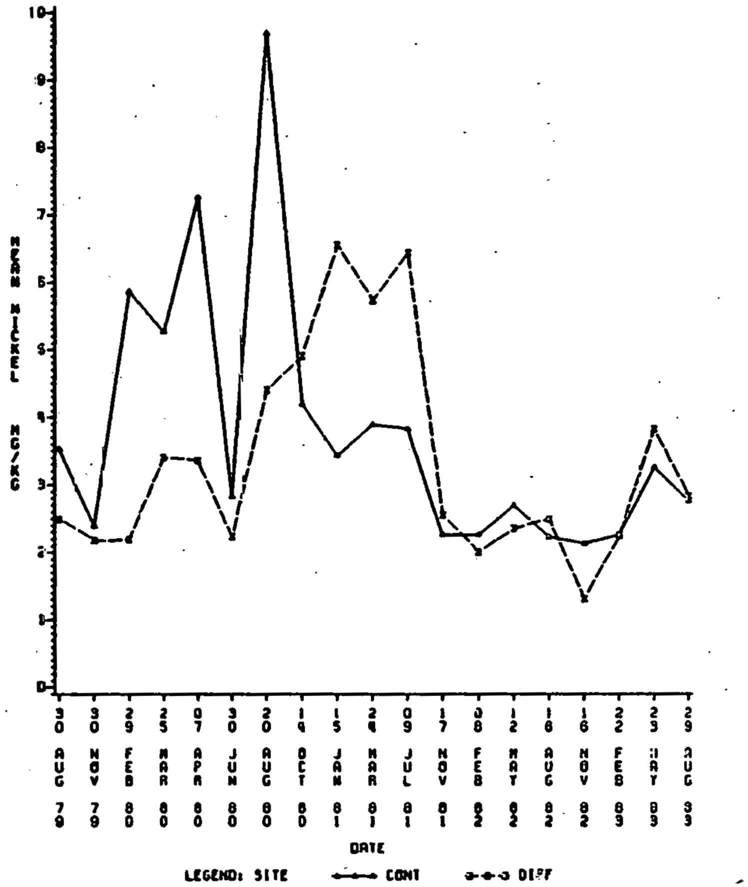


Figure 3-15. Mean nickel in sediment extracts for the diffuser area and control stations.

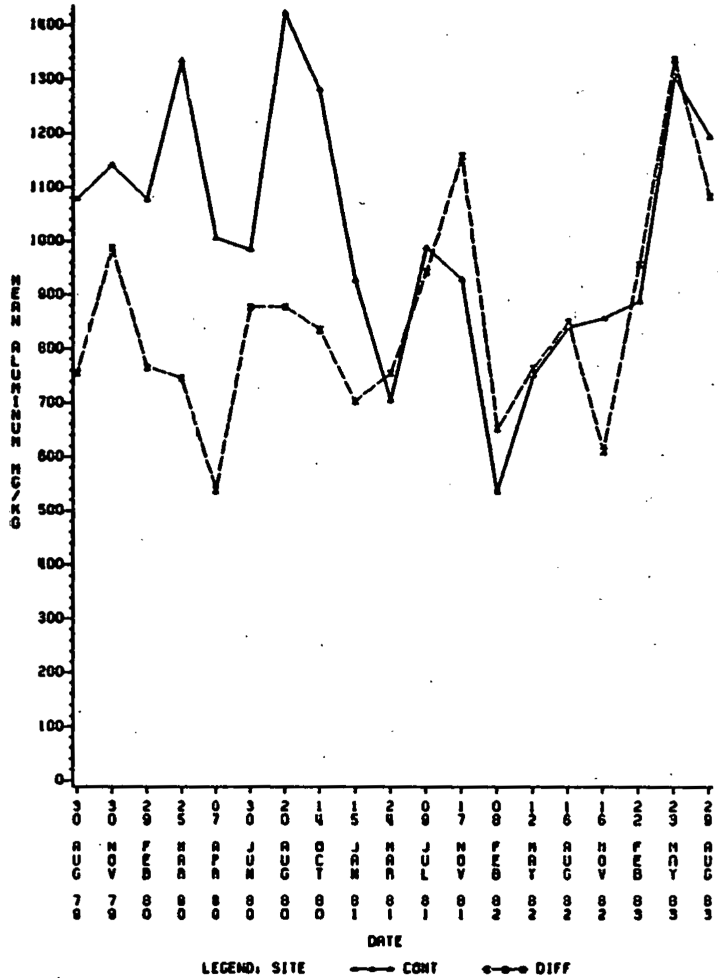


Figure 3-16. Mean aluminum in sediment extracts for the diffuser area and control stations.

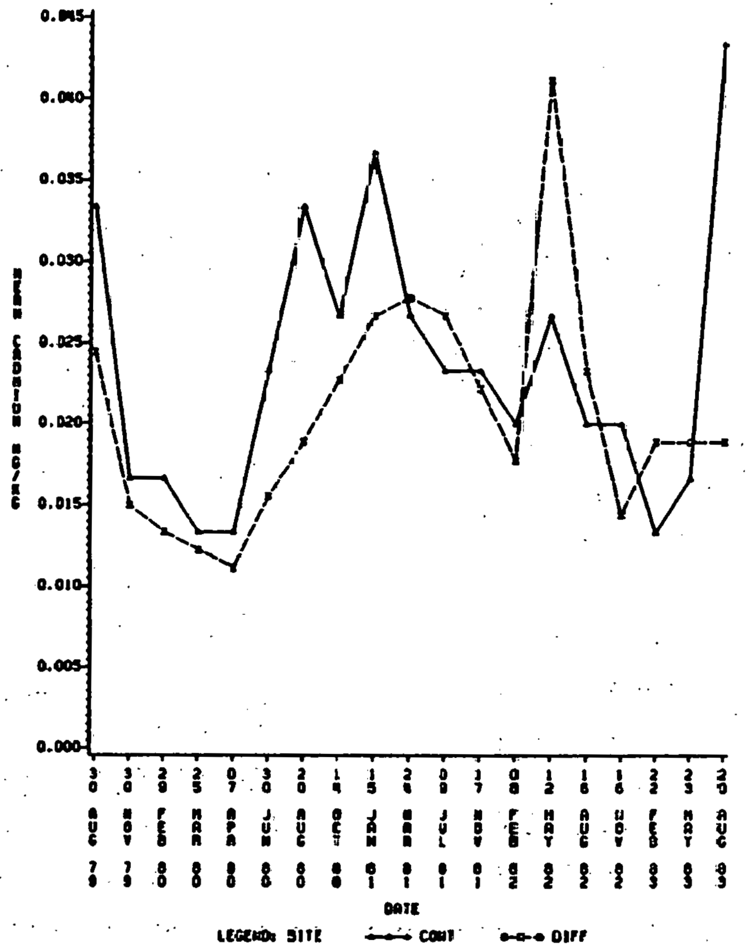


Figure 3-17. Mean cadmium in sediment extracts for the diffuser area and control stations.

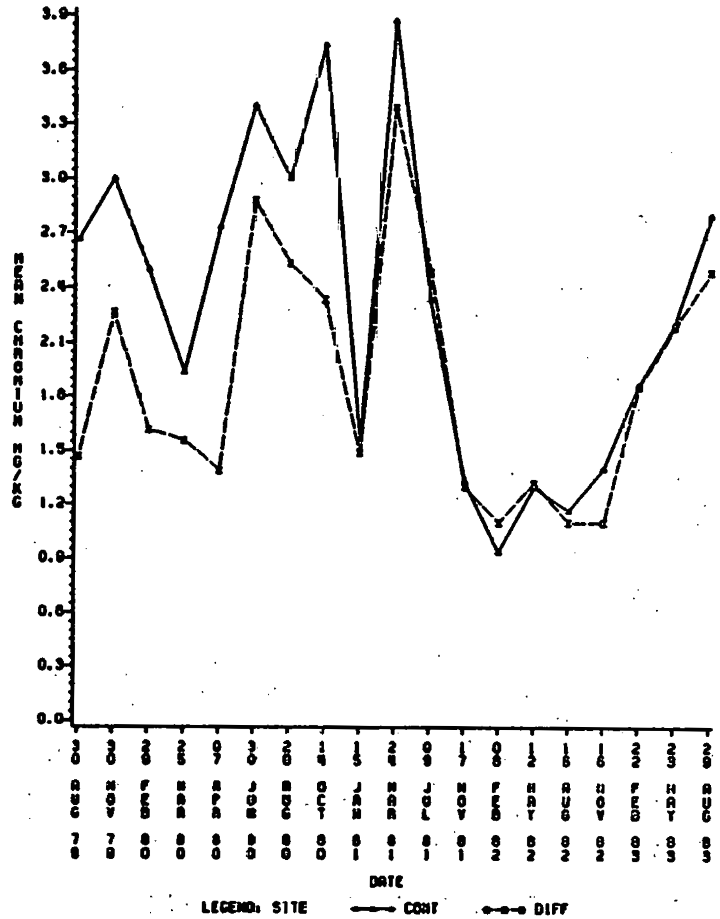


Figure 3-18. Mean chromium in sediment extracts for the diffuser area and control stations.

3-41

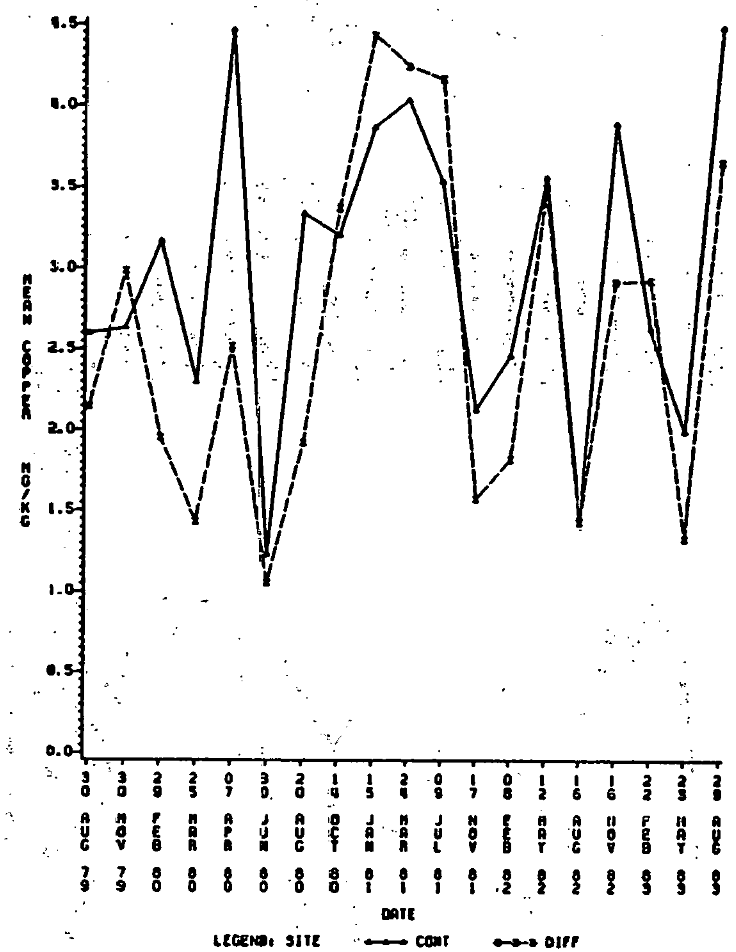


Figure 3-19. Mean copper in sediment extracts for the diffuser area and control stations.

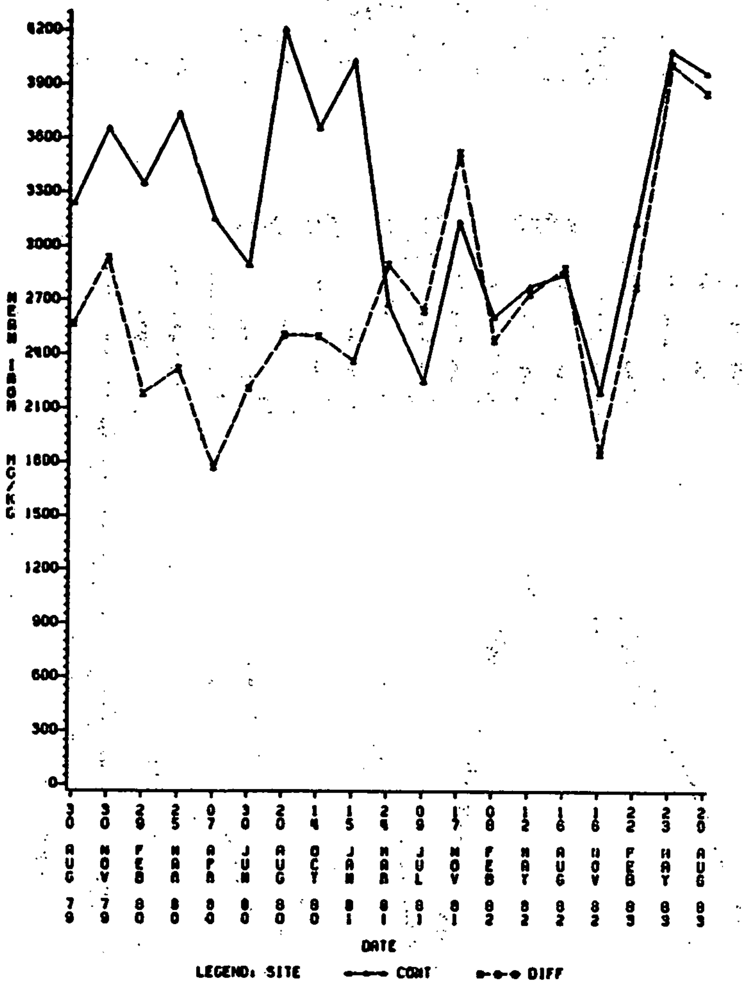


Figure 3-20. Mean iron in sediment extracts for the diffuser area and control stations.

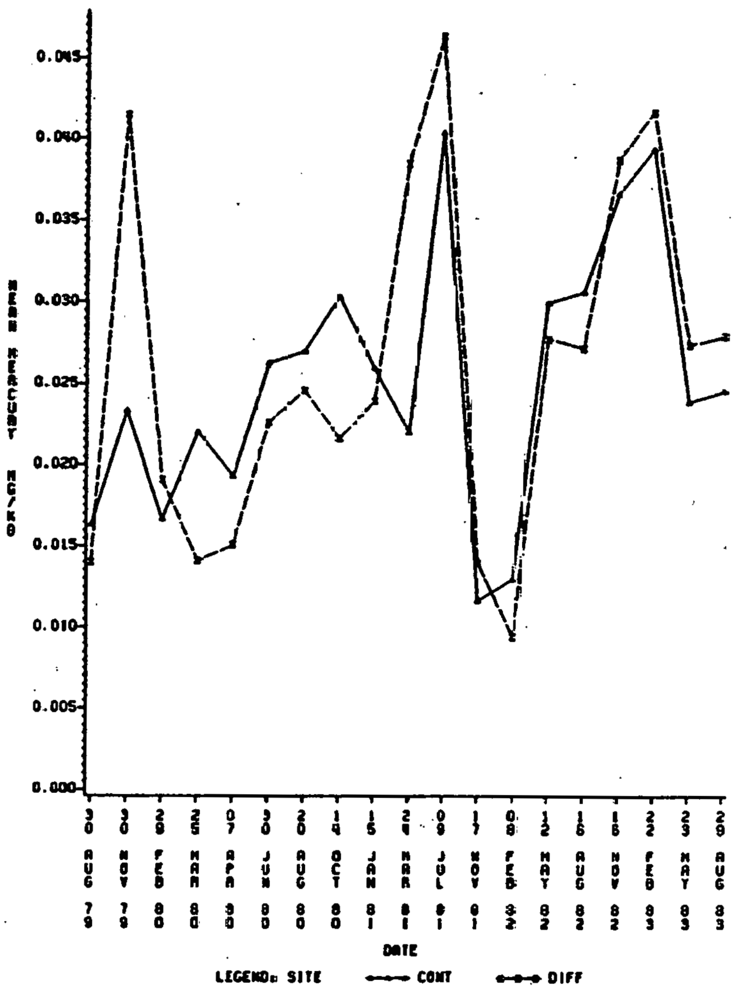


Figure 3-21. Mean total mercury levels in sediments for the diffuser area and control stations.

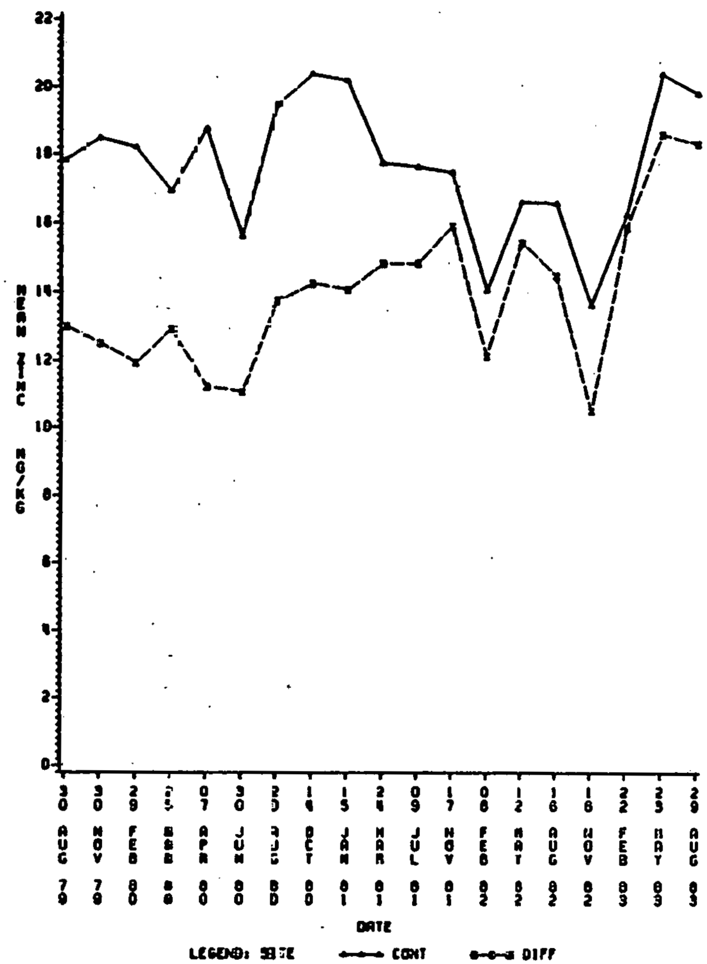


Figure 3-22. Mean zinc in sediment extracts for the diffuser area and control stations.

The effect of changing sediment grain size was especially evident for results obtained after Hurricane Alicia. Sediment samples collected on August 29, after the hurricane, showed considerable change in particle size (see Figure 3-13). As a result, increased metal levels were observed downcoast from the diffuser as finer grained material settled there.

Concern during previous years that cadmium levels around the diffuser might be increasing relative to ambient were not borne out by results for the past year. Mean cadmium levels were highest at the control stations during August and essentially the same for all stations the remainder of the year. As pointed out in Chapter 5, sediment cadmium concentrations have not reached biologically adverse levels at any time during this study.

3.3.7 High Molecular Weight Hydrocarbons

Large water samples (38 to 76 liters) were collected from the Brazos River input, the Bryan Mound brine pit and sea water near the surface and near the bottom at station D14 on February 22, 1983 and August 29, 1983 for heavy hydrocarbon analysis. At the same times, duplicate sediment samples at station D14 were also collected for the same purpose. These samples were extracted with suitable solvents, fractionated on silica gel into classes of hydrocarbons and further analyzed by gas chromatography and the aromatic and aliphatic fractions by mass spectrometry. Gas chromatography derived concentrations of heavy hydrocarbons for the fractions of the water and sediment samples are summarized in Table 3-10. It should be noted here that in some cases, duplicates of water and sediment samples do not agree as well as might be expected. This is particularly evident for the brine pit water and the sediment. For the brine pit, the reason may be that we use unfiltered water and a portion of

Table 3-10. Gas chromatography derived concentrations (µg/l for water and µg/g dry weight of sediments) of resolved hydrocarbons for water and sediment samples collected in February and August 1983.

Sample	Frac 1	Frac 2	Frac 3	Total	O/E	Pr/Phy	% > C23
			February 1983				
River 1	1.144	0.036	0.202	1.382	1.159	0.97	81.58
River 2	1.440	0.020	0.180	1.640	1.010	1.122	75.57
Brine 1	10.519	0.224	0.170	10.913	1.092	0.761	35.60
Brine 2	6.188	0.132	0.100	6.420	1.105	0.735	33.39
Surface SW(D14)	0.720	0.082	0.150	0.950	2.412	19.696	53.53
Deep SW(D14)	0.082	0.005	0.038	0.124	1.717	no phy.	61.85
D14 Sediment 1	0.378	0.020	0.086	0.484	2.562	n.d.	76.61
D14 Sediment 2	0.131	0.020	0.006	0.157	4.069	n.d.	91.80
			August 1983				
River 1	0.778	0.359	0.563	1.700	1.318	1.361	69.29
River 2	0.832	0.126	0.470	1.428	1.163	1.214	61.02
Brine 1	10.638	0.146	2.029	12.813	0.973	0.995	34.46
Brine 2	6.846	0.207	1.424	8.477	0.987	0.928	39.62
Surface SW(D14)	0.414	0.011	0.956	1.381	1.592	1.52	52.16
Deep SW(D14)	0.088	0.014	0.468	0.570	0.919	0.749	18.31
D14 Sediment 1	7.233	0.407	1.169	8.809	1.056	0.691	45.41
D14 Sediment 2	15.158	0.978	1.888	18.024	1.002	0.763	51.44

Frac 1 = Aliphatic (hexane) fraction
Frac 2 = Aromatic (40% benzene/hexane) fraction
Frac 3 = Polar (benzene) fraction

O/E = odd/even alkanes
Pr/Phy = pristane/phytane ratio

the hydrocarbons may be in colloidal or particulate form and the duplicate samples are not uniform. This lack of agreement on hydrocarbon concentrations in the brine pit water happens more frequently than in river water. The lack of agreement in sediment hydrocarbons is that we make no effort to homogenize the sediments before extraction and the sediment is usually a silty sand and simply is not homogeneous. In the following discussion, averages of the duplicates, when available, will be used.

Heavy hydrocarbon concentrations of surface and deep sea water and the D14 sediment for February were normal. For surface sea water the hydrocarbon concentration was 0.95 μg/l and the deep water was 0.124 μg/l. Sediment hydrocarbon concentration was 0.48 μg/g dry sediment. The hydrocarbon composition as indicated by gas chromatography and mass spectrometry indicated that the hydrocarbons present in both sea water and sediment were of natural origin. There were no detectable aromatics of petroleum origin by mass spectrometry.

Average hydrocarbon concentrations of Brazos River water for February were low, i.e., 1.52 μg/l. There were no detectable aromatics of petroleum origin in the river water. All the river water hydrocarbons were of natural origins. As usual, analysis of the brine pit hydrocarbons in February 1983, showed that most of the hydrocarbons in the brine pit were of petroleum origin. The average concentration in brine pit water was 8.50 μg/l, and gas chromatography and gas chromatography-mass spectrometry of the aliphatic and aromatic fractions indicated that crude oil was the source of brine pit hydrocarbons, not the river. See Table 3-10.

Analyses of the August 1983 water and sediment samples showed that river water hydrocarbons were about the same as they were in February at 1.57 $\mu g/l$, and these hydrocarbons were of natural origin. The brine pit hydrocarbon concentration was 10.64 $\mu g/l$, somewhat higher than it was in February. The brine pit hydrocarbons were predominantly of petroleum origin, because of the distribution of the alkanes, and odd/even ratio of 0.98 and the presence of methylated phenanthrenes and dibenzothiophenes in the aromatic fraction. See Table 3-10 and Figure 3-23.

Hydrocarbon concentrations of surface sea water at station D14 in August was 1.38 $\mu g/l$, and near bottom sea water hydrocarbon concentration was 0.57 $\mu g/l$, both higher than in February. However no petroleum contamination was detectable.

The hydrocarbon concentration of the D14 sediment sampled in August was unusually high, with an average of 13 $\mu g/g$ dry sediment. Hydrocarbons at this station traditionally have been under 1 $\mu g/g$. From the distribution of the alkanes in the gas chromatogram, it was noted that the bulk of the alkanes had carbon numbers less than C-23 (see Table 3-11) and that the odd/even ratio was 1.025. Both these observations indicated a petroleum source for the hydrocarbons. Examination of the mass spectra of the compounds in the aromatic fraction indicated that methylated phenanthrenes and methylated dibenzothiophenes were present, highly similar to the brine pit hydrocarbons. See Table 3-11 and Figure 3-23. It thus seems reasonably certain that the oil in the sediments is from the brine pit.

A sediment from station 39, a control station, that had been collected for grain size analyses at the same time that the hydrocarbon samples were collected, was also extracted and analyzed in the same way that D14 was. Gas chromatography and mass spectral data indicated that it

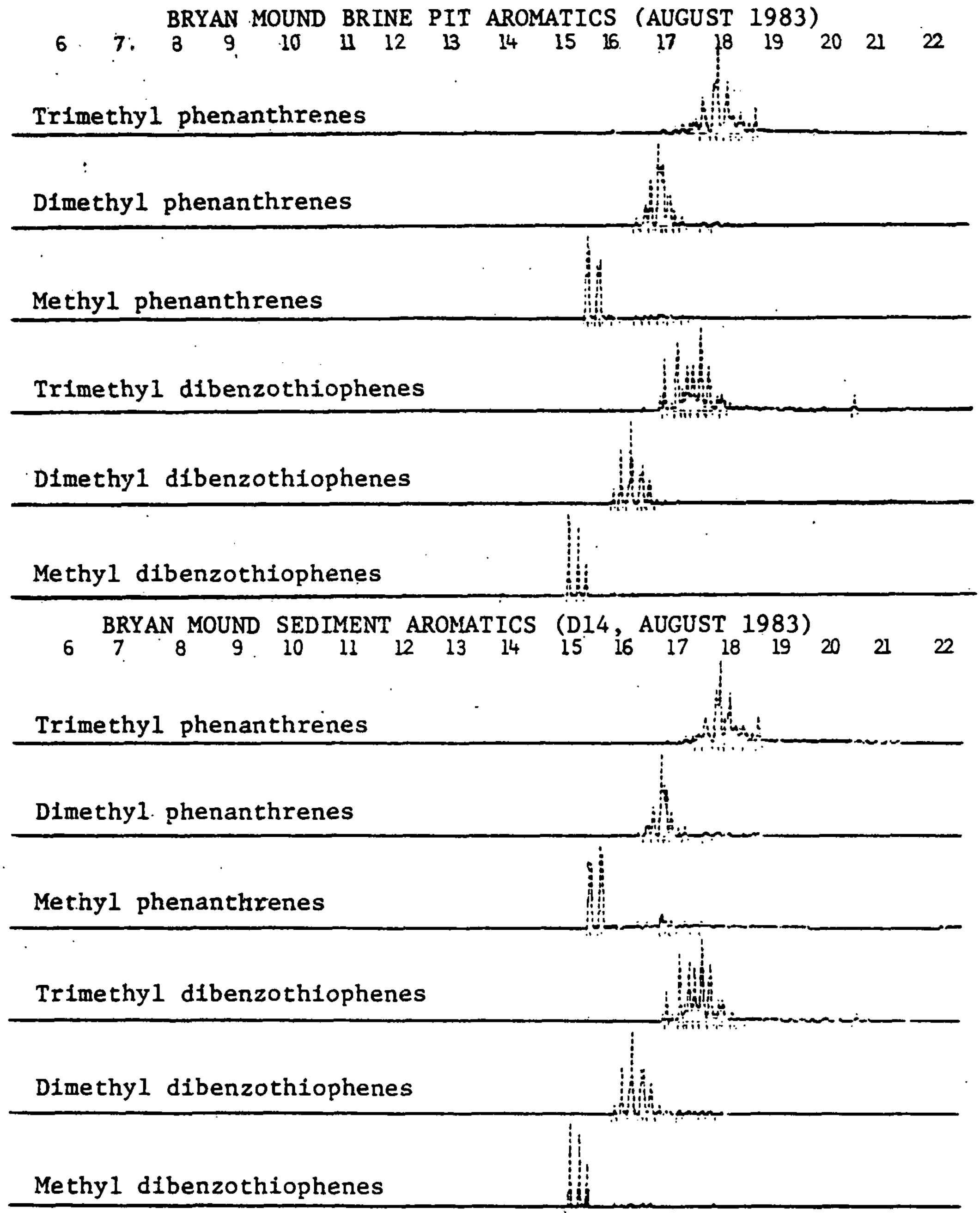


Figure 3-23. Bryan Mound brine pit aromatics and sediment (station D14) aromatics for August 1983.

Table 3-11. Evidence for petroleum contamination of D14 sediment and of brine pit water.

D14 SEDIMENT

Odd/even ratio of alkanes = 1.025

% alkanes > C_{23} = 48.42

Methylated phenanthrenes and dibenzothiophenes in aromatic fraction

BRINE PIT WATER

Odd/even ratio of alkanes = 0.98

% alkanes > C_{23} = 37.04

Methylated phenanthrenes and dibenzothiophenes in aromatic fraction was not petroleum contaminated. Also, a sediment sample from D14 collected in November 1983 for other analyses was extracted and analyzed. This latter analysis indicated that most of the oil contamination was gone.

The routine SPR discharge monitoring results before, during and after August 29, 1983 were obtained from POSSI and examined, and no unusual oil and grease content of the discharged brine was observed.

3.4 Conclusions and Recommendations

During the past year, brine discharge has lead to small increases in salinity, sodium and chloride in bottom waters and sediment pore waters near the diffuser relative to those further away. The increase has been higher in sediment pore waters (6 to 7%) than in the bottom waters. With a more uniform brine discharge rate, concentrations of pore water TDS, sodium and chloride at the diffuser are no longer increasing relative to ambient but appear to have stabilized at levels of about 6% over the ambient. In addition, values at all nine diffuser area stations were similar indicating this effect extended over the entire 305 m x 305 m grid. It should be pointed out that the high salinity event observed at the diffuser and extending several thousand meters out in June 1982 did not occur during the June 1983 sampling period but conditions leading to this event may occur again in the future. The present sampling grid is insufficient to properly evaluate such an event should it reoccur.

Major ion ratios in the sediment pore waters over the past year reflect the levels observed for TDS and suggest that ion migrations into the sediment have not led to ion exchange differences and ionic imbalance. The range of soluble heavy metals observed in the vicinity of the diffuser was similar to that for the control stations. Furthermore, levels of the metals during the past year never exceeded the maximum allowed EPA criteria level for marine aquatic life. In the sediments, lead levels near the diffuser continued to increase slightly relative to those at control stations. Since lead was found to be higher in the brine than in offshore waters, increases in sediment levels could be related to brine discharge. It should be pointed out that, at present, any increases in sediment metals at the diffuser relative to controls are small and that similar natural variations have been observed during previous years.

Hydrocarbon content of Brazos River water was essentially the same for both sample periods, being 1.5 to 1.6 µg/l. The river hydrocarbons appear to be from natural sources. The hydrocarbon concentrations in the brine ranged from 8.5 to 10.6 µg/l and were predominantly of a paraffinic crude oil nature. Levels in the offshore waters were 0.12 to 1.38 µg/l with no evidence of crude oil hydrocarbons. However, sediment hydrocarbons were 0.48 µg/g in February and 13 µg/g in August. Hydrocarbon distribution indicates the latter to be from a crude oil source. Gas chromatography analyses coupled with mass spectra data for both the August sediment and brine pit samples strongly suggest the brine pit was the source of the sediment hydrocarbons.

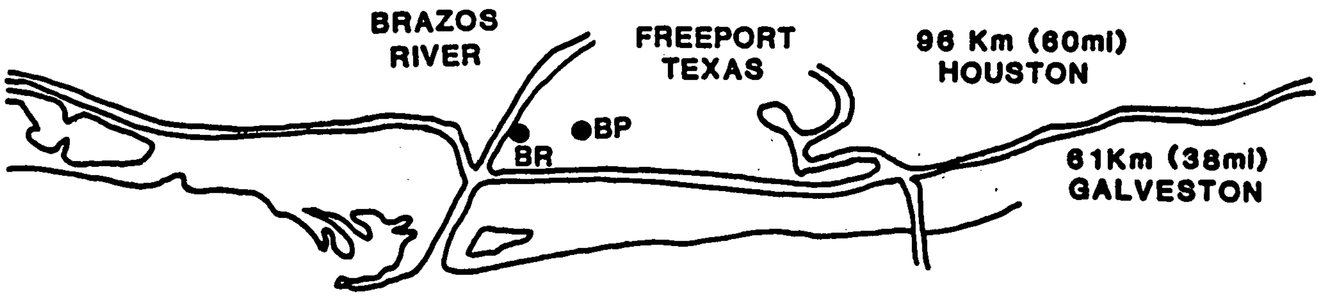
Based upon results of the past year, a number of changes in the Bryan Mound water and sediment quality monitoring appear warranted. At present, the nine diffuser area stations are sufficiently close together that pore water salinities and several other parameters appear to be the same at all nine stations much of the time. Moving four of these stations farther out would not affect our evaluation of what occurs at the diffuser proper but could be beneficial in determining the extent of quality changes when they extend beyond the 152-meter (500-foot) range of the present stations. It is recommended that the sampling station locations be modified as follows:

a. For <u>all</u> parameters, four of the immediate diffuser stations (D10, D12, D16, and D18) be eliminated and replaced by four stations located farther out (800 m or one-half mile) from the diffuser to determine if chemical parameters are affected farther from the diffuser than is possible with the present grid. These stations should be sampled on a quarterly basis as presently done.

b. For pore water salinity (or TDS), an additional seven sediment sampling stations be added to the above recommended stations to evaluate the extent of elevated pore water salinities. These stations should also be sampled on a quarterly basis and at the same time as the other water and sediment stations. These seven stations are located at some of our present CTD stations. Figure 3-24 shows all of the stations at which samples should be collected for pore water salinity measurements.

Should negative redox potential in the sediments continue, the potential for increased metal solubilization exists. The present 1 N acid extraction method might not detect subtle changes in metals that could affect benthic organisms. It is recommended that trace metal analyses in the sediments be expanded to include soluble metals in the pore waters.

Differences in the major ion levels at the diffuser and at ambient stations in the water column have been minimal. The brine discharge has not significantly affected the major ions or their ratios in the water column at the diffuser. The small changes that have occurred can be predicted from salinity differences between stations. It is therefore recommended that major ion analysis in the water column be discontinued.



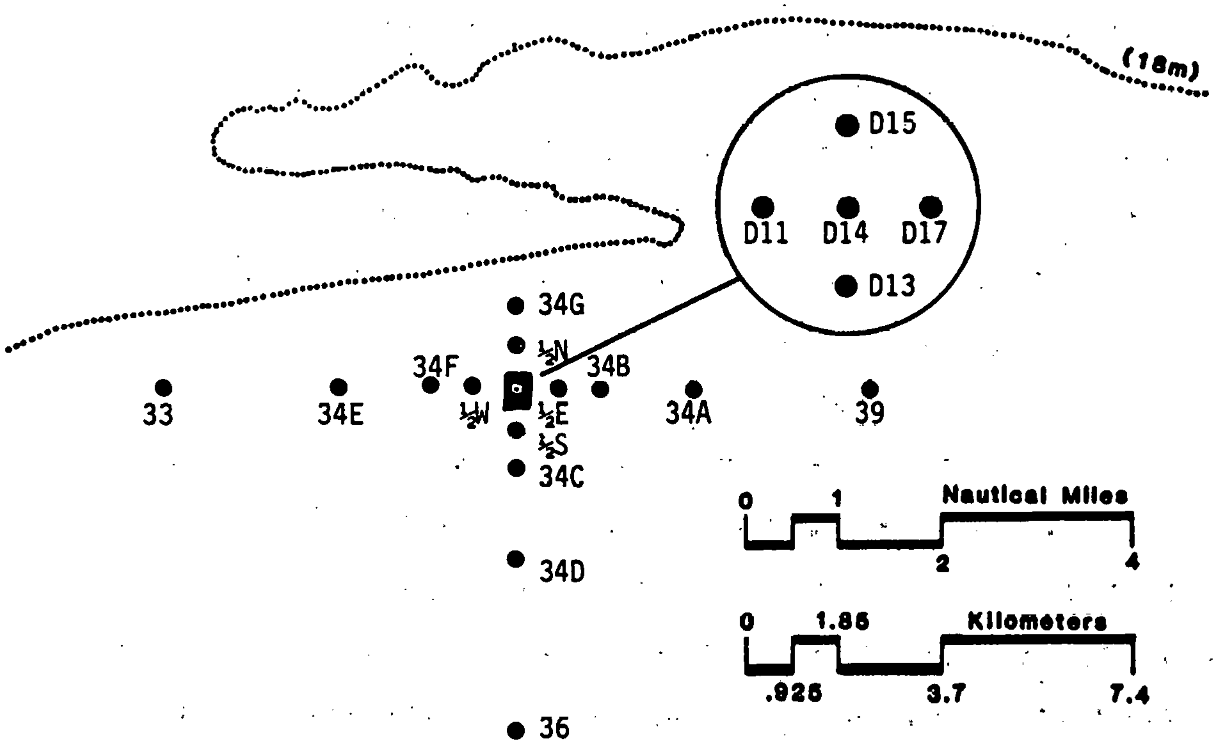


Figure 3-24. Additional recommended sampling stations for pore water salinity quarterly sampling.

CHAPTER 4

NEKTON

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4.1 Introduction

Coastal waters of the Gulf of Mexico off Freeport, Texas have become the receiving site for brine discharge from an underground salt dome being leached to provide storage for crude oil as part of the Strategic Petroleum Reserve Program of the U.S. Department of Energy. Earlier environmental assessments prior to and after discharge have provided a background against which effects of recent brine disposal can be examined. The present report analyzes effects of brine disposal in a one-year postdisposal period from September 1982 through August 1983 based on among-station patterns within a given cruise. These data are integrated with those from the predisposal study (Chittenden et al, 1981a), March 1980 through August 1981 eighteen-month postdisposal study (Chittenden et al, 1981b, 1982) and September 1981 through August 1982 postdisposal study (Pavela and Chittenden, 1983) in discussing the impact/non-impact of brine disposal.

This chapter describes the nekton community in the diffuser area off Freeport during the September 1982 through August 1983 postdisposal period. Field activity, experimental objectives, design, and analytical procedures are described in Section 4.2. Sections 4.3 - 4.5 provide background data for the diffuser area. Section 4.3 delineates affinities and differences among diffuser stations using cluster analysis; overall shrimp fauna and ichthyofauna compositions are described in Section 4.4, and individual station shrimp fauna and ichthyofauna compositions are described in Section 4.5. Thereafter, Sections 4.6 - 4.14 detail the effects of brine discharge on nekton including an analysis and discussion of field observations of the effects of brine on nekton (4.6), analysis of variance evaluations and individual degree of freedom comparisons of among-station and quarterly trends for total shrimp abundance (4.7), total fish abundance (4.8), total nekton biomass (4.9), and ichthyofauna diversity (4.10), comments on the occurrence of red drum and black drum (4.11), and an analysis of among-station size compositions of important nekton (4.12). Section 4.13 summarizes the overall effects of brine disposal on nekton and the final Section (4.14) presents basic conclusions.

4.2 Materials and Methods

Field and laboratory methods and procedures used in the collection and validation of biological and hydrographic data during the September 1982 through August 1983 postdisposal period were the same as those employed in previous postdisposal studies. A detailed description of these may by found in Pavela et al, 1983. The following sections summarize field activity during the present study and describe objectives of field collections, experimental design, and analytical procedures.

4.2.1 Field Activity

Four daytime cruises were completed aboard the R/V Excellence II at the Bryan Mound disposal site off Freeport during the September 1982 through August 1983 monitoring period. Cruises were made at three-month intervals during November 1982, and February, May and September 1983 to make collections at an array of 18 stations surrounding the diffuser. Collections made in September were to have been made in August, but were delayed because of Hurricane Alicia. Table 4-1 summarizes cruise and station collection dates. Station coordinates are listed in Table 4-2. Figure 4-1 illustrates their locations in relation to the diffuser.

4.2.2 Objectives, Experimental Design and Analytical Procedures

The objectives of field operations were to acquire data to describe the near-diffuser nekton community to include: 1) overall total shrimp and total fish abundance, total biomass and ichthyofauna diversity; 2) among-stations patterns in total shrimp and total fish abundance, total biomass and ichthyofauna diversity; and 3) specific evaluations of among stations effects of brine disposal. Among-station patterns at a given time (variation among stations, within a cruise) were the principal background against which the effects of brine disposal were evaluated (Chittenden et al, 1981b, 1982).

The experimental design and data analysis for the present period followed those of the predisposal and previous postdisposal studies (Chittenden et al, 1981a, 1981b, 1982; Pavela and Chittenden, 1983) and was preplanned in terms of its stations vs. cruises = months factorial nature.

Mean catch per trawl tow (C/f) for total fish abundance, total shrimp abundance, total biomass (shrimp and fish), and ichthyofauna diversity near the diffuser were evaluated by analysis of variance procedures using a two-way factorial experiment in a completely randomized design as calculated by the SAS program Proc GLM (Helwig and Council, 1979) with LOG_e transformation of data. Exceptions to this were that total biomass was not transformed and ichthyofauna diversity was calculated as Shannon-Weiner's H' using base 2 logs following Krebs (1972). Factors were stations and cruises. Individual degree of freedom comparisons (Steele and Torrie, 1980) were made to evaluate the effects of brine disposal using the following

Table 4-1. Nekton cruise and station collection dates during the September 1982 through August 1983 postdisposal period.

Station	8-10 November 1982	8-9 February 1983	19-22 May 1983	1-2 September 1983
9	10	9	22	2
20	10	9	20	2
21	10	9	20	2
22	10	9	20	2
B	9	8	19	1
14	9	8	19	1
C	8	8	19	1
18	8	8	19	1
15	8	8	19	1
16	8	8	19	1
19	8	8	19	1
D	8	8	19	2
17	8	8	19	2
E	8	8	19	2
23	9	8	22	2
24	9	9	22	2
25	9	9	22	2
26	9	9	22	2

Table 4-2. Latitude and longitude, LORAN C coordinates, and compass bearings for Bryan Mound nekton trawl stations.

Station	Latitude	Longitude	LORAN C Coordinates		Tow Bearing
9A	28°54.78'N	95°15.93'W	11056.1	25276.5	237°
9B	28°54.78'N	95°15.93'W	11056.2	25270.5	57°
14A	28°43.20'N	95°16.12'W	11058.8	25248.1	147°
14B	28°43.20'N	95°16.12'W	11059.4	25248.6	327°
15A	28°44.08'N	95°14.55'W	11058.4	25266.5	147°
15B	28°44.08'N	95°14.55'W	11059.1	25266.9	327°
16A	28°44.19'N	95°14.41'W	11058.4	25269.8	327°
16B	28°44.19'N	95°14.41'W	11059.1	25269.0	147°
17A	28°45.04'N	95°12.89'W	11058.1	25289.0	147°
17B	28°45.04'N	95°12.89'W	11058.7	25289.4	327°
18A	28°44.02'N	95°15.17'W	11058.5	25263.1	147°
18B	28°44.02'N	95°15.17'W	11059.1	25263.4	327°
19A	28°44.59'N	95°14.21'W	11058.4	25272.3	147°
19B	28°44.59'N	95°14.21'W	11059.1	25272.8	327°
20A	28°44.08'N	95°15.68'W	11058.2	25261.0	237°
20B	28°44.08'N	95°15.68'W	11058.3	25255.0	57°
21A	28°44.55'N	95°14.85'W	11056.0	25267.0	237°
21B	28°44.55'N	95°14.85'W	11058.1	25261.0	57°
22A	28°44.99'N	95°14.05'W	11057.9	25281.6	237°
22B	28°44.99'N	95°14.05'W	11058.0	25275.5	57°
23A	28°43.23'N	95°15.01'W	11059.5	25261.9	237°
23B	28°43.23'N	95°15.01'W	11059.6	25255.9	57°
24A	28°43.78'N	95°14.22'W	11059.3	25272.3	237°
24B	28°43.78'N	95°14.22'W	11059.4	25266.3	57°
25A	28°44.14'N	95°13.40'W	11059.2	25282.5	237°
25B	28°44.14'N	95°13.40'W	11059.3	25276.5	57°
26A	28°41.11'N	95°13.42'W	11062.8	25259.0	237°
26B	28°41.11'N	95°13.42'W	11062.6	25262.7	57°
BA	28°41.53'N	95°19.47'W	11059.5	25208.6	147°
BB	28°41.53'N	95°19.47'W	11061.1	25208.8	327°
CA	28°43.57'N	95°15.47'W	11058.7	25256.7	147°
CB	28°43.57'N	95°15.47'W	11059.3	25257.0	327°
DA	28°44.58'N	95°13.50'W	11058.2	25280.8	147°
DB	28°44.58'N	95°13.50'W	11058.8	25281.0	327°
EA	28°46.70'N	95°09.65'W	11057.4	25322.9	147°
EB	28°46.70'N	95°09.65'W	11058.0	25332.2	327°

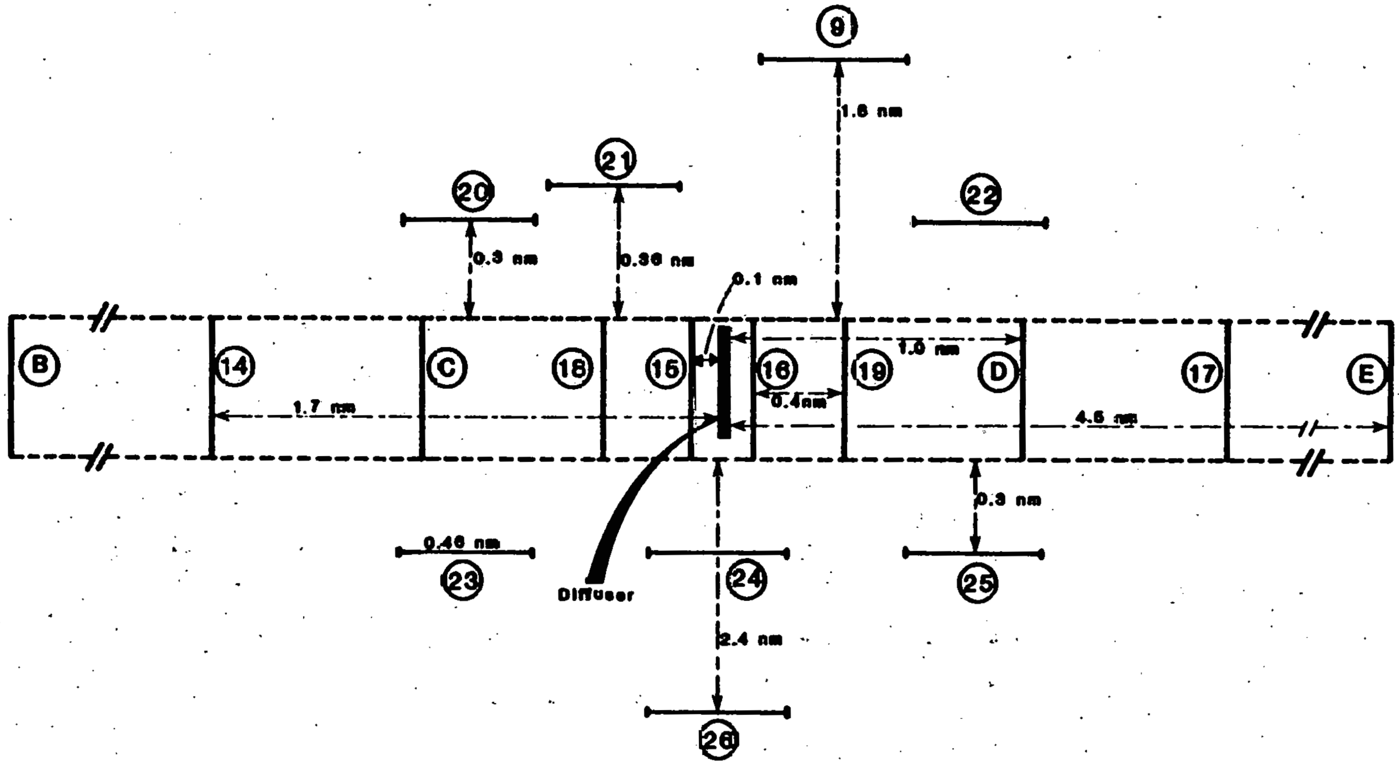

Figure 4-1. Schematic diagram of Bryan Mound nekton station locations in relation to the diffuser.

contrasts:

1) stations within the brine plume vs. stations outside the brine plume,

2) linear regression effects of brine concentrations above ambient, and

3) quadratic regression effects of brine concentrations above ambient.

Individual trawl tows made at each station were treated separately and not pooled. This was done to permit calculation of an error mean square for the factorial experiment; this then was used as the denominator in individual degree of freedom F tests. Comparisons were made within individual cruises and for all cruises pooled stations x cruises interaction when significant.

Trawl stations were assigned brine elevations using bottom salinity measured at each station during each cruise. Brine elevations were determined relative to ambient salinity which was defined as the arithmetic mean of bottom salinities at stations B and E. These stations are located at the same depth and parallel to the diffuser, 4.5 nautical miles upcoast and downcoast, and are always beyond the spread of the brine plume according to exposure rosettes (Randall and McLellan, 1983). Ambient salinity was measured daily to ensure that any natural variations in salinity, which might occur over the course of a cruise and conceal brine effects, would be recognized. Brine elevations at individual stations were coded 0 o/oo for salinities below ambient and between 0.0 - 0.4 o/oo above ambient, 1 o/oo for salinities 0.5 - 1.4 o/oo above ambient, 2 o/oo for salinities 1.5 - 2.4 o/oo above ambient, 3 o/oo for salinities 2.5 - 3.4 o/oo above ambient, and 4 o/oo for salinities 3.5 - 4.4 above ambient (Table 4-3). To emphasize possible effects of brine in the first contrast cited above, stations at ambient (0 o/oo) were compared against stations with brine elevations in excess of 1 o/oo; stations at 1 o/oo above ambient were excluded.

Table 4-3. Bottom ambient salinities (o/oo), observed surface and bottom water salinities, and assigned brine elevations measured at each station during the September 1982 through August 1983 postdisposal period. See Section 4.2.3 for procedures used to define ambient salinity and assign brine elevations. No surface salinity data was collected on 8-10 November 1982.

Cruise	Station	Surface Salinity	Bottom Salinity	Defined Ambient Salinity	Elevation Above Ambient Salinity	Assigned Brine Elevation
8-10 November 1982	9	--	31.6	32.6	-1.0	0
	20	--	32.0	32.6	-0.6	0
	21	--	31.9	32.6	-0.7	0
	22	--	31.9	32.6	-0.7	0
	B	--	32.5	32.6	-0.1	0
	14	--	32.6	32.7	-0.1	0
	C	--	33.3	32.7	+0.6	1
	18	--	32.6	32.7	-0.1	0
	15	--	34.6	32.7	+1.9	2
	16	--	34.6	32.7	+1.9	2
	19	--	33.8	32.7	+1.1	1
	D	--	32.7	32.7	0.0	0
	17	--	33.4	32.7	+0.7	1
	E	--	32.9	32.7	+0.2	0
	23	--	33.2	32.6	+1.0	1
	24	--	32.5	32.6	-0.1	0
	25	--	32.2	32.6	-0.4	0
	26	--	32.3	32.6	-0.3	0
8-9 February 1983	9	25.7	27.5	28.3	-0.8	0
	20	26.9	29.0	28.3	+0.7	1
	21	27.0	27.9	28.3	-0.4	0
	22	26.9	27.9	28.3	-0.4	0
	B	27.2	28.8	28.4	+0.4	0
	14	27.1	28.0	28.4	-0.4	0
	C	27.3	28.5	28.4	+0.1	0
	18	27.3	30.5	28.4	+2.1	2
	15	27.2	31.1	28.4	+2.7	3
	16	27.1	30.0	28.4	+1.6	2
	19	27.0	29.0	28.4	+0.6	1
	D	27.0	27.9	28.4	-0.5	0
	17	26.9	27.5	28.4	-0.9	0
	E	26.8	28.0	28.4	-0.4	0
	23	27.1	30.0	28.3	+1.7	2
	24	27.1	32.2	28.3	+3.9	4
	25	27.0	30.5	28.3	+2.2	2
	26	27.3	27.9	28.3	-0.4	0

Table 4-3. Continued.

Cruise	Station	Surface Salinity	Bottom Salinity	Defined Ambient Salinity	Elevation Above Ambient Salinity	Assigned Brine Elevation
19-22 May 1983	9	28.0	31.2	31.0	+0.2	0
	20	28.2	31.2	31.0	+0.2	0
	21	28.4	31.8	31.0	+0.8	1
	22	28.4	30.2	31.0	-0.8	0
	B	28.5	31.3	31.6	-0.3	0
	14	28.4	31.0	31.6	-0.6	0
	C	28.4	32.0	31.6	+0.4	0
	18	28.5	32.0	31.6	+0.4	0
	15	28.4	34.1	31.6	+2.5	3
	16	28.4	34.8	31.6	+3.2	3
	19	28.6	32.9	31.6	+1.3	1
	D	28.5	31.8	31.6	+0.2	0
	17	28.3	31.8	31.6	+0.2	0
	E	28.0	31.9	31.6	+0.3	0
	23	28.5	31.3	31.0	+0.3	0
	24	28.5	31.9	31.0	+0.9	1
	25	28.6	31.5	31.0	+0.5	1
	26	28.9	31.2	31.0	+0.2	0
1-2 September 1983	9	23.8	30.2	30.7	-0.5	0
	20	25.0	31.9	30.7	+1.2	1
	21	25.0	31.0	30.7	+0.3	0
	22	25.1	31.0	30.7	+0.3	0
	B	24.9	31.1	30.7	+0.4	0
	14	24.8	30.9	30.7	+0.2	0
	C	25.0	31.7	30.7	+1.0	1
	18	25.0	31.2	30.7	+0.5	1
	15	25.0	32.0	30.7	+1.3	1
	16	25.0	33.0	30.7	+2.3	2
	19	25.2	33.0	30.7	+2.3	2
	D	25.0	31.7	30.7	+1.0	1
	17	24.8	30.5	30.7	-0.2	0
	E	25.0	30.5	30.7	-0.2	0
	23	25.1	31.0	30.7	+0.3	0
	24	25.0	32.0	30.7	+1.3	1
	25	25.0	32.1	30.7	+1.4	1
	26	25.0	32.5	30.7	+1.8	2

Nekton patterns described for the diffuser area are based on stations 14-25, B, C, D, and E. Previous analyses of by-station nekton compositions (Chittenden et al, 1981a, 1981b, 1982) indicated valid exclusion of stations 9 and 26 from the diffuser station set because of subtle compositional changes associated with differences in depth and distance from shore. This precedent has been continued to facilitate inter-report comparisons. Diffuser station groupings were delineated by cluster analysis using the Bray-Curtis coefficient of similarity and flexible sorting (Clifford and Stephenson, 1975) which determines similarity/dissimilarity among stations and station sets based on relative species abundance.

4.3 Results and Discussion of Cluster Analysis

Cluster analysis produced a dendogram consisting of one major, relatively homogeneous station group comprised of all stations but station 26 (Figure 4-2). Station 26, located furthest offshore and in deeper water than all other stations, separated at the 0.48 Bray-Curtis value. The major group, similar at the 0.36 Bray-Curtis value, was made up of two minor station sets. The larger of these minor sets included 11 diffuser area stations which clustered into two subsets of neighboring stations. One subset consisted of stations furthest offshore (23, 24, 25) and upcoast (17, D, E) of the diffuser (0.30 Bray-Curtis); the other was made up of stations (15, 16, 18, 19, C) which immediately straddle the diffuser on either side (0.22 Bray-Curtis). The second minor station set, similar at the 0.26 Bray-Curtis value and situated inshore and farthest downcoast of the diffuser, was formed by six stations (9, an inshore station and historically not considered a diffuser area station; 14, 20, 21, 22, B).

The small differences in major station group Bray-Curtis values continue

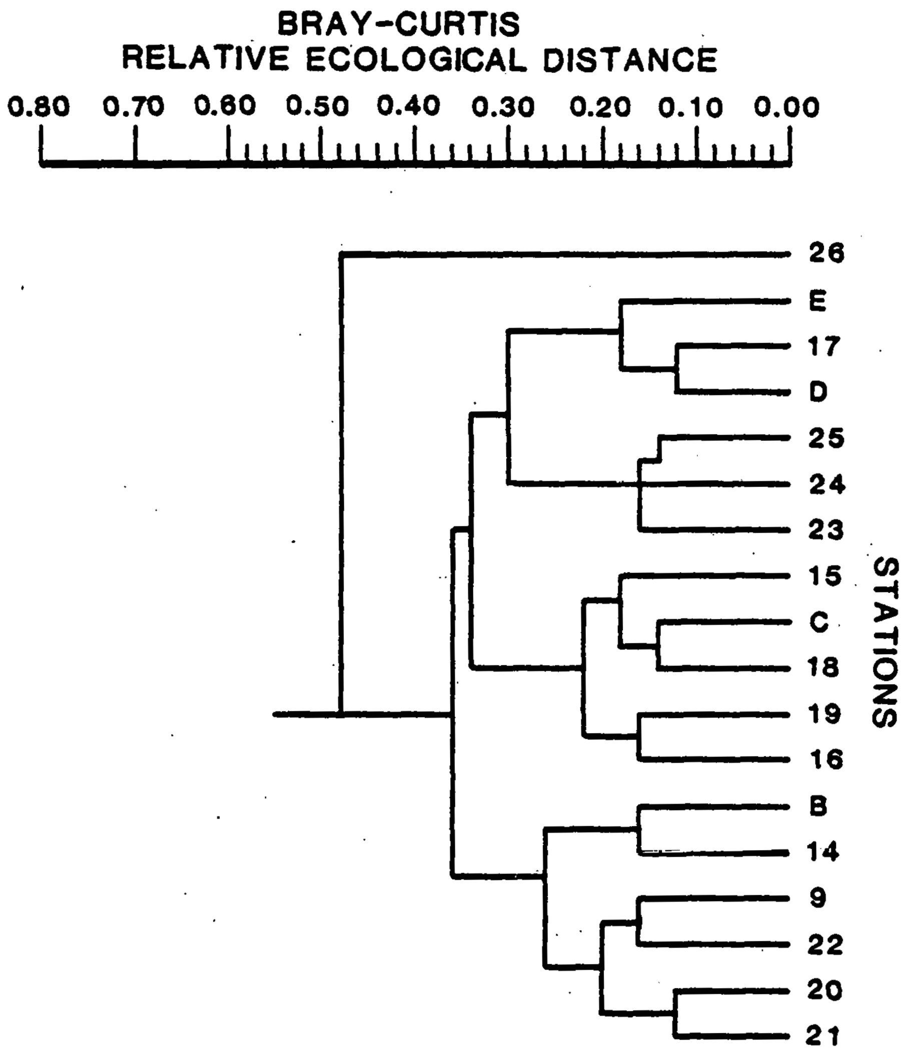

Figure 4-2. Cluster analysis dendogram of nekton (shrimps and fishes) from 18-station quarterly data during the September 1982 through August 1983 postdisposal period.

to indicate the diffuser area forms a basically homogeneous nekton community. Results of predisposal and earlier postdisposal cluster analyses indicate the nekton community has become slightly more dissimilar since the commencement of brine disposal, but observed predisposal/postdisposal differences show no constant trend toward increasing ecological heterogeneity. During the predisposal period (Chittenden et al., 1981a), major station groups differed by no more than 0.08 Bray-Curtis. Respective differences among major station groups increased to 0.12 and 0.30 Bray-Curtis during the March 1980 through February 1981 (Chittenden et al., 1981b) and March through August 1981 (Chittenden et al., 1982) postdisposal periods, but decreased to 0.22 Bray-Curtis during the preceding study (Pavela and Chittenden, 1983) and were no greater than 0.14 Bray-Curtis in the present study.

4.4 Results and Discussion of Overall Nekton Compositions in the Diffuser Area

A total of 2,176 shrimps and 54,206 fishes of 83 species were captured in 128 trawl tows made in the diffuser area (stations 14 through 25 and B through E) during the September 1982 through August 1983 period (Tables 4-4 and 4-5). Data on shrimp and fish compositions at stations 9 and 26, located inshore and offshore of the diffuser area at different depths, are presented in Tables D-1 through D-8.

Penaeus aztecus (64.2%) and *P. setiferus* (27.8%) dominated the shrimp catch in the diffuser area and together made up 91.9% of the total (Table 4-4). *Penaeus duorarum* (8.1%) was much less abundant.

Only eight species of fish each made up greater than 2% of the total fish catch and comprised 86.0% of the diffuser area catch (Table 4-5). The remaining 13.9% was distributed among 75 less abundant species. *Stenotomus*

Table 4-4. Overall composition of dominant and non-dominant species of shrimp in the diffuser area (stations 14 through 25 and B through E) during September 1982 through August 1983 postdisposal period.

	Total Catch	Mean Catch	%	CUM %
Dominant Species (3)				
PENAEUS AZTECUS	1396	10.91	64.15	64.15
PENAEUS SETIFERUS	604	4.72	27.76	91.91
PENAEUS DUORARUM	176	1.38	8.09	100.00
Non-Dominant Species (0)				

Number of tows = 128
Total = 2176

Table 4-5. Overall composition of dominant and non-dominant species of fish in the diffuser area (stations 14 through 25 and B through E) during September 1982 through August 1983 postdisposal period.

	Total Catch	Mean Catch	%	CUM %
Dominant Species (8)				
STENOTOMUS CAPRINUS	14023	109.55	25.87	25.87
CYNOSCION NOTHUS	11461	89.54	21.14	47.01
SYACIUM GUNTERI	5705	44.57	10.52	57.54
ANCHOA HEPSETUS	5449	42.57	10.05	67.59
CHLOROSCOMBRUS CHRYSURUS	4851	37.90	8.95	76.54
PEPRILUS BURTI	2181	17.04	4.02	80.56
TRACHURUS LATHAMI	1592	12.44	2.94	83.50
PEPRILUS PARU	1371	10.71	2.53	86.03
Non-Dominant Species (75)				
SELENE SETAPINNIS	687	5.37	1.27	87.30
POLYDACTYLUS OCTONEMUS	644	5.03	1.19	88.48
ANCHOA MITCHILLI	601	4.70	1.11	89.59
TRICHIURUS LEPTURUS	524	4.09	0.97	90.56
SPHOEROIDES PARVUS	489	3.82	0.90	91.46
DIPLECTRUM BIVITTATUM	448	3.50	0.83	92.29
PRIONOTUS RUBIO	437	3.41	0.81	93.09
ARIOPSIS FELIS	424	3.31	0.78	93.88
SYNODUS FOETENS	382	2.98	0.70	94.58
ETROPUS CROSSOTUS	373	2.91	0.69	95.27
LARIMUS FASCIATUS	272	2.13	0.50	95.77
CITHARICHTHYS SPILOPTERUS	211	1.65	0.39	96.16
LEPOPHIDIUM GRAELLSI	201	1.57	0.37	96.53
PORICHTHYS PLECTRODON	185	1.45	0.34	96.87
CYNOSCION ARENARIUS	165	1.29	0.30	97.18
MICROPOGONIAS UNDULATUS	160	1.25	0.30	97.47
SYMPHURUS CIVITATUS	142	1.11	0.26	97.73
CENTROPRISTIS PHILADELPHICA	133	1.04	0.25	97.98
SELAR CRUMENOPHTHALMUS	108	0.84	0.20	98.18
OGCOCEPHALUS DECLIVIROSTRIS	108	0.84	0.20	98.38
SAURIDA BRASILIENSIS	100	0.78	0.18	98.56
UPENEUS PARVUS	92	0.72	0.17	98.73
LEIOSTOMUS XANTHURUS	82	0.64	0.15	98.88
BREVOORTIA PATRONUS	62	0.48	0.11	99.00
HALIEUTICHTHYS ACULEATUS	60	0.47	0.11	99.11
UROPHYCIS FLORIDANUS	44	0.34	0.08	99.19
MENTICIRRHUS AMERICANUS	42	0.33	0.08	99.27
LAGODON RHOMBOIDES	36	0.28	0.07	99.33
BOLLMANNIA COMMUNIS	33	0.26	0.06	99.39
PARALICHTHYS LETHOSTIGMA	30	0.23	0.06	99.45
CYCLOPSETTA CHITTENDENI	30	0.23	0.06	99.51
PRIONOTUS TRIBULUS	24	0.19	0.04	99.55
CARANX CRYSOS	22	0.17	0.04	99.59

Table 4-5. Continued.

	Total Catch	Mean Catch	%	CUM %
ORTHOPRISTIS CHRYSOPTERA	22	0.17	0.04	99.63
LUTJANUS CAMPECHANUS	20	0.16	0.04	99.67
HARENGULA JAGUANA	19	0.15	0.04	99.70
SCORPAENA CALCARATA	14	0.11	0.03	99.73
PRIONOTUS SALMONICOLOR	12	0.09	0.02	99.75
RHIZOPRIONODON TERRAENOVAE	12	0.09	0.02	99.77
GYMNACHIRUS TEXAE	11	0.09	0.02	99.79
BAGRE MARINUS	11	0.09	0.02	99.81
OPISTHONEMA OGLINUM	10	0.08	0.02	99.83
OPHIDION WELSHI	9	0.07	0.02	99.85
PRIONOTUS OPHRYAS	8	0.06	0.01	99.86
OGCOCEPHALUS PANTOSTICTUS	7	0.05	0.01	99.88
RAJA TEXANA	5	0.04	0.01	99.89
LAGOCEPHALUS LAEVIGATUS	5	0.04	0.01	99.89
LUTJANUS SYNAGRIS	4	0.03	0.01	99.90
SCOMBEROMORUS CAVALLA	4	0.03	0.01	99.91
ANCYLOPSETTA QUADROCELLATA	3	0.02	0.01	99.91
ANCHOA LYOLEPIS	3	0.02	0.01	99.92
BROTULA BARBATA	3	0.02	0.01	99.93
EUCINOSTOMUS GULA	3	0.02	0.01	99.93
POGONIAS CROMIS	3	0.02	0.01	99.94
STEPHANOLEPIS SETIFER	3	0.02	0.01	99.94
SARDINELLA AURITA	3	0.02	0.01	99.95
GYMNOTHORAX NIGROMARGINATUS	2	0.02	0.00	99.95
SYMPHURUS PLAGIUSA	2	0.02	0.00	99.96
GOBIONELLUS HASTATUS	2	0.02	0.00	99.96
SYNGNATHUS LOUISIANAE	2	0.02	0.00	99.96
PARALICHTHYS ALBIGUTTA	2	0.02	0.00	99.97
SPHYRAENA GUACHANCHO	2	0.02	0.00	99.97
BALISTES CAPRISCUS	2	0.02	0.00	99.97
EUCINOSTOMUS ARGENTEUS	2	0.02	0.00	99.98
BELLATOR MILITARIS	2	0.02	0.00	99.98
EUCINOSTOMUS MELANOPTERUS	1	0.01	0.00	99.98
CHILOMYCTERUS SCHOEPFI	1	0.01	0.00	99.98
ACANTHOSTRACION QUADRICORNIS	1	0.01	0.00	99.99
DECAPTERUS PUNCTATUS	1	0.01	0.00	99.99
DASYATIS AMERICANUS	1	0.01	0.00	99.99
SPHYRNA TIBURO	1	0.01	0.00	99.99
SELENE VOMER	1	0.01	0.00	99.99
ALECTIS CILIARIS	1	0.01	0.00	100.00
ETRUMEUS TERES	1	0.01	0.00	100.00
HEMICARANX AMBLYRHYNCHUS	1	0.01	0.00	100.00

Number of tows = 128
Total = 54206

caprinus was the most numerous species, accounting for 25.9% of the total. Other dominants were Cynoscion nothus (21.1%), Syacium gunteri (10.5%), Anchoa hepsetus (10.1%), Chloroscombrus chrysurus (9.0%), Peprilus burti (4.0%), Trachurus lathami (2.9%), and Peprilus paru (2.5%).

Diffuser area biomass compositions of principal shrimps and fishes were generally similar to those by abundance. Penaeus aztecus (54.6%) and P. setiferus (41.7%) together formed 96.3% of total shrimp biomass (Table 4-6.) Penaeus duorarum (3.7%) made up a minor portion of the catch by weight.

Ten species each made up greater than 2% of the total fish biomass and accounted for 84.4% of the total fish biomass in the diffuser area (Table 4-7). The remaining 15.6% was distributed among 73 less abundant species. The numerical dominants (Table 4-5) were generally among the principal species when ranked by weight also. Stenotomus caprinus, the most numerous species, also formed the greatest portion of total biomass (19.0%). Other numerical dominants that were also dominants by weight were: C. nothus (15.7%), C. chrysurus (14.2%), S. gunteri (8.9%), A. hepsetus (7.4%), P.burti (4.7%), and T. lathami (3.9%). Several species which were minor numerically, were dominants by weight because of their large relative sizes. These included Ariopsis felis (6.3%), Rhizoprionodon terraenovae (2.3%) and Pogonias cromis (2.1%).

Relative abundance rankings of shrimps in the present study were similar to those on day-cruises in analogous months during predisposal and eighteen-month postdisposal studies (Chittenden et al, 1981a, 1981b and 1982), but rankings for both abundance and biomass in the present study reversed from those in the preceding postdisposal period (Pavela and Chittenden, 1983). In the former studies (Chittenden et al, 1981a, 1981b and 1982) P. aztecus (72.9 % number) dominated diffuser area catches as in

Table 4-6. Overall biomass compositions of dominant and non-dominant shrimp in the diffuser area (Stations 14 through 25 and B through E) during September 1982 through August 1982 postdisposal period.

Species	Total Biomass (kg.)	Mean Catch	%	CUM %
Dominant Species (3)				
PENAEUS AZTECUS	25.3	0.198	54.64	54.64
PENAEUS SETIFERUS	19.3	0.151	41.68	96.32
PENAEUS DUORARUM	1.7	0.038	3.67	100.00
Non-Dominant Species (0)				

Number of tows = 128
Total Biomass = 46.3

Table 4-7. Biomass compositions of dominant and non-dominant fishes in the diffuser area (Stations 14 through 25 and B through E) during the September 1982 through August 1983 postdisposal period.

Species	Total Biomass (kg.)	Mean Catch	%	CUM %
Dominant Species (10)				
STENOTOMUS CAPRINUS	196.3	1.533	19.04	19.04
CYNOSCION NOTHUS	161.5	1.262	15.67	34.71
CHLOROSCOMBRUS CHRYSURUS	145.9	1.139	14.15	48.86
SYACIUM GUNTERI	91.5	0.715	8.88	57.74
ANCHOA HEPSETUS	76.4	0.597	7.41	65.15
ARIOPSIS FELIS	64.8	0.506	6.29	71.44
PEPRILUS BURTI	48.1	0.376	4.67	76.11
TRACHURUS LATHAMI	40.2	0.314	3.90	80.01
RHIZOPRIONODON TERRAENOVAE	24.0	0.188	2.33	82.34
POGONIAS CROMIS	21.5	0.168	2.09	84.43
Non-dominant Species (73)				
SYNODUS FOETENS	18.0	0.141	1.75	86.18
CYNOSCION ARENARIUS	16.8	0.131	1.63	87.81
PEPRILUS PARU	16.4	0.128	1.59	89.40
SELENE SETAPINNIS	12.1	0.095	1.17	90.57
PARALICHTHYS LETHOSTIGMA	11.3	0.088	1.10	91.67
MENTICIRRHUS AMERICANUS	10.3	0.081	1.00	92.67
TRICHIURUS LEPTURUS	9.8	0.076	0.95	93.62
MICROPOGONIAS UNDULATUS	7.4	0.058	0.72	94.34
BREVOORTIA PATRONUS	5.8	0.045	0.56	94.90
PRIONOTUS RUBIO	5.7	0.045	0.55	95.45
LEPOPHIDIUM GRAELLSI	5.0	0.039	0.49	95.94
POLYDACTYLUS OCTONEMUS	5.0	0.039	0.49	96.43
LEIOSTOMUS XANTHURUS	4.7	0.037	0.46	96.89
DIPLECTRUM BIVITTATUM	3.2	0.025	0.31	97.20
BAGRE MARINUS	2.9	0.023	0.28	97.48
RAJA TEXANA	2.8	0.022	0.27	97.75
PORICHTHYS PLECTRODON	2.4	0.019	0.23	97.98
LARIMUS FASCIATUS	2.2	0.017	0.21	98.19
UPENEUS PARVUS	1.8	0.014	0.17	98.36
SELAR CRUMENOPHTHALMUS	1.7	0.013	0.16	98.52
ETROPUS CROSSOTUS	1.6	0.013	0.16	98.68
CENTROPRISTIS PHILADELPHICA	1.4	0.011	0.14	98.82
OPISTHONEMA OGLINUM	1.3	0.010	0.13	98.95
DASYATIS AMERICANA	1.1	0.009	0.11	99.06
UROPHYCIS FLORIDANUS	1.1	0.009	0.11	99.17
ANCHOA MITCHILLI	1.0	0.008	0.10	99.27
PARALICHTHYS ALBIGUTTA	0.8	0.006	0.08	99.35

Table 4-7. Continued.

Species	Total Biomass (kg.)	Mean Catch	%	CUM %
CARANX CRYSOS	0.7	0.006	0.07	99.42
CITHARICHTHYS SPILOPTERUS	0.7	0.006	0.07	99.49
HARENGULA JAGUANA	0.7	0.006	0.07	99.56
GYMNOTHORAX NIGROMARGINATUS	0.6	0.005	0.06	99.62
SYMPHURUS CIVITATUS	0.6	0.005	0.06	99.68
LUTJANUS CAMPECHANUS	0.6	0.005	0.06	99.74
PRIONOTUS TRIBULUS	0.5	0.004	0.05	99.79
BALISTES CAPRISCUS	0.4	0.003	0.04	99.83
SPHYINA TRIBURO	0.4	0.003	0.04	99.87
OPHIDION WELSHI	0.4	0.003	0.04	99.91
CHILOMYCTERUS SCHOEPFI	0.3	0.002	0.03	99.94
ANCYLOPSETTA QUADROCELLATA	0.2	0.002	0.02	99.96
LAGODON RHOMBOIDES	0.2	0.002	0.02	99.98
ALECTIS CILIARIS	0.1	0.001	0.01	99.99
OGCOCEPHALUS PANTOSTICTUS	0.1	0.001	0.01	100.00
EUCINOSTOMUS GULA	0.1	0.001	0.01	100.00
ACANTHOSTRACION QUADRICORNIS	0.1	0.001	0.01	100.00
PRIOCANTHUS ARENATUS	0.1	0.001	0.01	100.00
PRIONOTUS SALMONICOLOR	0.1	0.001	0.01	100.00
SPHOEROIDES PARVUS	0.1	0.001	0.01	100.00
CYCLOPSETTA CHITTENDENI	0.1	0.001	0.01	100.00
Other Species (25)	<0.1	<0.001	<0.01	100.00

Number of tows = 128
Total Biomass = 1,030.9

the present study (91.9% number; 96.3% weight), but P. setiferus (62.71% number; 78.5% weight) was the principal shrimp found by Pavela and Chittenden, 1983. Penaeus duorarum continued to be the least important commercial penaeid captured, though its abundance (8.1%) was greater than in earlier studies when it generally constituted less than 2% of the catches.

Diffuser area ichthyofauna compositions continue to be dominated by relatively few species. The same species tend to appear year after year though relative abundance of individual species generally fluctuate greatly. Overall, the eight numerical dominants in the present study (86.0% number; 84.4% weight) made up 74.9% and 70.1% of ichthyofauna by number and weight during the September 1981 through August 1982 study period. Though these percentages are comparable, those of some component species are not. Four species showed large increases in relative abundance including S. caprinus (25.9% vs. <0.1%), A. hepsetus (10.1% vs. 3.8%), T. lathami (2.9% vs. 0.1%), and P. paru (2.5% vs. <0.1%) while two others, C. nothus (21.1% vs. 40.9%) and S. gunteri (10.5% vs. 17.4%), showed large decreases in relative abundance between the present and preceding study period (Pavela and Chittenden, 1983). Similarly, several non-dominant species, notably Selene setapinnis, Polydactylus octonemus, Anchoa mitchelli, Sphoeroides parvus, Diplectrum bivittatum and Prionotus rubio were more abundant in the present study, while Upeneus parvus, Trichiurus lepturus, Cynoscion arenarius, Synodus foetens, Paralichthys lethostigma, Menticirhus americanus and Lutjanus campechanus were less abundant in the present study. Such great fluctuations in species compositions have been previously reported and have been observed throughout the Bryan Mound study (Chittenden et al, 1981a, 1981b, and 1982). They likely reflect annual changes in abundance and biomass related to seasonal movements, short life spans and extremely high mortality rates described for some of these species (Williams, 1955; Perez-Farfante, 1969; Chittenden and McEachran, 1976; White and Chittenden, 1977; Murphy, 1981; Shlossman and Chittenden, 1981; Devries and Chittenden, 1982; Geoghegan and Chittenden, 1982; Standard and Chittenden, in press).

4.5 Results and Discussion of Compositions by Station of Shrimps and Ichthyofauna in the Diffuser Area

Percentage compositions of shrimps and fishes varied greatly among stations, but this variation did not appear to reflect station location relative to the diffuser.

Compositions of the principal shrimp, *P. aztecus* ranged from 27.3% at station E to 86.5% at station 21 (Table 4-8), stations infrequently impacted (0 to 24% exposure time) by the defined (2 o/oo) brine plume (See Chapter 2; Figures 2-28 through 2-33). Compositions also varied greatly from 33.3% at station 15 to 73% at station 16, stations nearly always and most influenced by brine (90 to 100% exposure time). Compositions of *P. setiferus* showed similar great station to station fluctuations, ranging from 11.4% at station B to 57.9% at station D, stations rarely (0 to 6% exposure time) impacted by the plume. Compositions were both high (57.1%) and low (24.7%) at stations 15 and 16 which are often influenced by brine.

Total percentage compositions of the more abundant ichthyofauna were very homogeneous in the diffuser area. Nineteen species made up 90.6 to 98.0% of the catch (Table 4-8). Lowest total compositions occurred at station 24 which is frequently influenced (68% exposure time) by the plume; highest totals occurred at station 19 which is influenced by brine less often (46% exposure time). Total compositions at stations 15 (96.2%) and 16 (95.8%), which are most exposed to brine, were intermediate in value and about the same as those at stations such as stations 14, 17, B and E which

Table 4-8. Percentage compositions of shrimps and more abundant ichthyofauna (>0.5% of the total catch) by station during the September 1982 through August 1983 postdisposal period. Stations 9 and 26 are included for comparison.

Species	Stations 9	20	21	22	B	14	C	18	15	16
PENAEUS AZTECUS	64.22	73.63	86.51	77.09	80.68	64.91	62.69	52.63	33.33	72.94
PENAEUS SETIFERUS	30.28	26.37	12.56	14.98	11.36	22.81	32.84	44.21	57.14	24.71
PENAEUS DUORARUM	5.50	0.00	0.93	7.93	7.95	12.28	4.48	3.16	9.52	2.35
STENOTOMUS CAPRINUS	14.28	20.15	17.63	13.50	7.51	20.48	34.06	33.71	28.10	37.73
CYNOSCION NOTHUS	43.99	26.93	30.55	32.76	29.30	23.12	8.72	11.11	9.20	4.80
SYACIUM GUNTERI	6.69	5.33	4.96	12.74	12.50	9.67	10.01	10.18	20.33	22.91
ANCHOA HEPSETUS	6.44	14.17	25.01	14.03	8.51	11.86	10.32	18.59	12.79	5.01
CHLOROSCOMBRUS CHRYSURUS	4.26	8.21	4.17	9.05	11.47	9.11	16.78	8.85	8.38	4.24
PEPRILUS BURTI	5.74	4.40	2.71	4.19	11.53	3.92	5.89	1.74	1.32	2.26
TRACHURUS LATHAMI	0.45	1.13	1.14	0.23	0.25	0.42	0.44	1.52	1.29	5.01
PEPRILUS PARU	0.39	1.73	0.85	0.33	3.40	7.03	0.69	0.68	1.73	3.78
SELENE SETAPINNIS	0.67	5.80	2.97	0.50	1.68	2.97	0.69	0.43	0.51	0.64
POLYDACTYLUS OCTONEMUS	4.06	1.43	0.50	1.96	0.53	0.75	1.32	0.68	0.68	0.60
ANCHOA MITCHILLI	4.76	0.60	0.27	0.57	0.37	0.36	0.80	0.65	4.78	0.39
TRICHIURUS LEPTURUS	0.53	1.31	0.48	0.33	1.12	1.78	1.21	1.52	0.58	0.39
SPHOEROIDES PARVUS	0.87	0.48	0.29	0.40	2.87	0.67	0.61	0.65	1.59	0.95
DIPLECTRUM BIVITTATUM	0.20	0.60	0.66	0.67	1.47	0.42	0.88	1.80	1.09	0.88
PRIONOTUS RUBIO	1.15	0.60	0.29	0.67	2.12	1.67	0.36	0.96	0.58	2.12
ARIOPSIS FELIS	1.04	1.37	1.22	0.90	0.09	0.83	1.62	0.22	0.03	1.87
SYNODUS FOETENS	0.03	0.03	0.03	0.20	0.37	0.33	0.94	1.27	1.97	1.38
ETROPUS CROSSOTUS	0.14	0.48	0.27	0.67	0.37	1.06	0.77	0.81	1.19	0.85
LARIMUS FASCIATUS	0.95	1.37	1.67	1.06	0.25	0.36	0.22	0.03	0.10	0.00
TOTALS	96.64	96.12	95.67	94.76	95.91	96.81	96.33	95.40	96.24	95.81

Table 4-8. Continued.

Species	Stations 19	D	17	E	23	24	25	26	Diffuser Station Percentage Range
PENAEUS AZTECUS	53.85	34.58	40.82	27.27	57.81	39.20	45.76	78.33	27.3 - 86.5
PENAEUS SETIFERUS	43.96	57.94	25.51	59.74	34.38	56.00	34.75	20.00	11.4 - 59.7
PENAEUS DUORARUM	2.20	7.48	33.67	12.99	7.81	4.80	19.49	1.67	0.0 - 33.7
STENOTOMUS CAPRINUS	23.13	19.49	25.75	36.23	43.72	18.47	27.75	0.43	7.51 - 43.7
CYNOSCION NOTHUS	13.66	35.20	29.23	24.86	9.68	23.32	29.19	11.77	4.8 - 35.2
SYACIUM GUNTERI	10.27	10.39	12.43	10.79	7.80	7.85	6.61	10.22	5.0 - 22.9
ANCHOA HEPSETUS	10.08	5.46	1.98	0.03	5.58	8.71	7.22	2.72	<0.1 - 25.0
CHLOROSCOMBRUS CHRYSURUS	4.97	7.35	8.36	11.46	10.10	9.73	9.82	41.40	4.2 - 16.8
PEPRILUS BURTI	5.19	5.23	6.30	4.21	1.61	3.35	2.08	3.02	1.3 - 11.1
TRACHURUS LATHAMI	1.92	2.78	1.65	1.83	10.92	7.78	5.19	6.84	0.2 - 10.9
PEPRILUS PARU	18.46	0.89	0.12	0.00	0.06	0.00	0.05	0.00	0.0 - 18.5
SELENE SETAPINNIS	0.56	0.26	0.33	0.12	0.81	1.13	0.46	0.38	0.1 - 5.8
POLYDACTYLUS OCTONEMUS	1.03	1.75	3.25	0.78	0.86	1.40	2.05	0.46	0.5 - 3.3
ANCHOA MITCHILLI	0.69	0.52	1.19	1.41	1.98	1.95	1.37	0.05	0.3 - 4.8
TRICHIURUS LEPTURUS	0.69	1.44	0.54	0.39	0.98	1.88	0.68	4.98	0.3 - 1.9
SPHOEROIDES PARVUS	1.00	0.63	0.62	0.57	0.43	1.71	1.37	4.80	0.3 - 2.9
DIPLECTRUM BIVITTATUM	0.47	0.75	0.91	0.93	0.84	0.68	0.43	1.80	0.4 - 1.8
PRIONOTUS RUBIO	0.75	0.57	0.82	0.54	0.53	0.38	0.38	0.99	0.3 - 2.1
ARIOPSIS FELIS	2.78	0.06	0.08	0.09	0.53	0.61	0.08	0.61	<0.1 - 2.8
SYNODUS FOETENS	1.50	1.15	1.19	0.84	0.14	0.38	0.23	2.13	<0.1 - 2.0
ETROPUS CROSSOTUS	0.81	0.78	0.41	0.36	0.41	0.85	1.04	0.41	0.3 - 1.2
LARIMUS FASCIATUS	0.06	0.66	1.19	0.36	0.06	0.44	0.41	0.05	0.0 - 1.7
TOTALS	98.02	95.36	96.35	95.80	97.04	90.62	96.41	93.06	90.6 - 98.0

are beyond the influence of the brine plume (0% brine exposure).

Station to station percentage compositions of individual ichthyofauna varied more than overall compositions. However, as with shrimp, no pattern among the abundant species suggested a relationship between compositions and brine exposure. Stenotomus caprinus, an offshore species which was the principal fish, accounted for 28.1% and 37.7% of the catches at the most often impacted stations 15 and 16, respectively (Table 4-8). The range of these percentages is very similar to that for all other diffuser stations where compositions ranged from 18 to 44%, ignoring the very low 7.5% value at station B. Syacium gunteri, an offshore species which ranked third numerically, in contrast was much more abundant at stations 15 and 16 (20.3 to 22.9%) compared to its compositions elsewhere (5.0 to 12.7%). Cynoscion nothus, the second most abundant species, made up only 5 and 9% of the catches at stations 15 and 16, but its compositions were also very low (9 to 10%) at stations C and 23 where brine exposures are much lower (8 to 28%). Similarly, compositions of C. chrysurus (8.4%, 4.2%, respectively) and P. burti (1.3%, 2.3%, respectively) were low at stations 15 and 16, but similar low values also occurred at stations 17, 19, 20, 21, D, 18, 23 and 25 which are much less often impatcted by the plume.

The generally similar of overall compositions of abundant nekton among diffuser area stations suggest no relationship existed between station location and, in the present study, brine exposure. Individual species compositions were both high and low at stations most frequently exposed to brine. Similar patterns in compositions among stations have been noted in previous postdisposal studies (Chittenden et al, 1981a, 1981b, and 1982; Pavela and Chittenden, 1983).

4.6 Field Observations of the Effects of Brine on Nekton

Field observations indicated no dramatic lethal effects or extraordinary hydrographic events at any station during any of the four cruises in the September 1982 through August 1983 postdisposal period. Data recorded on special observation forms at no time or at any station suggested any unusual behavior of the nekton in the catch or dead or dying nekton in the water. Onboard observations of total biomass and species abundance did not show obvious sharp reductions in the catch in relation to the brine plume or station proximity to the diffuser. This continued absence of dramatic lethal effects is similar to observations made during all preceding postdisposal periods (Chittenden et al, 1981a, 1981b, 1982; Pavela and Chittenden, 1983).

Highest brine elevations were never greater than 4 o/oo and rarely exceeded 3 o/oo (Table 4-9). Bottom D.O. values usually exceeded 6.0 mg/l (Table 4-9) and were at least 4.0 mg/l except for one measurement of 3.1 mg/l at station B on 1-2 September 1983.

4.7 Total Shrimp Abundance Analyses

4.7.1 Results of Significance Tests and General Overview of Among-Cruises and Among-Stations Trends in Total Shrimp Abundance

Analysis of variance on total shrimp abundance found highly significant differences existed among cruises, among stations and for stations x cruises interaction during the September 1982 through August 1983 postdisposal period (Table 4-10). Significant differences among day-cruises have been found throughout the Bryan Mound study (Chittenden et al, 1981a, 1981b, and 1982; Pavela and Chittenden, 1983). Among-station effects and interaction have also always been significant except during the March 1980 through February 1981 postdisposal period (Chittenden et al, 1981b).

Table 4-9. Observed surface (S) and bottom (B) water dissolved oxygen levels (mg/l) at each station during cruises in the September 1982 through August 1983 postdisposal periods. No surface data was collected on 8-10 November 1982.

Station	Cruise							
	8-10 November 1982		8-9 February 1983		19-22 May 1983		1-2 September 1983	
	S	B	S	B	S	B	S	B
9	---	6.2	7.2	7.0	7.0	6.0	6.5	5.7
20	---	6.4	7.3	7.0	7.1	6.5	6.6	4.0
21	---	6.5	7.4	7.0	7.2	6.5	6.6	4.2
22	---	6.5	7.4	7.0	7.2	6.5	6.5	4.2
B	---	6.4	7.4	7.1	7.1	7.0	6.6	3.1
14	---	6.5	7.2	7.1	7.3	7.0	6.5	4.0
C	---	6.6	7.2	7.0	7.2	7.0	6.5	4.0
18	---	6.8	7.2	7.1	7.2	6.6	6.6	4.2
15	---	7.0	7.2	7.3	7.3	6.4	6.6	4.5
16	---	7.0	7.4	7.1	7.4	7.0	6.6	4.5
19	---	6.7	7.3	7.0	7.3	7.6	6.5	4.2
D	---	6.7	7.1	7.0	7.4	7.0	6.6	4.5
17	---	6.5	7.2	7.1	7.3	6.7	6.5	4.7
E	---	6.7	7.2	7.1	7.3	7.1	6.5	5.4
23	---	6.6	7.2	7.1	7.3	7.4	6.6	5.3
24	---	6.7	7.1	7.0	7.2	7.1	6.6	5.4
25	---	6.7	7.0	7.0	7.3	6.9	6.5	5.1
26	---	6.7	7.2	7.1	7.4	7.0	6.3	4.8

Table 4-10. Summary of two-way analysis of variance for total shrimp abundance during the September 1982 through August 1983 postdisposal period. An asterisk (*) after an F-value indicates significance at $\alpha = 0.05$.

Source of Variation	df	SS	MS	F	Pr>F	r^2
Corrected Total	127	116.48	--	--	--	1.0000
Cruises	3	8.96	2.99	15.11*	0.0001	0.0769
Stations	15	19.31	1.29	6.51*	0.0001	0.1658
Interaction	45	75.56	1.68	8.50*	0.0001	0.6487
Error	64	12.65	0.20	--	--	0.1086

Interaction was the largest source of overall model variation (r^2 = 64.9%). Variation associated with among-stations (r^2 = 16.6%) and among-cruises (r^2 = 7.7%) effects, and random variation (r^2 = 10.9%) were much less important.

Shrimp abundance was significantly different among cruises in the present study (Table 4-10). Catches in May, September and November were similar in magnitude, C/f values being 12.2 to 13.8 (Figure 4-3). February catches were much lower, averaging less than 6.9 shrimp. November, February and May catches were both higher and lower, September catches much greater than those observed in analogous day-cruises during the predisposal and earlier postdisposal studies (Chittenden et al, 1981a, 1981b and 1982; Pavela and Chittenden, 1983).

Among-station effects and stations x cruises interaction were significant for total shrimp abundance during the present period (Table 4-10). Significant interaction implies station to station patterns of abundance were not consistent and varied from cruise to cruise.

Overall shrimp abundance did not exhibit any apparent pattern relative to station location about the diffuser (Figure 4-4). Catches were about equal upcoast and downcoast of the diffuser and slightly greater inshore than offshore. Catches were low at stations 15 and 16 (C/f = 6.5 and 8.1, respectively), stations impacted by brine elevations of 2 o/oo more than 90% of the time according to exposure rosettes (See Chapter 2; Figures 2-28 through 2-33). However, catches were as low or lower at stations 23 and C (C/f = 6.6 and 6.9, respectively), located farther afield and impacted by the brine plume less frequently (8 to 28% exposure time).

Following the procedure of Chittenden et al (1981b) no multiple range tests within station x cruise cells were examined to explore the nature of

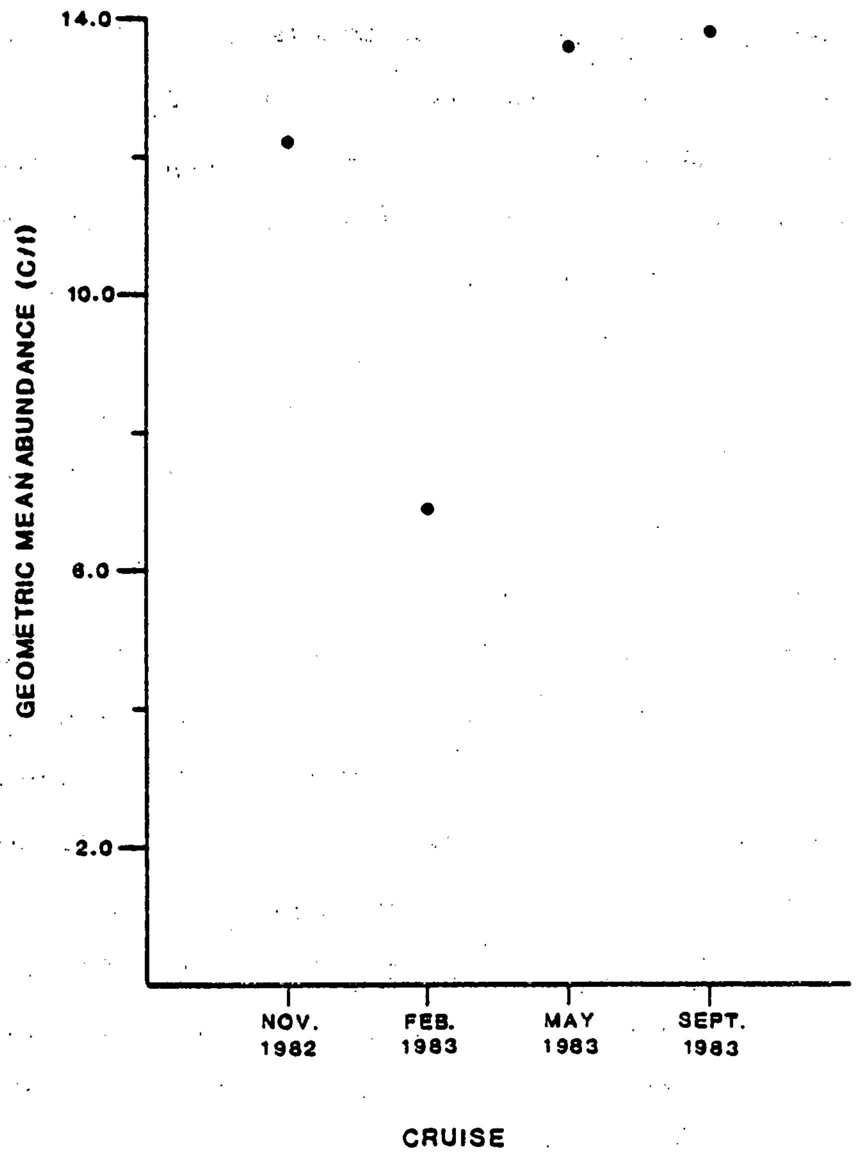

Figure 4-3. Geometric mean abundance per trawl tow (C/f) of shrimps in the diffuser area by cruise for September 1982 through August 1983 postdisposal period.

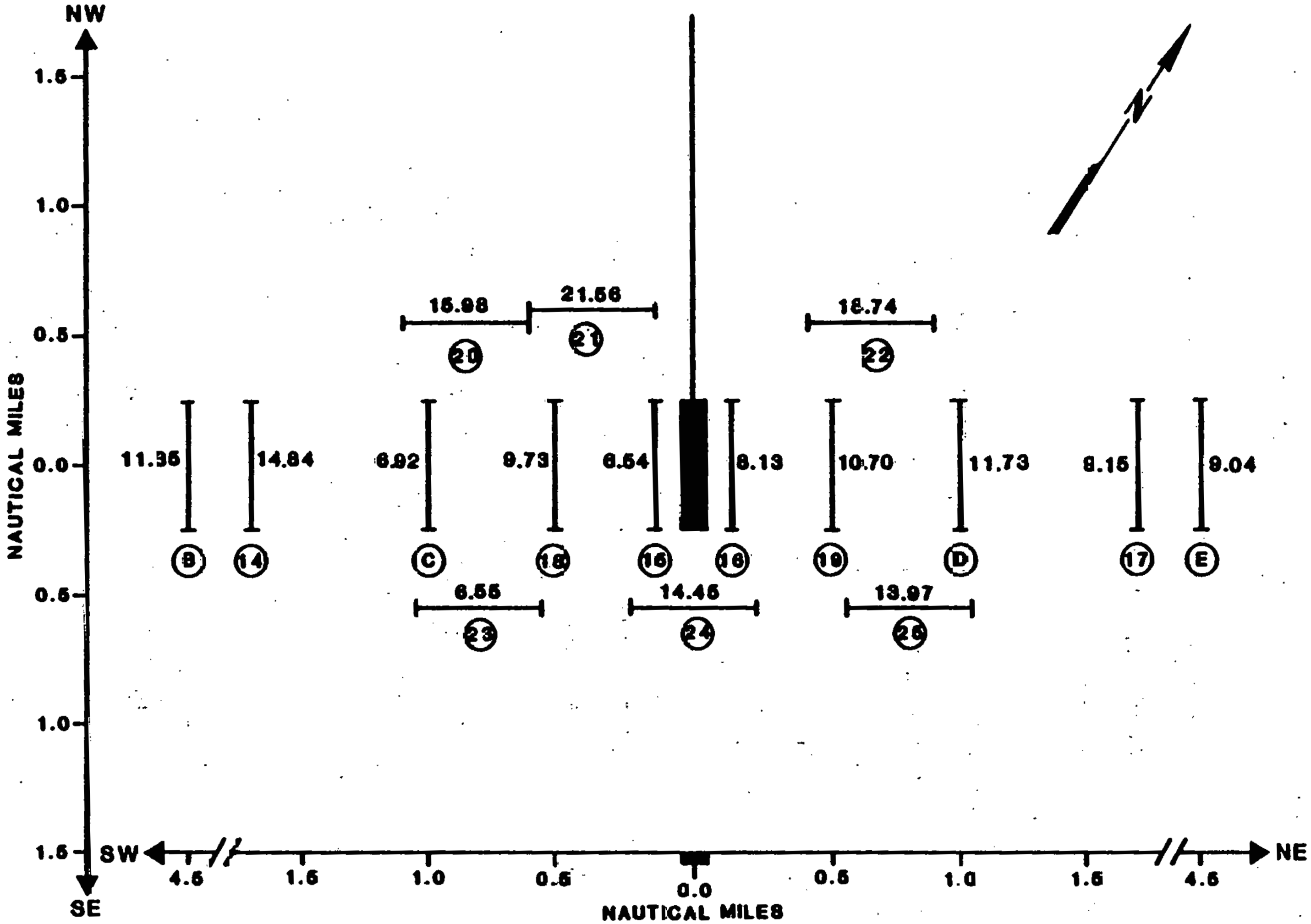

Figure 4-4. Geometric mean abundance per trawl tow (C/f) cf shrimps at diffuser stations for all cruises during September 1982 through August 1983 postdisposal period.

among-station variation because: 1) similar large fluctuations in catches were observed during the predisposal and preceding postdisposal studies, and 2) direct within-cruise individual degree of freedom brine vs. no brine contrasts are by far the most important objectives.

4.7.2 Individual Degree of Freedom Evaluations of Brine Disposal on Total Shrimp Abundance

Significant interaction (Table 4-10) implies station to station catch patterns were not consistent from cruise to cruise and that within-cruise individual degree of freedom contrasts are the most appropriate analyses to determine if brine disposal affected abundance.

Brine vs. no brine contrasts showed no significant differences in shrimp catches for the cruises of 8-9 February, 19-22 May, and 1-2 September (Table 4-11), and regression relations for these cruises were also non-significant. Brine vs. no brine and linear and quadratic contrasts were significant for the 8-10 November cruise. Shrimp abundance was significantly lower in the plume than at ambient salinity on the 8-10 November cruise (Figure 4-5).

Patterns of shrimp abundance in the brine plume were not constant, changing from cruise to cruise. Catches were both significantly lower in the brine plume on 8-10 November, about equal in and outside the plume on 8-9 February and 19-20 May, and higher in the plume on 1-2 September (Table 4-11; Figure 4-5).

4.7.3 Section Summary and Discussion

Brine disposal appeared to have had little effect on total shrimp abundance during the September 1982 through August 1983 postdisposal period. This is the same basic conclusion that was drawn during each preceding postdisposal monitoring period (Chittenden et al, 1981a, 1981b and 1982;

Table 4-11. Summary of individual degree of freedom contrasts of the effects of brine disposal on total shrimp abundance during the September 1982 through August 1983 postdisposal period. An asterisk (*) after an F-value indicates significance at $\alpha = 0.05$.

Cruise Date	Contrast	Mean Shrimp Abundance 2 - 4 o/oo	Mean Shrimp Abundance Ambient	F	r^2 (%)	Comments
8-10 Nov 1982	brine vs. no brine	2.50	42.30	96.28*	23.98	Significantly lower abundance in brine plume
	brine linear			56.41*	14.05	
	brine quadratic			8.06*	2.01	
	random variation				59.96	
8-9 Feb 1983	brine vs. no brine	8.75	7.25	2.36	3.98	Slightly greater abundance in brine plume
	brine linear			0.86	1.46	
	brine quadratic			0.57	0.97	
	random variation				93.59	
19-22 May 1983	brine vs. no brine	13.69	16.23	0.76	1.90	Slightly lower abundance in brine plume
	brine linear			0.65	1.63	
	brine quadratic			0.00	0.00	
	random variation				96.47	
1-2 Sept 1983	brine vs. no brine	22.50	15.21	2.96	6.82	Greater abundance in brine plume
	brine linear			3.78	8.71	
	brine quadratic			0.65	1.49	
	random variation				82.98	

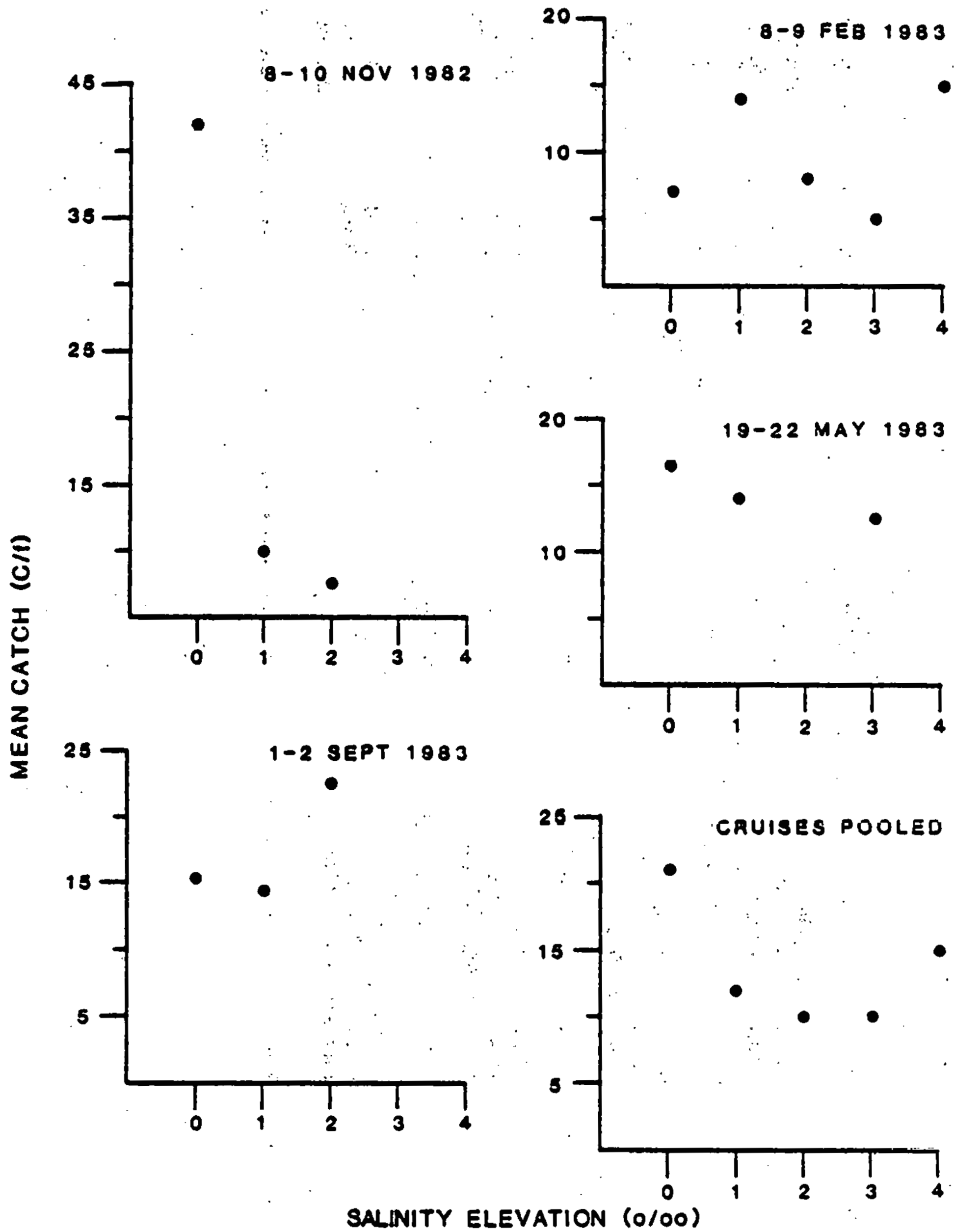

Figure 4-5. Trends in mean catch (C/f) of shrimps in the brine plume.

Pavela and Chittenden, 1983).

Historically, among-cruises effects (r^2 = 61 to 70%) have been significant and the principal source of variation in shrimp catches at Bryan Mound, reflecting distinct annual trends in abundance (Chittenden et al, 1981a, 1981b and 1982). Among cruise effects have been less important since September 1981 (r^2 = 7 to 28%), possibly reflecting decreased sampling periodicity after that date. Stations x cruises interaction was the principal source of variation (r^2 = 65%) in the present study as in the preceding postdisposal study (r^2 = 40%) (Pavela and Chittenden, 1983).

Among-stations shrimp abundance varied significantly. It was low at the two stations nearest the diffuser, but catches were lower at several stations farther afield. There was no overall progression of increasing or decreasing catches upcoast or downcoast of the diffuser. The lack of brine related effects is illustrated by the fact that within cruise individual degree of freedom contrasts were not significant in three of four cruises. The one significant contrast indicated depressed abundance in the plume. There was however, no constant response of abundance to brine as the significant interaction indicates. Catches reversed between higher and lower brine abundances from cruise to cruise. The pattern of few significant brine contrasts and inconsistent abundance trends has been noted during day-cruises in past postdisposal studies which show: 1) only three instances of significance among 17 within day cruise brine vs. no brine contrasts, and 2) abundance greater in the plume on nine cruises, lower on ten.

4.8 Total Fish Abundance Analyses

4.8.1 Results of Significance Tests and General Overview of Among-Cruises and Among-Stations Trends in Total Fish Abundance

Analysis of variance on total fish abundance found highly significant differences among cruises, among stations, and a stations x cruises interaction during the September 1982 though August 1983 postdisposal period (Table 4-12). These results concur with two-way ANOVA analyses on total fish abundance for day-cruises during all earlier studies (Chittenden et al, 1981a, 1981b, 1982; Pavela and Chittenden, 1983).

Among-cruises effects (r^2 = 63.1%) was the most important source of overall model variation (Table 4-12). Random variation (r^2 = 31.5%) and interaction (r^2 = 24.1%) were also substantial sources of variation. Among-stations effects (r^2 = 5.4%) accounted for only a small portion of the total variation in fish catches.

Fish abundance was significantly different between cruises (Table 4-12). Abundance declined from November to February, when catches were low (C/f = 347 and 182, respectively), and increased thereafter through May (C/f = 308) and September (C/f = 865), when catches were greatest (Figure 4-6). Catches in each cruise in the present study were similar to those in analogous day-cruises during most earlier studies (Chittenden et al, 1981a, 1981b and 1982). However, catches in November and February during the September 1981 through August 1982 postdisposal period (Pavela and Chittenden, 1983) were much larger than catches in the present and other studies cited.

Among-stations effects and station x cruises interaction were significant for total fish abundance (Table 4-12). Significant interaction however, implies station to station patterns varied from cruise to cruise. As for shrimp, and for similar reasons (see Section 4.7.1), multiple range

Table 4-12. Summary of two-way analysis of variance for total fish abundance during the September 1982 through August 1983 postdisposal period. An asterisk (*) after an F-value indicates significance at $\alpha = 0.05$.

Source of Variation	df	SS	MS	F	Pr>F	r^2
Corrected	127	68.49	--	--	--	1.0000
Cruises	3	43.24	14.41	183.51*	0.0001	0.6313
Stations	15	3.69	0.25	3.14*	0.0008	0.0539
Interaction	45	16.53	0.37	4.68*	0.0001	0.2413
Error	64	5.03	0.08	--	--	0.3151

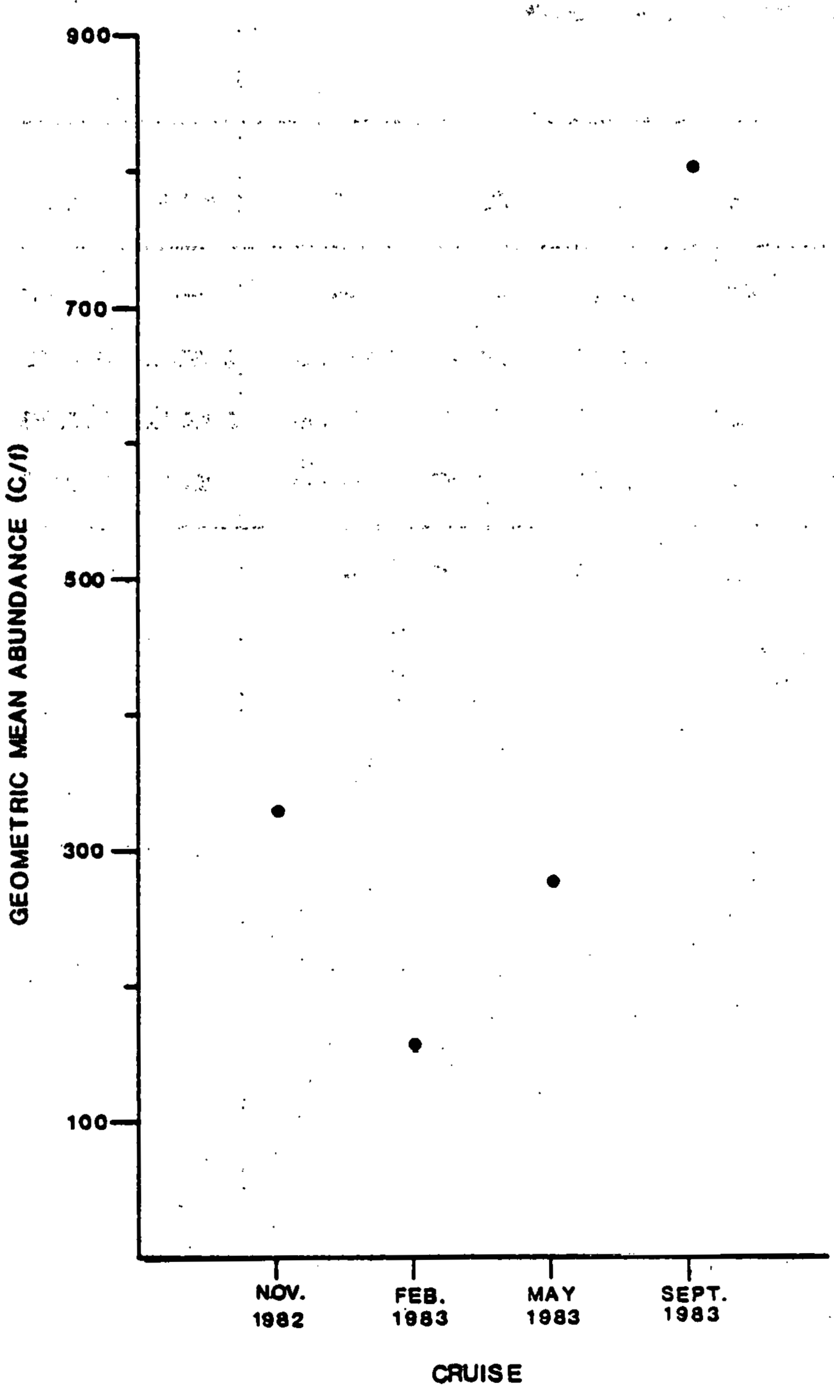

Figure 4-6. Geometric mean abundance per trawl tow (C/f) of fishes in the diffuser area by cruise for September 1982 through August 1983 postdisposal period.

tests were not employed to examine the nature of inconsistent variation although overall station patterns are described below.

Overall, among-station fish abundance displayed no apparent pattern. However, catches were lowest at stations 15 and 16 (C/f = 253.3 and 225.6, respectively; Figure 4-7), which are situated nearest the diffuser and under the influence of 2 o/oo brine elevations more than 90% of the time (See Chapter 2; Figures 2-28 through 2-33). Fish catches at other stations, whether upcoast or downcoast, inshore or offshore, did not appear related to their location about the diffuser. For example, catches at station 17 (C/f = 276.4) which is never impacted by the defined brine plume (0% exposure time), were lower than those those at stations 18 through 25 and C and D (C/f = 294.2 to 433.8) which are more impacted by brine (6 to 71% exposure time). Therefore, only stations very near the diffuser might exhibit decreased abundance related to brine.

4.8.2 Individual Degree of Freedom Evaluations of Brine Disposal on Total Fish Abundance

Significant interaction implies that station to stations patterns of total fish abundance were inconsistent from cruise to cruise (Table 4-12), and that within-cruise individual degree of freedom contrasts are most appropriate to determine if brine affected total fish abundance.

Two of four within-cruise brine vs. no brine contrasts and linear regression contrasts (8-9 February and 19-22 May) were significant (Table 4-13). Brine quadratic regression contrasts were significant for 8-9 February and 8-10 November. Fish abundance was significantly less in the brine plume than at ambient salinity on the 8-9 February and 19-22 May cruises (Figure 4-8). However, this trend was not constant for all cruises. Catches were greater in the plume on 8-10 November and 1-2 September though

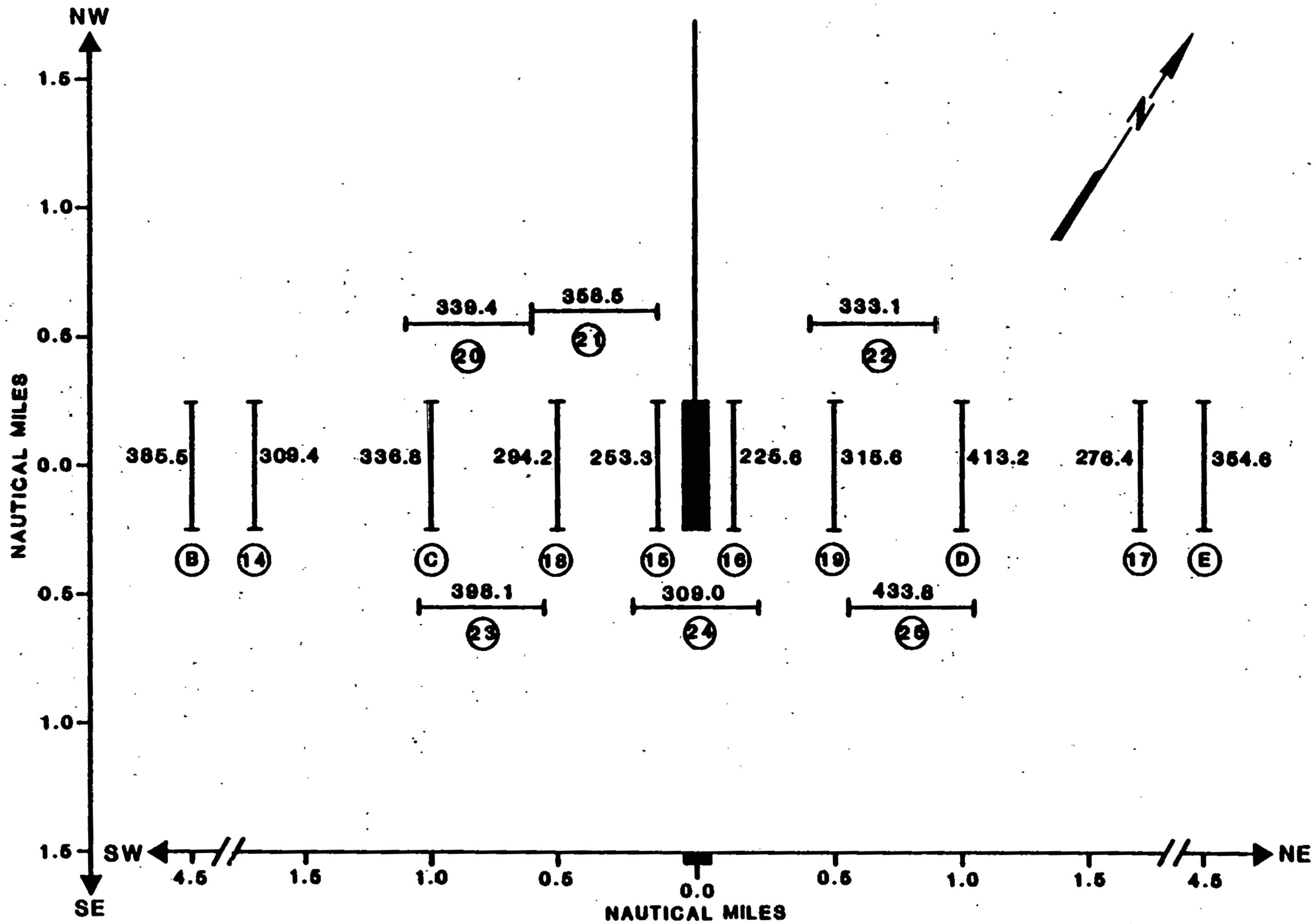

Figure 4-7. Geometric mean abundance per trawl tow (C/f) of fishes at diffuser stations for all cruises during September 1982 through August 1983 postdisposal period.

Table 4-13. Summary of individual degree of freedom contrasts of the effects of brine disposal on total fish abundance during the September 1982 through August 1983 postdisposal period. An asterisk (*) after an F-value indicates significance at $\alpha = 0.05$.

Cruise Date	Contrast	Mean Fish Abundance 2 - 4 o/oo	Mean Fish Abundance Ambient	F	r^2 (%)	Comments
8-10 Nov 1982	brine vs. no brine	394.25	362.75	0.18	0.39	Slightly greater
	brine linear			0.76	1.63	abundance in
	brine quadratic			5.41*	11.62	brine plume
	random variation				86.36	
8-9 Feb 1983	brine vs. no brine	161.75	199.19	11.76*	9.97	Significantly lower
	brine linear			4.65*	3.94	abundance in
	brine quadratic			8.23*	6.98	brine plume
	random variation				79.11	
19-22 May 1983	brine vs. no brine	165.25	343.19	26.10*	27.06	Significantly lower
	brine linear			30.20*	31.31	abundance in
	brine quadratic			1.16	1.20	brine plume
	random variation				40.43	
1-2 Sept 1983	brine vs. no brine	991.00	865.36	1.05	1.73	Slightly greater
	brine linear			1.87	3.08	abundance in
	brine quadratic			0.78	1.28	brine plume
	random variation				93.91	

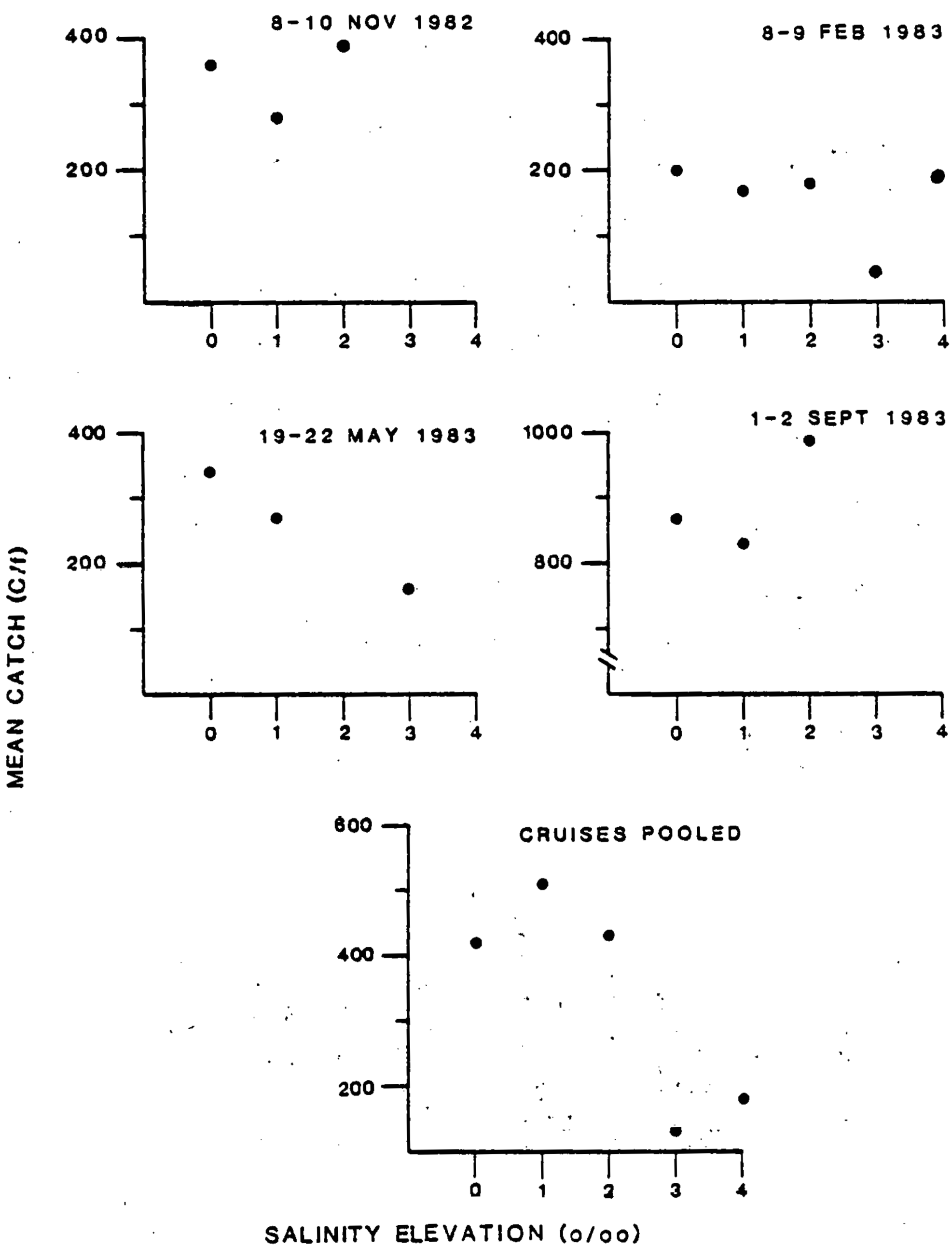

Figure 4-8. Trends in mean catch (C/f) of fishes in the brine plume.

differences were not significant.

4.8.3 Summary and Discussion

The impact of brine disposal on total fish abundance, if any, was small during the September 1982 through August 1983 study period. Similar conclusions were reached during all preceding studies (Chittenden et al, 1981a, 1981b and 1982; Pavela and Chittenden, 1983).

Results of two-way ANOVA analysis generally agree with those of all past day-cruise analyses. Among-cruises effects have always been significant and usually the major source of overall model variation (r^2 = 49 to 86%) except in the September 1981 through August 1982 study period when interaction (r^2 = 39%) was the primary source of variation (Chittenden et al, 1981b and 1982; Pavela and Chittenden, 1983). Significant among-cruises variation probably reflects trends in ichthyofauna abundance related to life history patterns (Chittenden et al, 1981a, 1981b and 1982). Among-stations effects and interaction have always been significant in the past with the former usually begin a minor source and the latter usually being a substantial source of overall model variation. Overall abundance patterns continue to indicate abundance is independent of station location relative to the diffuser, except possibly at stations 15 and 16, where abundance was lowest and potential brine exposure highest. The significant interaction implies that patterns between stations were not constant from cruise to cruise, however.

Results of within cruise brine vs. no brine total fish abundance contrasts appear to present a dilemma in interpretation because comparisons were evenly divided between significantly reduced plume fish abundance and non-significant increased plume fish abundance. This, however, is not the case when considering the totality of analyses. Valid conclusions regarding whether there has or has not been a distinct impact can only be made if: 1) among stations effects are significant and a primary or a very substantial source of variation (high r^2 value); 2) results of within cruise brine vs. no brine contrasts are significant in the majority of comparisons (three of four contrasts at present); 3) all instances of significant within cruise brine contrast abundance trends are in agreement; and 4) all non-significant within cruise brine contrast abundance trends agree with significant brine contrast abundance trends. In satisfying the above criteria, it would be apparent that brine discharge distinctly influenced the nekton parameter in question. Total fish abundance analyses only fulfilled the third criterion and the first one partially. Significant brine contrast abundance trends were in agreement and among station effects significant; however, station to station differences were not a major source of overall model variation. Further, results of significant within cruise brine contrasts were not preponderant for indicating some impact had occurred nor was there agreement between significant and non-significant brine contrast abundance trends. Therefore, the only valid conclusion that can be drawn is that brine discharge had no more than a minor impact, and certainly not a distinct impact, on total fish abundance. This finding is corroborated by those made in all earlier postdisposal studies (Chittenden et al., 1981b, 1982; Pavela and Chittenden, 1983). Only four significant within cruise brine contrasts have been observed in 17 prior day cruise comparisons -- three of which were significant for increased abundance at ambient salinity, the other for increased abundance in the plume. Among non-significant contrasts, abundance has been greater at ambient on ten cruises and greater in the plume on three cruises. Additionally, random variation has been and continues to be a much more important source of variation in fish catches than among stations or brine effects.

4.9 Total Nekton Biomass Analyses

4.9.1 Results of Significance Tests and General Overview of Among-Cruises and Among-Stations Trends in Total Nekton Biomass

Analysis of variance on total nekton (shrimps and fishes) biomass found highly significant differences among cruises, among stations, and a stations x cruises interaction during the September 1982 through August 1983 postdisposal period (Table 4-14). These results agree with those found in the preceding study (Pavela and Chittenden, 1983) when biomass analyses were first initiated at Bryan Mound.

Among-cruises effects (r^2 = 60.0%) was the principal source of overall model variation (Table 4-14), and interaction (r^2 = 23.5%) was next most important. Random variation (r^2 = 10.7%) and among-stations effects (r^2 = 5.7%) were the least important sources of variation.

Total nekton biomass was significantly different between cruises during the present study (Table 4-14). Temporal patterns and differences in the magnitude of biomass (Figure 4-9) were identical to those for fish abundance (Figure 4-6), something expected because fishes make up nearly all the nekton biomass (Tables 4-6 and 4-7). Overall, biomass declined from November (C/f = 7.8 kg) to February (C/f = 3.4 kg) when catches were lowest, and increased thereafter through May (C/f = 7.3 kg) and September (C/f = 16.8 kg), when catches were greatest. Nekton biomass in February and May was only half that in these months in 1982, November catches were about identical, and September catches were twice as large as those in August 1982 (Pavela and Chittenden, 1983).

Among-stations effects and stations x cruises interaction were significant for total nekton biomass (Table 4-14). Significant interaction,

Table 4-14. Summary of two-way analysis of variance for total biomass (fishes and shrimps) during the September 1982 through August 1983 postdisposal period. An asterisk (*) after an F-value indicates significance at $\alpha = 0.05$.

Source of Variation	df	SS	MS	F	Pr>F	r^2
Corrected Total	127	5165.63	--	--	--	1.0000
Cruises	3	3100.68	1033.56	119.28*	0.0001	0.6003
Stations	15	296.62	19.77	2.28*	0.0118	0.0574
Interaction	45	1213.78	26.97	3.11*	0.0001	0.2350
Error	64	554.56	8.66	--	--	0.1074

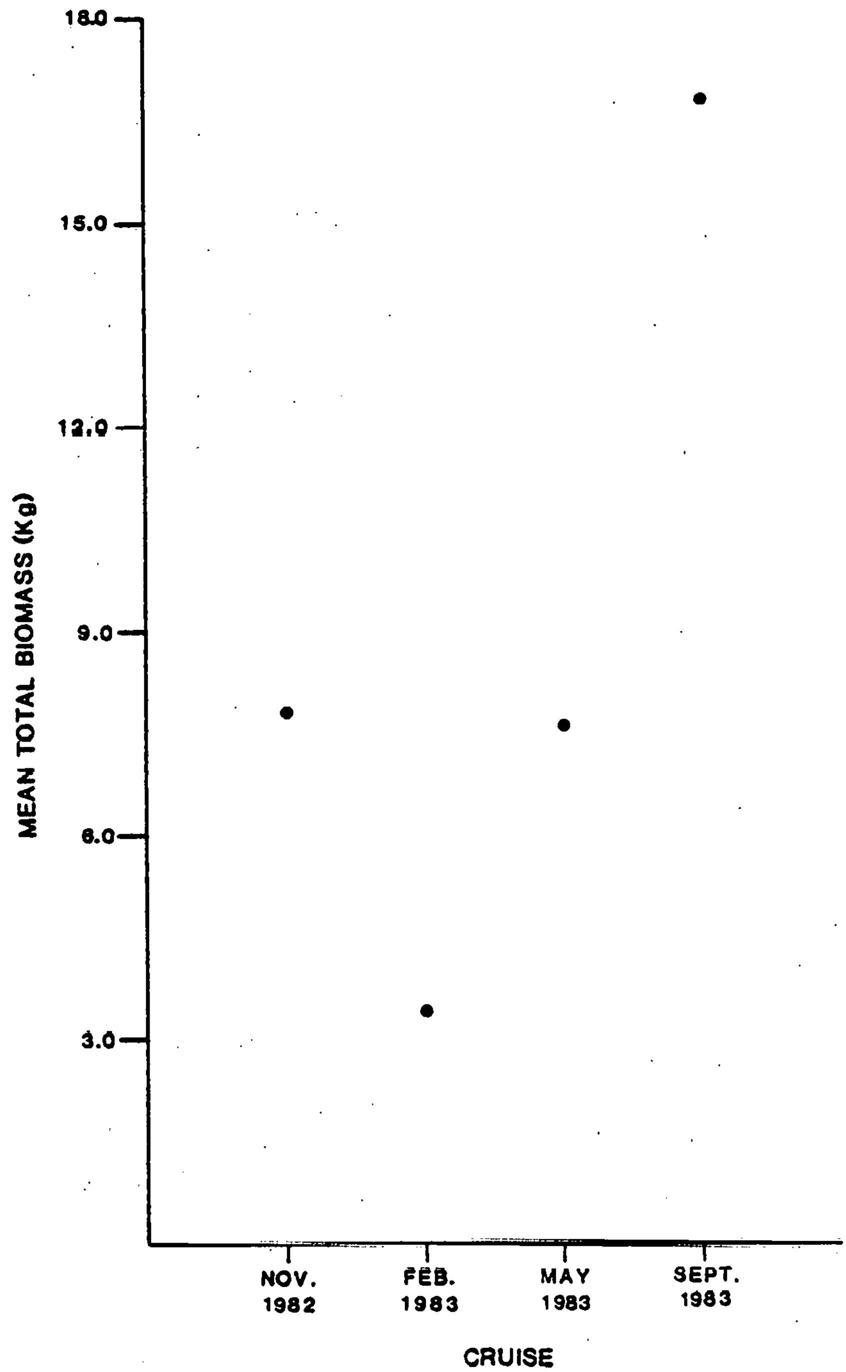

Figure 4-9. Mean total nekton biomass (kg) per trawl tow (C/f) in the diffuser area by cruise during September 1982 through August 1983 postdisposal period.

however, implies station to station patterns varied from cruise to cruise. As for shrimp and fish abundance analyses, and for similar reasons (see Section 4.7.1), multiple range tests were not used to determine the nature of inconsistent variation although overall station patterns are described below.

Overall, among station nekton biomass displayed no apparent pattern in relation to the diffuser. Biomass was low at stations 15 and 16 (C/f = 6.9 and 7.8 kg, respectively; Figure 4-10), which straddle the diffuser on either side and are impacted by 2 o/oo brine elevations more than 90% of the time (See Chapter 2; Figures 2-28 through 2-33). However, catches at station 15 and 16 were as large or larger than those at several stations (17, 20, and 22; C/f = 6.3, 6.9 and 7.4 kg, respectively) exposed to the plume much less often (0 to 24% exposure time).

4.9.2 Individual Degree of Freedom Evaluations of Brine Disposal on Total Nekton Biomass

Significant interaction (Table 4-14) implies that station to station biomass patterns were inconsistant between cruises and that within-cruise individual degree of freedom contrasts are most appropriate to assess if brine affected nekton biomass.

Two of four within-cruise (8-10 November, 8-9 February) brine vs. no brine and linear and quadratic regression contrasts were not significant (Table 4-15). In contrast, significant brine vs. no brine and/or regression contrasts occurred on 19-22 May and 1-2 September. However, the response of biomass to brine concentration was not consistent whether significant or not significant. In the instances of non-significant differences, catches in the brine plume on 8-10 November and 8-9 February were about equal in magnitude to those at ambient salinity (Figure 4-11) even though catches

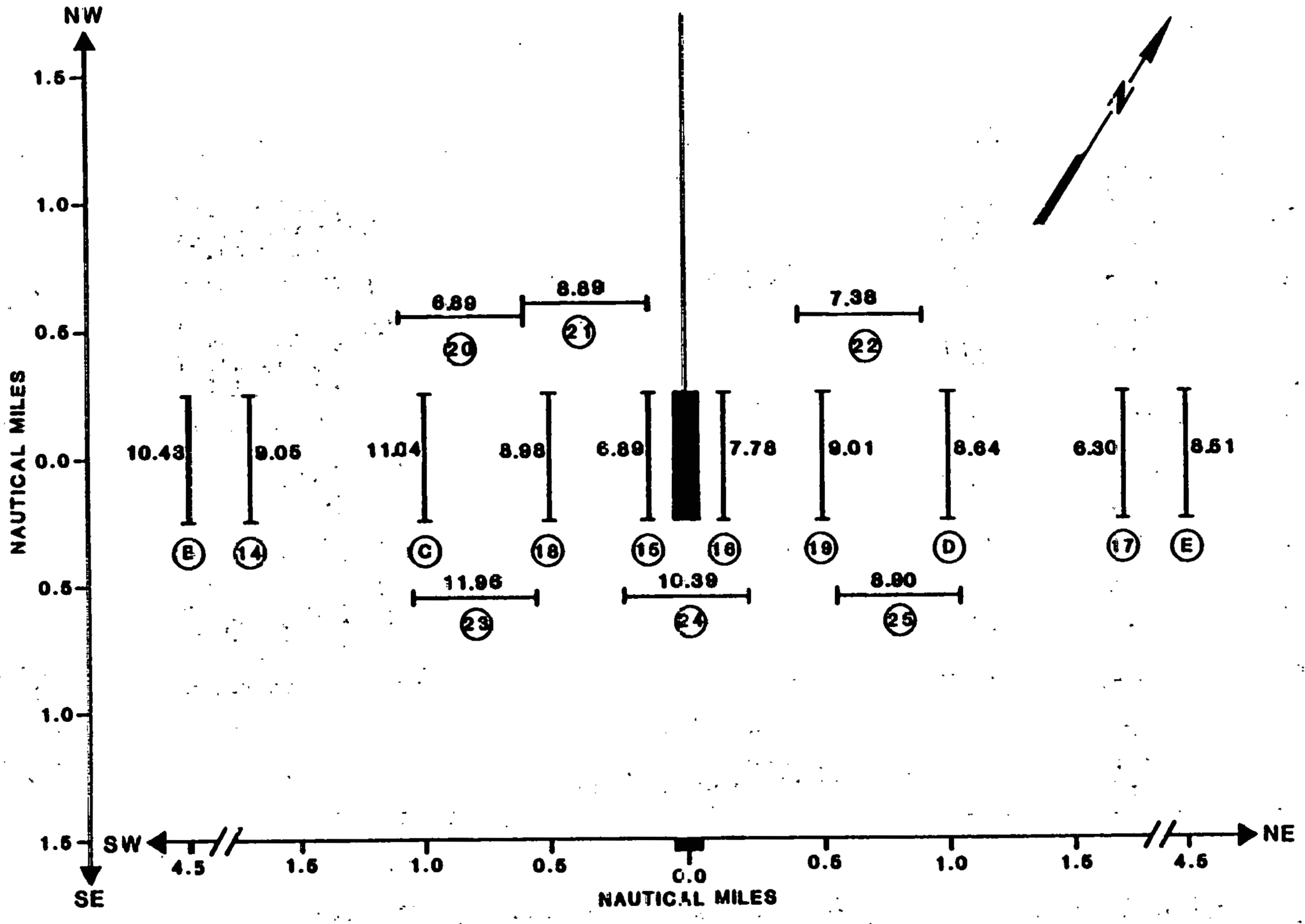

Figure 4-10. Mean total nekton biomass (kg) per trawl tow (C/f) at stations in the diffuser for all cruises during September 1982 through August 1983 postdisposal period.

Table 4-15. Summary of individual degree of freedom contrasts of the effects of brine disposal on total biomass (shrimps and fishes) during the September 1982 through August 1983 postdisposal period. An asterisk (*) after an F-value indicates significance at $\alpha = 0.05$.

Cruise Date	Contrast	Mean Biomass 2 - 4 o/oo	Abundance Ambient	F	r^2 (%)	Comments
8-10 Nov 1982	brine vs. no brine	8.18	7.56	0.34	0.70	Catches slightly greater in brine plume
	brine linear			0.15	0.30	
	brine quadratic			0.08	0.16	
	random variation				98.84	
8-9 Feb 1983	brine vs. no brine	2.58	4.15	1.77	7.66	Catches lower in brine plume
	brine linear			0.38	1.63	
	brine quadratic			0.84	3.64	
	random variation				87.07	
19-22 May 1983	brine vs. no brine	3.75	8.25	8.75*	28.69	Catches significantly lower in brine plume
	brine linear			7.95*	25.95	
	brine quadratic			0.00	0.00	
	random variation				45.36	
1-2 Sept 1983	brine vs. no brine	20.93	16.33	3.64	2.69	Catches slightly greater in brine plume
	brine linear			7.59*	3.55	
	brine quadratic			4.83*	3.53	
	random variation				88.23	

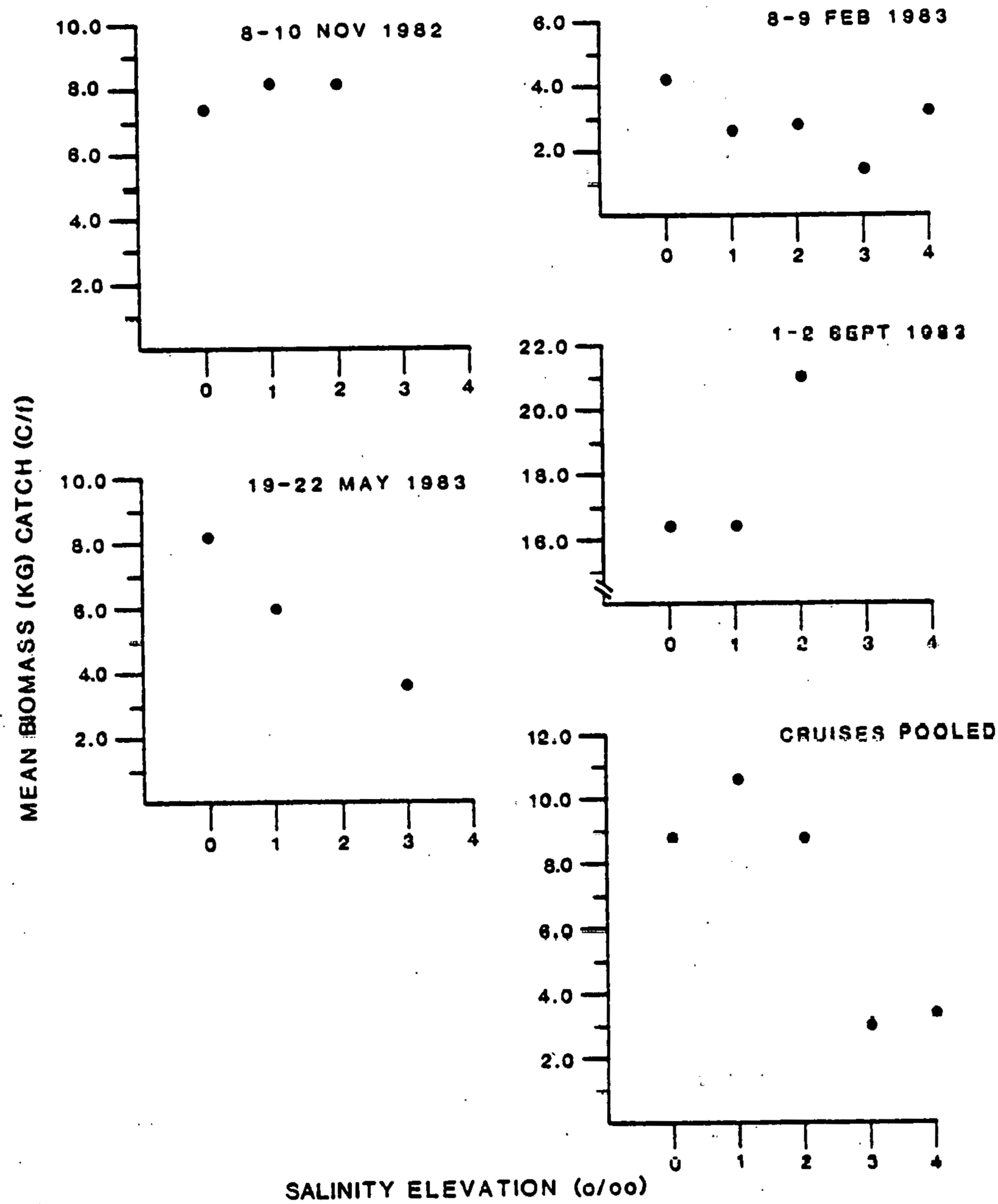

Figure 4-11. Trends in mean biomass catch (C/f) in the brine plume.

were higher in the plume on one date (8-10 November) and lower on the other (8-9 February). In the instances of significant differences, catches were lower in the brine plume on 19-22 May but slightly greater in the brine plume than at ambient salinity on 1-2 September (Figure 4-11).

4.9.3 Summary and Discussion

Brine disposal appears to have had little or no influence on total nekton biomass in the September 1982 through August 1983 period, a conclusion similar to that for the preceding study (Pavela and Chittenden, 1983).

ANOVA analyses agree that main effects and interaction were significant in both this and the preceding study (Pavela and Chittenden, 1983). Variation due to among-cruises effects (r^2 = 60%), however, were much greater in the present study than in the last study (r^2 = 27%). Variation among stations (r^2 = 6%) was much less in the present study than in the preceding study (r^2 = 25%), and overall patterns of biomass continue to be inconsistent and independent of station location relative to the diffuser.

To date, whether the differences are significant or not, biomass has been greater in the plume on two cruises and less in the plume on three. Random variation has always been a more important source of variation than among stations or brine effect-related variations.

4.10 Ichthyofauna Diversity Analyses

4.10.1 Results of Significance Test and General Overview of Among-Cruises and Among-Stations Trends in Total Fish Abundance

Analysis of variance on ichthyofauna diversity found highly significant differences among cruises, among stations, and a stations x cruises interaction during the September 1982 through August 1983 postdisposal period (Table 4-16). These results agree with analyses on day-cruise diversity during all earlier studies (Chittenden et al, 1981a, 1981b, and 1982; Pavela and Chittenden, 1983).

Interaction (r^2 = 39.2%) was the principal source of total model variation. Among-cruises effects (r^2 = 27.4%) and random variation (r^2 = 21.0%) also accounted for much variation. Among-station effects (r^2 = 12.5%) were least important.

Ichthyofauna diversity differed significantly between cruises during the present study period (Table 4-16) though no cruise to cruise trend was apparent. Diversity was greatest and essentially equal in November (2.49) and May (2.48). Diversity was lowest in February (1.81) with the September (2.06) value intermediate between the extremes (Figure 4-12).

Ichthyofauna diversity differed significantly among stations during the present study (Table 4-16). Significant interaction, however, implies station to station patterns varied from cruise to cruise. For reasons similar to those cited in Section 4.7.1, multiple range tests were not employed to examine the nature of inconsistent variation although overall patterns are described below.

No pattern of ichthyofauna diversity was evident among stations in relation to the diffuser (Figure 4-13). Stations 15 and 16, which are nearly always affected (>90% exposure time) by the defined brine plume (2 o/oo and greater), exhibited diversities (2.15 and 2.31, respectively) higher than at stations 17, 21, 22, 23, 25, D and E (1.74 to 2.13) which are less frequently (0 to 46% exposure time) in the plume (See Chapter 2; Figures 2-28 through 2-33). However, diversity at stations 15 and 16 was also less than those at stations 14, 18, 19, 24 and C (2.33 to 2.56) which are less influenced by brine (0 to 71% exposure time).

Table 4-16. Summary of two-way analysis of variance for ichthyofauna diversity during the September 1982 through August 1983 postdisposal period. An asterisk (*) after an F-value indicates significance at $\alpha = 0.05$.

Source of Variation	df	SS	MS	F	Pr>F	r^2
Corrected Total	127	39.25	--	--	--	1.0000
Cruises	3	10.77	3.59	27.92*	0.0001	0.2743
Stations	15	4.89	0.33	2.54*	0.0052	0.1245
Interaction	45	15.37	0.34	2.66*	0.0002	0.3915
Error	64	8.23	0.13	--	--	0.2097

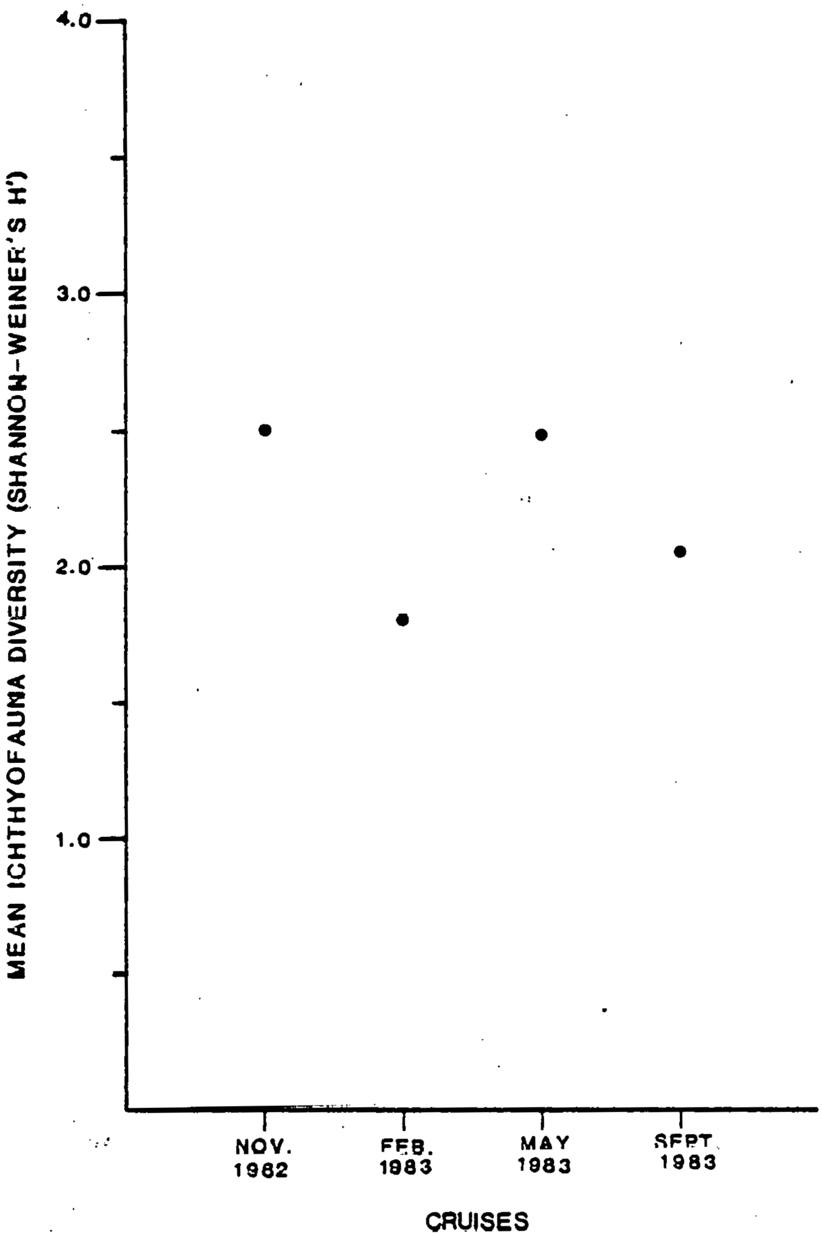

Figure 4-12. Mean ichthyofauna diversity (Shannon-Wiener's H') per trawl tow in the diffuser area by cruise during September 1982 through August 1983 postdisposal period.

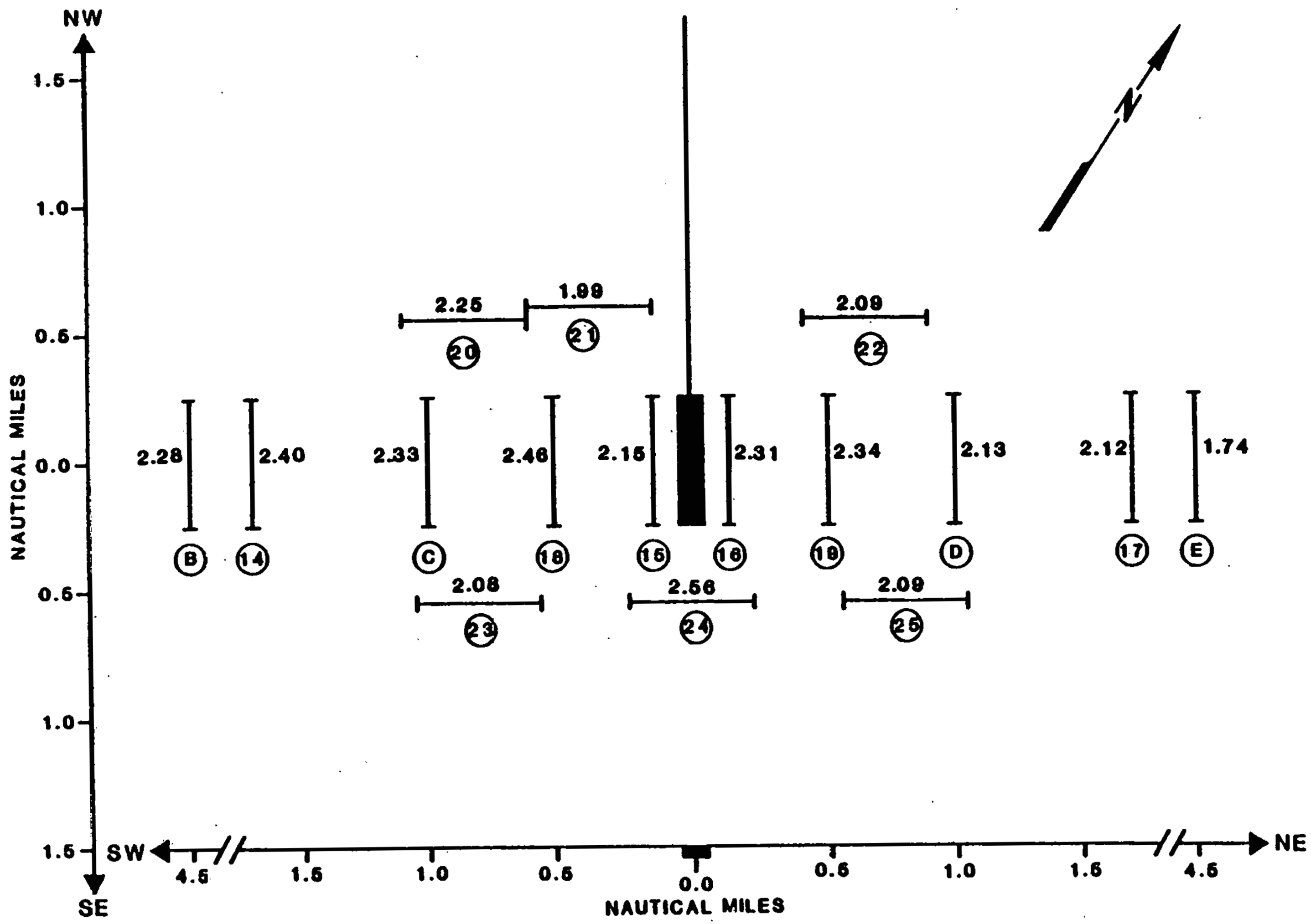

Figure 4-13. Mean ichthyofauna diversity (Shannon-Wiener's H') at stations in the diffuser area for all cruises during September 1982 through August 1983 postdisposal period.

4.10.2 Individual Degree of Freedom Evaluations of Brine Disposal on Ichthyofauna Diversity

Significant interaction implies that station to station patterns in ichthyofauna diversity were not constant from cruise to cruise, and that within-cruise individual degree of freedom contrasts are most appropriate to assess the effects of brine on diversity.

Two of four within-cruise (19-22 May, 1-2 September) brine vs. no brine and/or regression contrast sets were not significant (Table 4-17). In contrast, significant brine vs. no brine and/or regression contrasts occurred on 8-10 November and 8-9 February. Even when significant, however, the response of diversity to brine concentration was not consistent (Figure 4-14). Diversity in the plume equaled or was greater than at ambient salinity on 8-9 February; in contrast, diversity in the plume equaled or was less than that at ambient salinity on 8-10 November.

4.10.3 Summary and Discussion

Brine disposal appears to have had no effect on diversity during the September 1982 through August 1983 study period, a finding that agrees with those made in all earlier postdisposal studies (Chittenden et al, 1981a, 1981b and 1982; Pavela and Chittenden, 1983).

Among-cruises and among-stations effects and stations x cruises interaction were all significant. These results are similar to those of day-cruise ANOVA analyses throughout the entire Bryan Mound study except for one instance of non-significance ($p = 0.08$) in a predisposal analysis (Chittenden et al, 1981a). The amount of variation attributable to each model effect in the present study agreed with values for the predisposal and March 1980 through August 1981 postdisposal studies (Chittenden et al,

Table 4-17. Summary of individual degree of freedom contrasts of the effects of brine disposal on ichthyofauna diversity during the September 1982 through August 1983 postdisposal period. An asterisk (*) after an F-value indicates significance at $\alpha = 0.05$.

Cruise Date	Contrast	Mean Ichthyofauna Abundance 2 - 4 o/oo	Ambient	F	r^2 (%)	Comments
8-10 Nov 1982	brine vs. no brine	1.9420	2.5321	2.83	4.27	Diversity lower in brine plume
	brine linear			9.03*	13.37	
	brine quadratic			6.98*	10.34	
	random variation				72.02	
8-9 Feb 1983	brine vs. no brine	2.0180	1.6906	7.71*	12.27	Diversity greater in brine plume
	brine linear			5.70*	9.07	
	brine quadratic			0.33	0.52	
	random variation				78.14	
19-22 May 1983	brine vs. no brine	2.7740	2.4501	0.86	1.75	Diversity greater in brine plume
	brine linear			2.76	5.64	
	brine quadratic			1.69	3.45	
	random variation				89.16	
1-2 Sept 1983	brine vs. no brine	2.2423	2.0500	0.30	0.71	Diversity greater in brine plume
	brine linear			0.89	2.12	
	brine quadratic			0.94	2.23	
	random variation				94.94	

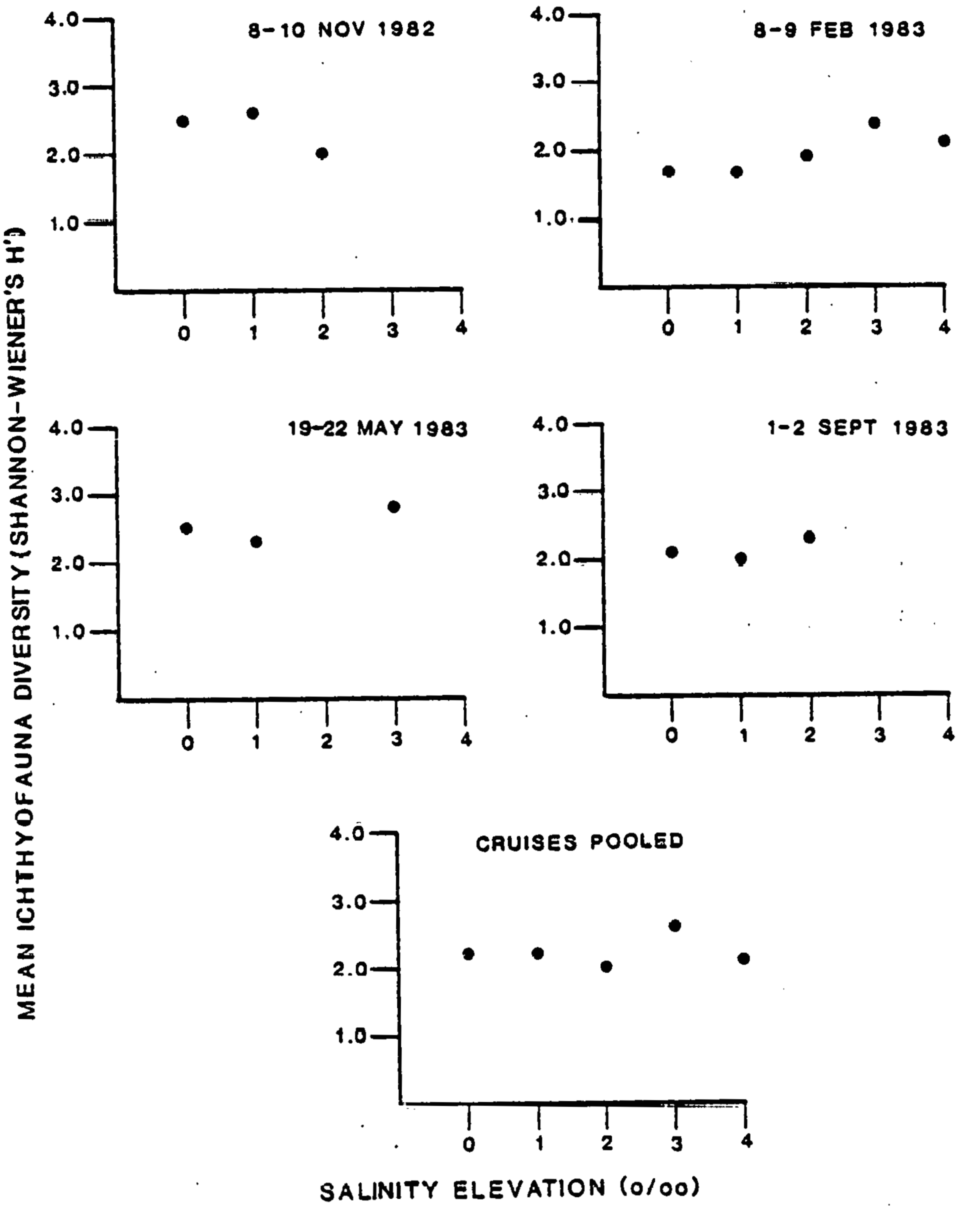

Figure 4-14. Trends in mean ichthyofauna diversity in the brine plume.

1981a, 1981b and 1982), but differed from Pavela and Chittenden (1983) who found values much greater for among-cruises variation (75% for September 1981 through August 1982 and 27% for the present study) and much less for interaction (r^2 = 12% and 39%, respectively).

Results of within-cruise individual degree of freedom contrasts generally agree with past postdisposal studies and suggest brine has little or no effect on ichthyofauna diversity, and does not have a consistent pattern even if significant. Two of four within-cruise brine contrasts, or regression relation sets, were significant in the present studies, but diversity was both higher and lower in the plume. Only one (9-11 August 1982) of 17 within day cruise brine vs. no brine comparisons has been significant (Chittenden et al, 1981a, 1981b and 1982; Pavela and Chittenden, 1983). However, again response of diversity to brine has not been uniform in the past, being both higher (11 cruises to date) and lower (six cruises to date) in the brine plume. Moreover, random variation has always been a more important source of variation than among station or brine-related effects.

4.11 Comments on the Occurrence of Red Drum and Black Drum

This section continues the practice of previous reports and describes captures of red drum (*Sciaenops ocellatus*), and black drum (*Pogonias cromis*) because these species support important recreational, and until recently, commercial fisheries along the Texas coast. Both species reside in estuaries during the warm months, but enter and apparently spawn in the Gulf from autumn until spring (Pearson, 1929; Simmons and Breuer, 1962). Both species were captured during the predisposal and earlier postdisposal studies, but not in large numbers because they are large active fishes that can easily avoid nets towed slowly over short distances.

Three black drum but no red drum were captured during the September 1982 through August 1983 period. These three fish were collected on the 8-9 February cruise at stations B, D and E and measured 708, 722 and 843 mm TL. Occurrence of black drum in the diffuser area in the present study coincided with its November through April periodicity reported in previous studies (Chittenden et al, 1981a, 1981b, and 1982; Pavela and Chittenden, 1983).

4.12 Results and Discussion of Comparative by Station Size Compositions of Selected Nekton near the Diffuser Area

The abundance of a fisheries stock is determined by a balance in which some processes--recruitment and immigration--increase abundance and other processes--mortality and emigration--decrease abundance. Stock abundance decreases if mortality increases in comparison to recruitment. Unless brine effects are marked, decreased abundance may be difficult to detect because of contagion or because immigration may be comparatively more important.

Stock size or age composition also is sensitive to change in mortality rates (Ricker, 1975). As mortality increases, a stock becomes juvenesced, a phenomenon in which composition changes from a stock with many older and larger individuals to one with relatively many younger, smaller individuals. Juvenescence is a classic symptom in exploited fisheries stocks because a fishery increases mortality rates, particularly a large fishery. Local stock juvenescence may also appear in polluted areas because pollution might increase local mortality rates. Such changes would be most apparent in sedentary species not influenced greatly by immigration or emigration. Dissimilar size compositions might also occur as a result of size dependent avoidance or attraction to the brine plume due to size dependent differences in salinity tolerance and avoidance-attraction responses.

Target species selected for analysis of size compositions and reasons for selection include: 1) Penaeus aztecus and P. setiferus because they are commercially important shrimp that regularly occur in the diffuser area, 2) Syacium gunteri, Prionotus rubio and Squilla empusa because they often are common in the diffuser area, exhibit adaptations for a strict demersal or benthic existence, such as burrowing, and may be fairly sedentary, 3) Cynoscion nothus because it is the most common sciaenid species in the diffuser area year round, and 4) Chloroscombrus chrysurus, Peprilus burti, and Anchoa hepsetus because they are pelagic fishes that are seasonally very abundant in the diffuser area. Length frequency compositions of the target nekton at stations 14 through 25 and B through E inclusive were visually compared within cruises to detect differences in size ranges and central tendencies.

There appeared to be no station to station variation in size compositions of any target species within any cruise during the September 1982 through August 1983 period. This is illustrated in Figures 4-15 to 4-23 which present size compositions of target nekton during the May 1983 cruise. These show central tendencies and size ranges were similar at all diffuser stations. There was no obvious shift in these parameters at stations 15 and 16, where brine salinities are generally highest and exposure most pervasive, compared to stations less affected by the plume. Size compositions for other cruises in this period (Figures D-1 to D-27) show the same homogeneity in size compositions. Similar observations were made on all cruises during earlier postdisposal studies (Chittenden et al, 1981a, 1981b and 1982; Pavela and Chittenden, 1983). Hence, brine disposal has caused no apparent stock juvenescence or size dependent avoidance or attraction throughout the entire postdisposal period.

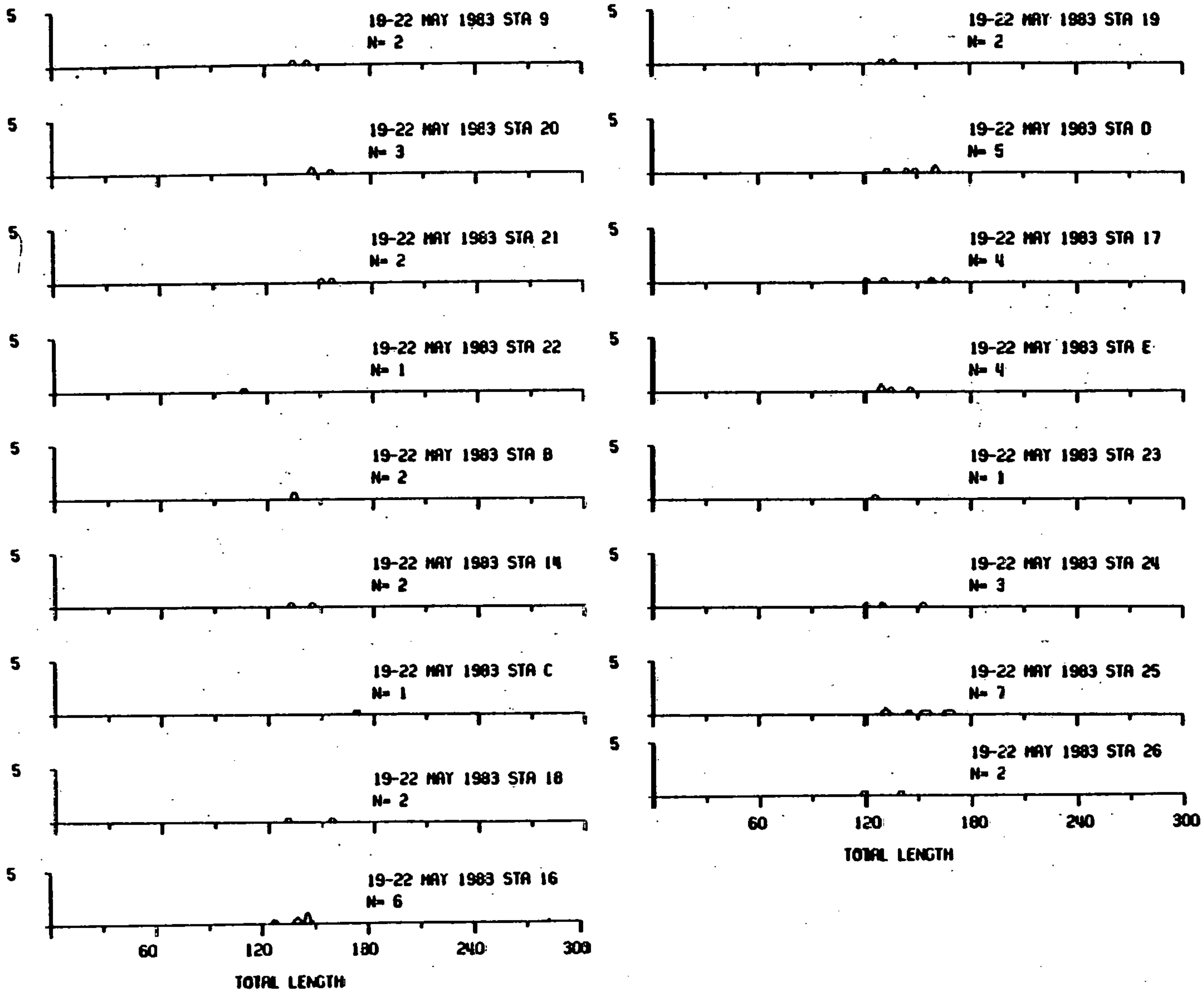

Figure 4-15. Length frequency compositions of <u>Penaeus aztecus</u> by station in the diffuser area during the May 1983 cruise. Stations 9 and 26 are included for comparison.

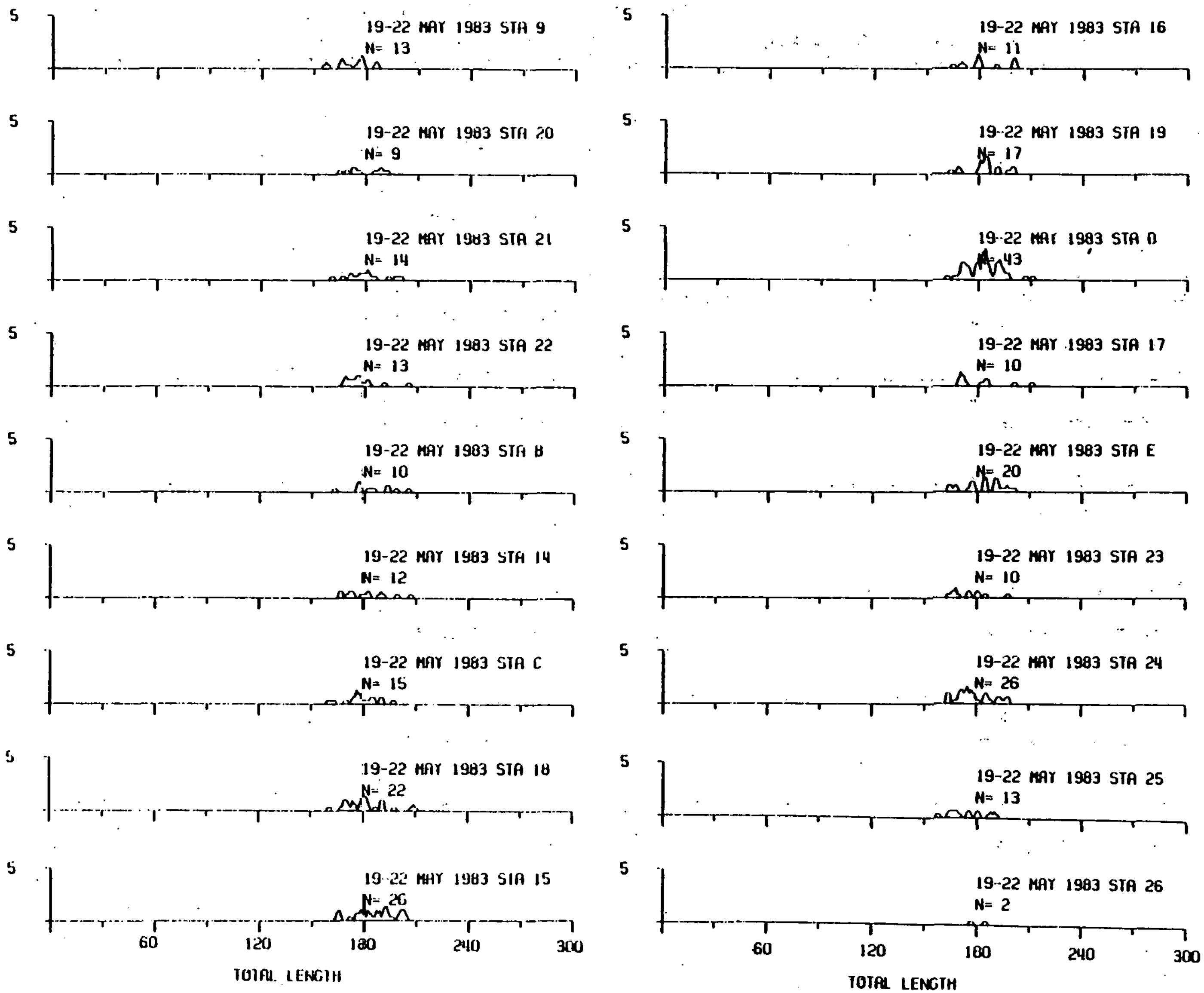

Figure 4-16. Length frequency compositions of Penaeus setiferus by station in the diffuser area during the May 1983 cruise. Stations 9 and 26 are included for comparison.

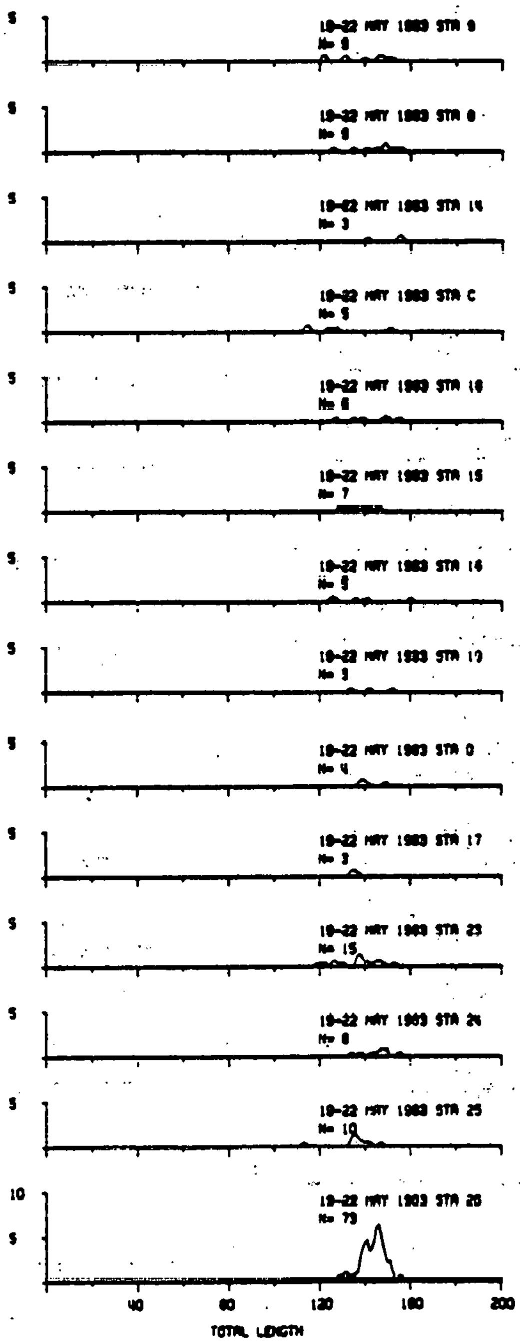

Figure 4-17. Length frequency compositions of Anchoa hepsetus by station in the diffuser area during the May 1983 cruise. Stations 9 and 26 are included for comparison.

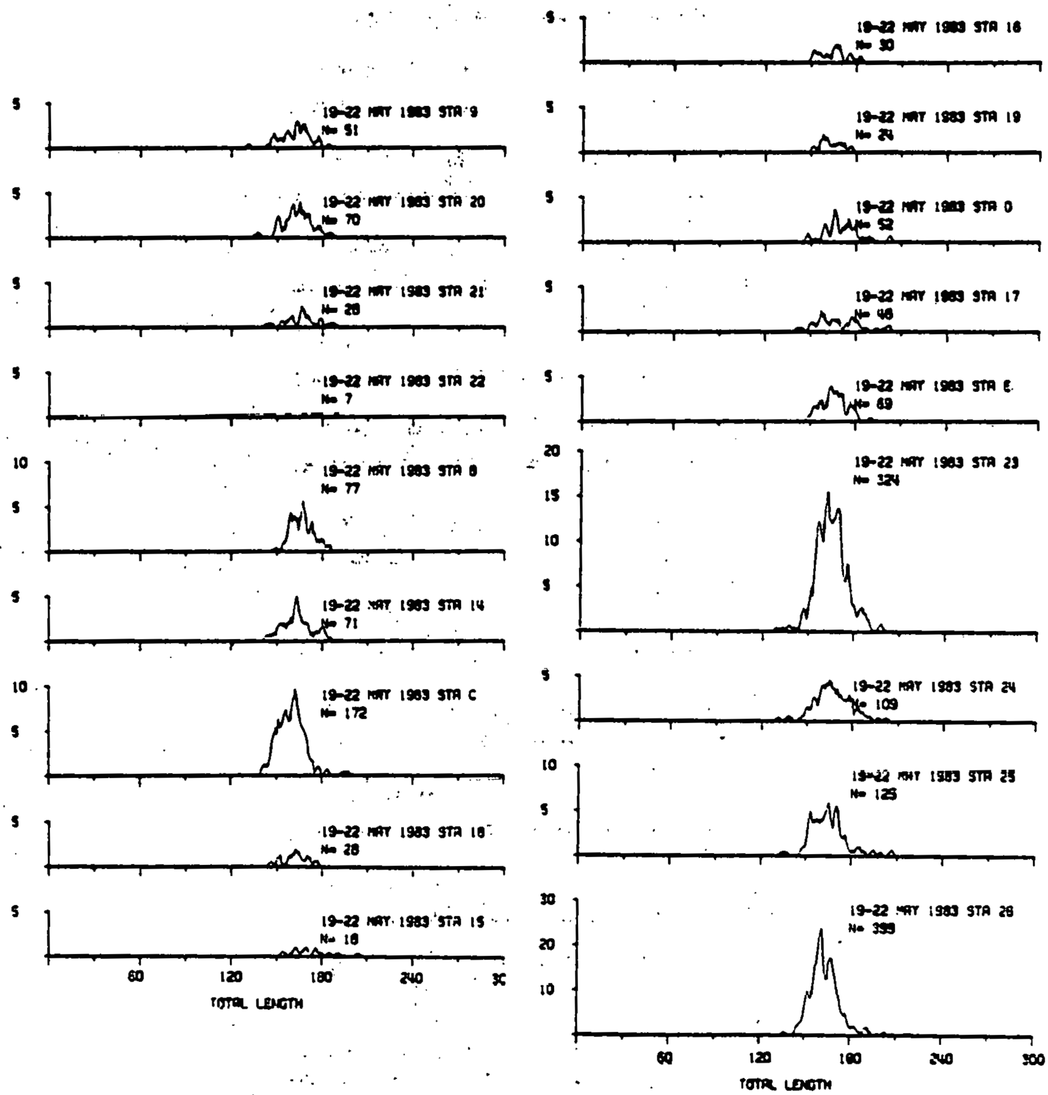

Figure 4-18. Length frequency compositions of Chloroscombrus chrysurus by station in the diffuser area during the May 1983 cruise. Stations 9 and 26 are included for comparison.

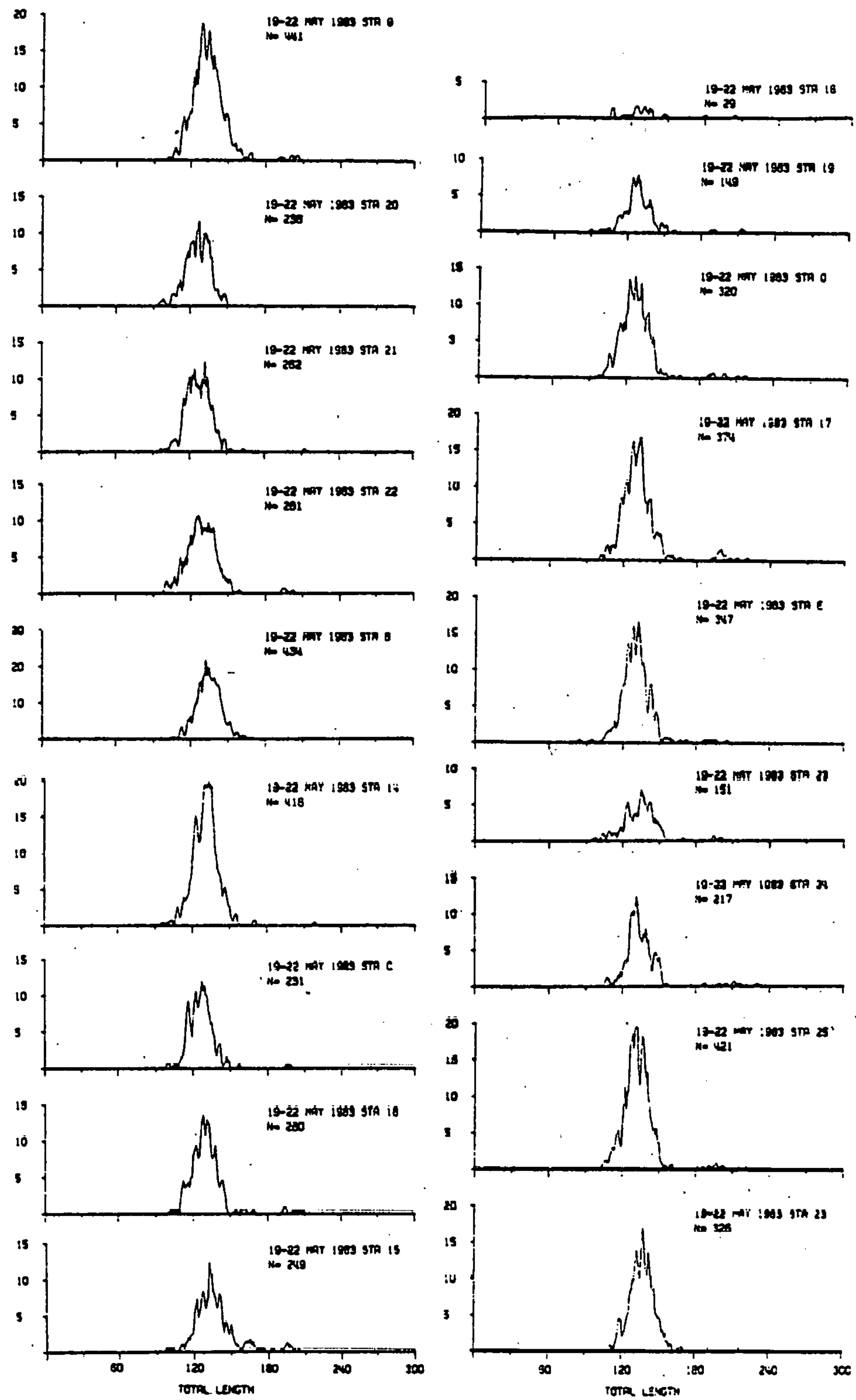

Figure 4-19. Length frequency compositions of Cynoscion nothus by station in the diffuser area during the May 1983 cruise. Stations 9 and 26 are included for comparison.

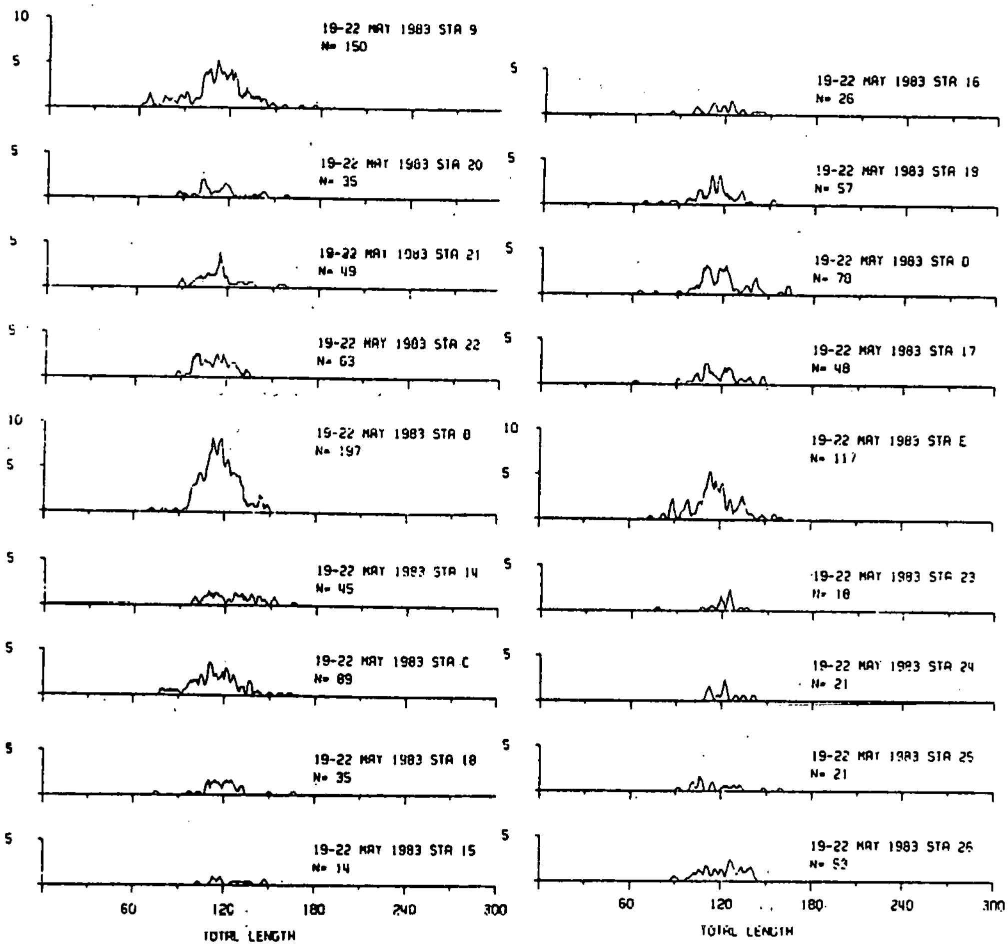

Figure 4-20. Length frequency compositions of Peprilus burti by station in the diffuser area during the May 1983 cruise. Stations 9 and 26 are included for comparison.

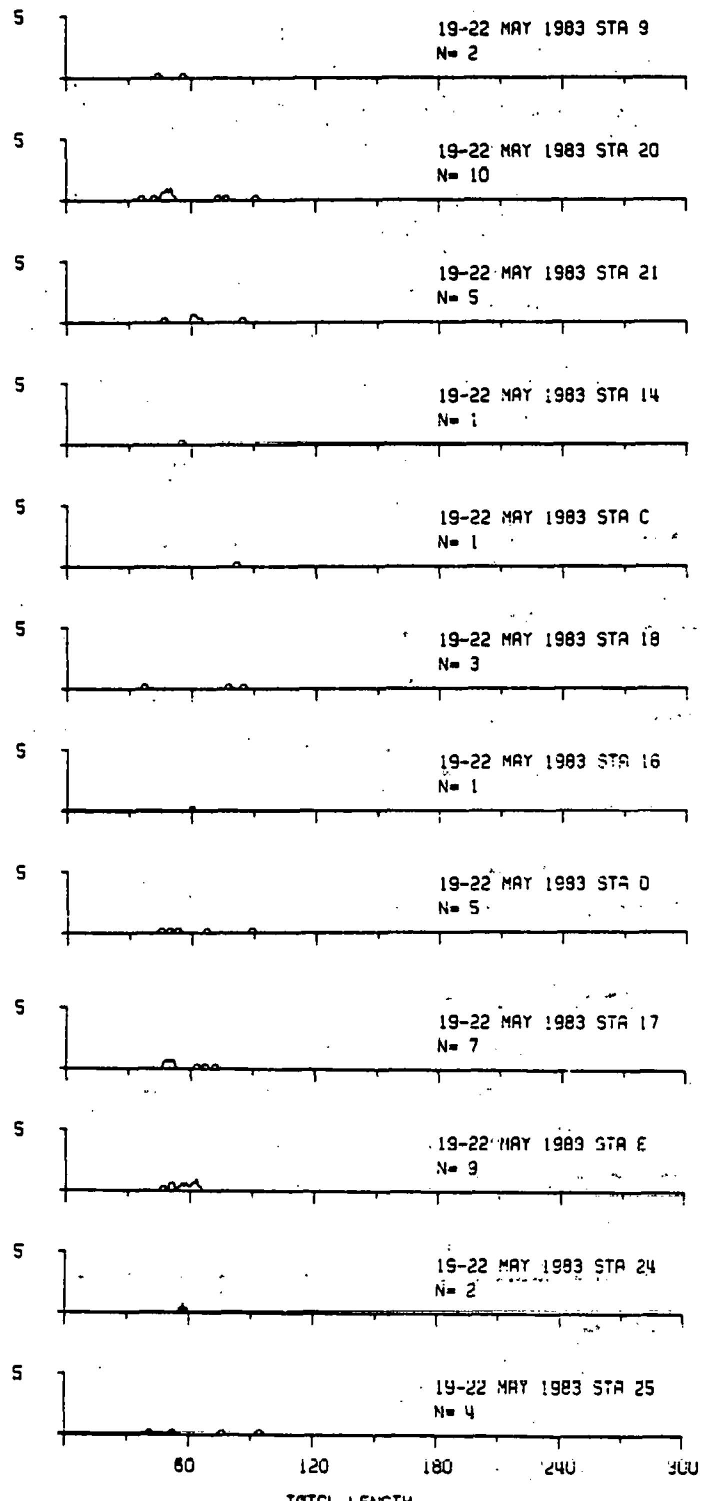

Figure 4-21. Length frequency compositions of Prionotus rubio by station in the diffuser area during the May 1983 cruise. Stations 9 and 26 are included for comparison.

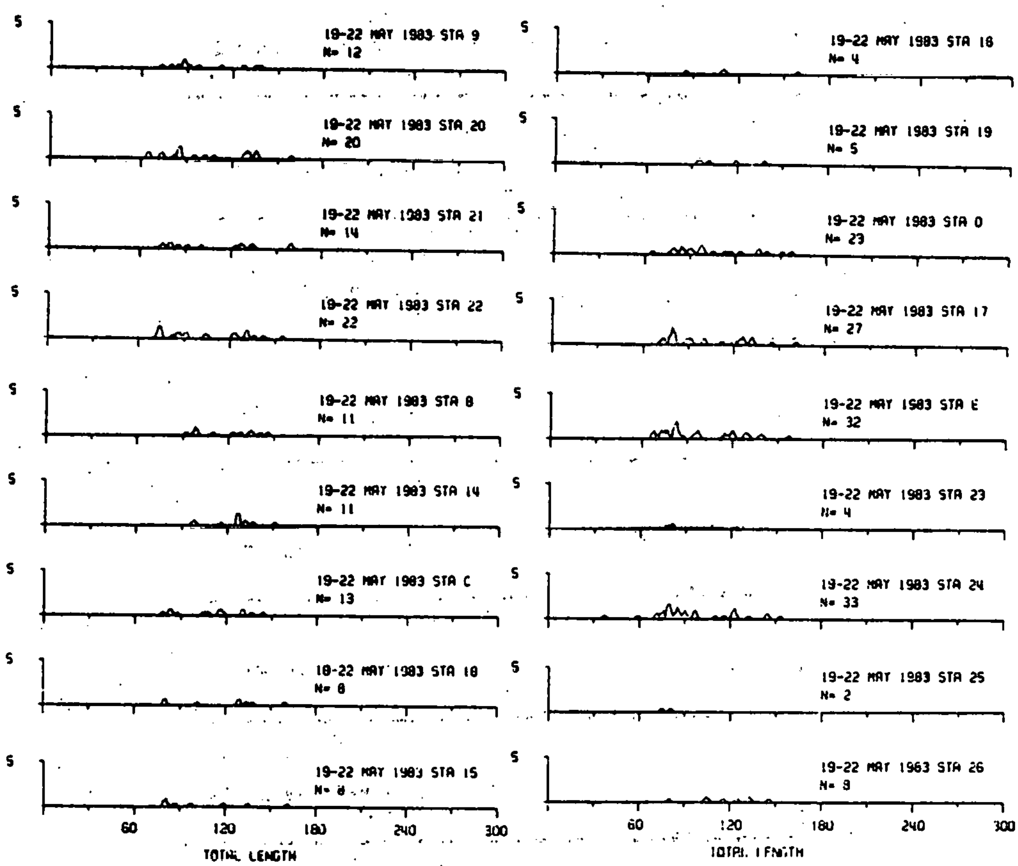

Figure 4-22. Length frequency compositions of Syacium gunteri by station in the diffuser area during the May 1983 cruise. Stations 9 and 26 are included for comparison.

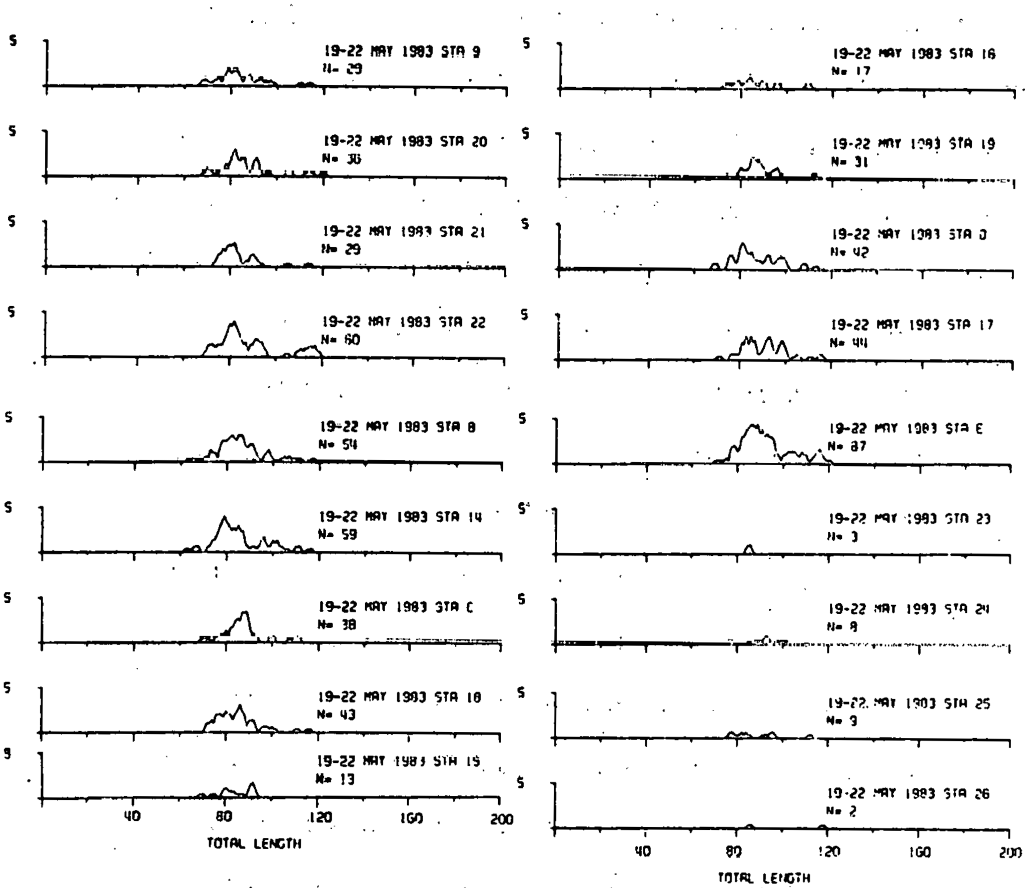

Figure 4-23. Length frequency compositions of Squilla empusa by station in the diffuser area during the May 1983 cruise. Stations 9 and 26 are included for comparison.

4.13 Summary

Overall compositions and rankings of shrimps in the diffuser area contrast with those of the preceding year, but agree with day-cruises in all other studies. These studies show P. aztecus has been the principal species, except during September 1981 through August 1982 study period when P. setiferus was the principal species.

Following the pattern of earlier studies, overall diffuser area ichthyofauna was dominated by very few species whose year to year abundance continue to fluctuate widely. Stenotomus caprinus was the most numerous species, comprising a much greater percentage of catches than it had to date. Cynoscion nothus and Chloroscombrus chrysurus, dominants on day-cruises in prior studies, were less abundant, though still principal species. Other fishes that have been consistently abundant and usually principal species in inter-report comparisons included Syacium gunteri, Anchoa hepsetus and Peprilus burti. Temporal changes in relative species abundance have persisted throughout the Bryan Mound study and are not unusual. During the predisposal and eighteen-month postdisposal studies, increases and decreases in compositions in the diffuser area were consistent with those which occurred over a wide cross-shelf transect, far beyond the spread of the brine plume. Therefore, differing compositions observed during the present study probably resulted from real annual changes in species abundance and are not related to brine disposal.

Cluster analysis and among-stations species compositions provide no evidence to suggest brine disposal adversely affects the internal integrity of the diffuser area nekton community. Dissimilarities in among-stations relative species abundances illustrated by cluster analysis continued to be minor; relative abundances at near field and far field diffuser stations were comparable. This indicates diffuser stations still form an essentially homogeneous set. Similarly, differences in compositions of individual species were inconsistent among stations. Observed trends showed compositions of some species were higher at near-field diffuser stations while others were lower.

Field observations made during the September 1982 through August 1983 period showed no dramatic lethal effects at any station during any cruise. These findings correspond with those made since brine disposal began at Bryan Mound.

There were no indications that brine disposal had much, if any influence on total shrimp abundance. Overall station to station patterns in total fish abundance and within cruise size compositions of the principal shrimps were uniform from station to station regardless of location and possible exposure to brine. Brine abundance trends were contradictory from cruise to cruise and only one within-cruise brine vs. no brine contrast was significant. Furthermore, among-stations and brine related effects accounted for a relatively small portion of overall model variation.

Any impact of brine disposal might have had on total fish abundance was small. Though two of four within-cruise brine contrasts indicated significant reductions in abundance in the brine plume, this response was not constant and reversed in the two non-significant contrasts. Variation attributable to among-station and brine effects was very small compared to among-cruise main effects and random variation. Overall station trends in total fish abundance and within cruise size compositions of target ichthyofauna were relatively homogeneous among stations despite station location and brine impact.

The effects of brine disposal on total nekton biomass, if any, were minor. Overall station biomass patterns were independent of station locations and potential brine impact. Three of four brine vs. no brine contrasts indicated biomass was not significantly different inside or outside the plume. Brine catch trends reversed from cruise to cruise. Also, variation due to among-stations and brine effects were less important than among-cruise main effects and random variation.

Patterns in ichthyofauna diversity suggest it was not influenced by brine disposal. There was no overall diversity pattern based on probable brine exposure; stations within the plume had essentially the same diversity as those outside the plume. Only one cruise was significant for the brine vs. no brine contrast, exhibiting reduced brine diversity, but the opposite trend was observed in two non-significant contrasts. Moreover, random variation and among-cruise main effects were more important sources of variation than among-station or brine effects.

4.14 Conclusions

It appears that brine disposal at Bryan Mound has had neglible if any influence on the nekton community surrounding the diffuser -- or even could have had a greater effect. The responses of nekton to the plume have not been constant, brine contrasts generally have been non-significant and variability attributable to among stations or to brine effects usually small. The lack of impact seems related to several factors including the intrinsic dynamism of shrimp and fish populations, the negligible area covered by the brine plume in comparison to areas stocks may range over, the rapidity with which the brine plume dilutes and disperses, and the fact that maximum brine elevations measured are well below those that evoke mortality or avoidance in laboratory tests.

Abundant nekton inhabiting the inner continental shelf (0 to 40 m) of the northwestern Gulf of Mexico have evolved against a background of great natural environmental variation. This is reflected in a life history pattern common to most species and best adapted to great natural flux. This pattern stresses rapid turnover of biomass and is characterized by small sizes, short life spans (generally 1 to 2 years), high mortality rates (usually > 90%) and rapid maturity (before or by age one year) (Chittenden and McEachran, 1976; Chittenden, 1977; White and Chittenden, 1977; Murphy, 1981; Shlossman and Chittenden, 1981; DeVries and Chittenden, 1982; Geohegan and Chittenden, 1982; Standard and Chittenden, in press).

Brine plume measurements indicate brine exiting the diffuser at salinities generally greater than 250 o/oo dilutes to salinities of no more than 5 to 6 o/oo above ambient in the very near field and lower salinities within a very restricted area. To date greatest areal extent of the defined (2 o/oo) brine plume has been 24.5 km^2, but usually it is less than 10.0 km^2 (Randall and McLellan, 1983; Chapter 2, Section 2.4). The maximum limits of higher observed brine elevations (3 to 6 o/oo) are much smaller (0.1 to 9.3 km^2). Therefore, areas impacted by the defined brine plume are neglible in comparison to areas occupied by populations which may range across large portions of the inner northwestern Gulf shelf between the Mississippi and Rio Grande Rivers (34,900 km^2, planimeter estimation), or even in comparison to possible local stocks which might inhabit only the shelf (4050 km^2) between the region's two most important estuaries (East) Matagorda and (West) Galveston Bays. Moreover, the highest measured brine elevations are well below levels that evoke avoidance responses or increased mortalities in postlarvae and adults of some common shrimps (Howe, 1981) and fishes (Perez, 1969; Neff et al, 1981; Owens et al, 1981). Because brine salinities have been low and the area of the plume has been limited, any possible increased mortalities, attraction/avoidance, etc., must be restricted to a very small area, most likely to the very near diffuser field within 600 ft (180 m) of the diffuser because nekton trawling cannot be done closer to the diffuser, and our studies over several years have shown no consistent brine effects. Any increased mortality within this restricted area must be very small in comparison to natural or fishing mortalities suffered by local stocks and much less in comparison to more broadly ranging Gulf populations.

Though there is little evidence to suggest brine disposal has had any direct impact on the nekton community about the diffuser, it is possible brine may affect them indirectly through its influence on benthic organisms which are important foods for some species. Though few dietary analyses have been conducted on nekton which inhabit the diffuser area, several shrimps and fishes including: Penaeus aztecus, P. setiferus, Anchoa mitchilli, Cynoscion arenarius, C. nothus, Diplectrum bivittatum, Leiostomus xanthurus, Menticirrhus americanus, Micropogonias undulatus, Paralichthys lethostigma, Stenotomus caprinus, and Urophycis floridanus, are known to feed on various benthos, especially crustaceans, during part or all of their life histories (Darnell, 1958; Sikora et al., 1972; Diener et al., 1974; Harwood et al., 1978; Sheridan, 1978; Overstreet and Heard, 1978, 1982; Bortone et al., 1981; Hodson et al., 1981). These nekters all exhibit a polyphagous diet; none feeds exclusively on any single organism. Therefore, it would likely take major disruptions of the total benthic community around the diffuser (not isolated individual species populations as cited in Chapter 5), before there might be any more than minor impacts on local nekton stocks/populations.

CHAPTER 5

BENTHOS

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5.1 Introduction

The Bryan Mound salt diapir, located near Freeport, Texas, was chosen by the U.S. Department of Energy to be used for oil storage as part of the Strategic Petroleum Reserve Program. Large caverns are being created within this salt dome by solution mining. Fresh water is pumped into the diapir, dissolving the salt, and the resultant brine (usually 230 to 250 o/oo) is pumped through a buried pipeline to a disposal site in 21-meter depth, 19 km offshore in the Gulf of Mexico. At the disposal site, brine is ejected through a series of vertical ports (the diffuser system) at a velocity of 12 m/sec. This disposal method reduces the salinity of the brine to near-ambient by turbulent mixing, but a plume of above ambient saline water still falls to the bottom and is carried away from the diffuser area by prevailing currents. During the first six months of operation, beginning in March 1980, maximum volumes of disposed brine were less than 200,000 barrels/day. Beginning in September 1980 discharge volumes increased to 500,000 barrels of brine per day and the rate was increased again to about 1,000,000 barrels/day in January 1981.

The data presented herein represent the results of six years of field research on the benthic communities off Freeport, Texas. Monthly sampling

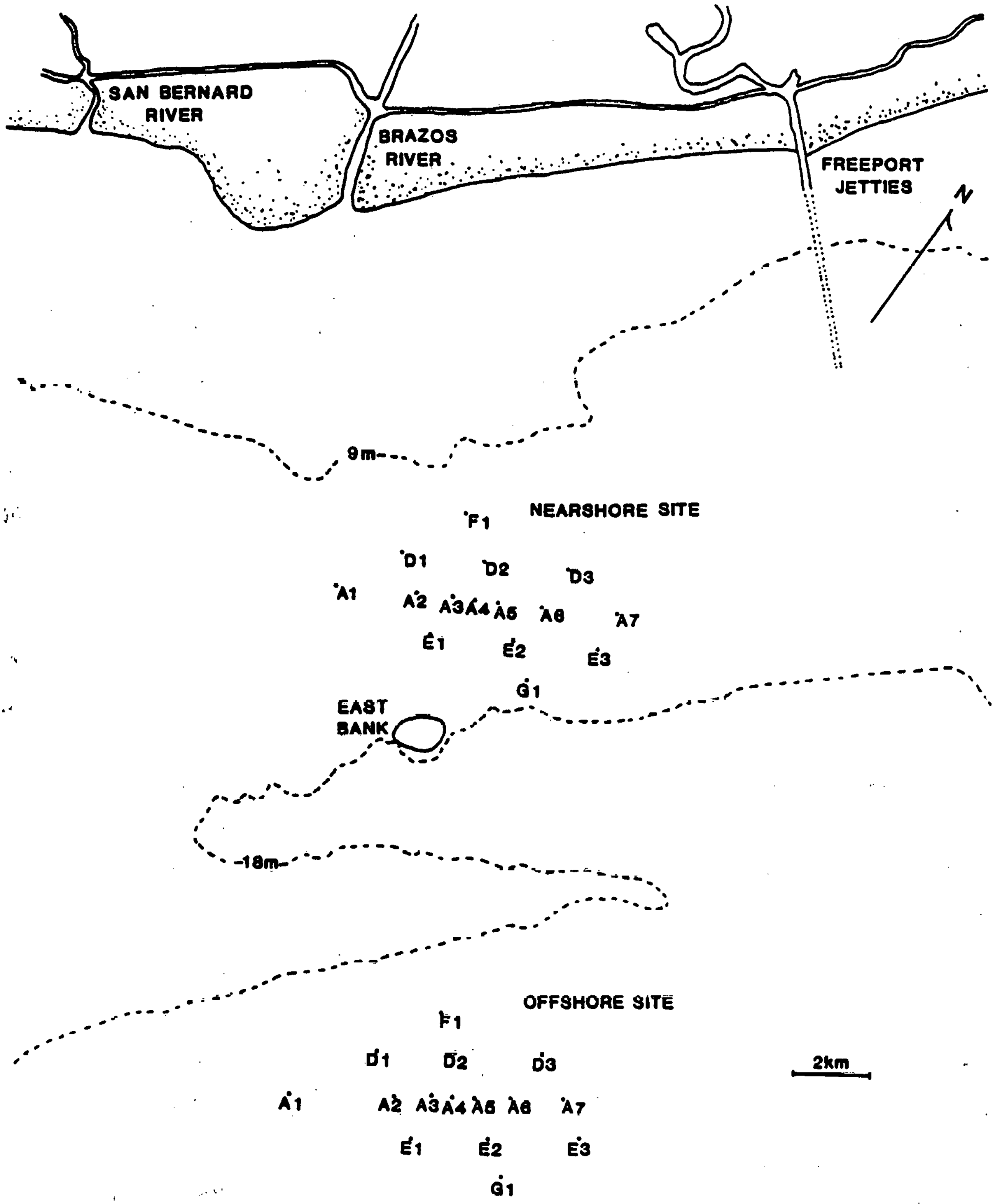


Figure 5-1. Chart of the area off Freeport showing locations of the offshore and nearshore study area.

was conducted at two sites (Figure 5-1) for 4.5 years. The nearshore site was dropped at the end of February 1982 and will not be discussed in this report. At the offshore site, approximately 2.3 years of predisposal data were gathered prior to diffuser startup (Harper and McKinney, 1980; Harper, McKinney, Salzer and Case, 1981).

Benthic macroinvertebrates make ideal subjects for studying acute and chronic effects associated with discharge of organic and toxic pollutants into the marine environment. The benthos are primarily non-motile or slow moving, small organisms that cannot easily escape an environmental stress; those that cannot tolerate the stress perish. If stress is caused by an organic substance, i.e. sewage, one tolerant, opportunistic species may successfully invade the habitat and completely dominate the assemblage. If the stress is caused by a toxic substance, both numbers of species (diversity) and individuals are usually greatly reduced compared with non-impacted control areas (Filice, 1959). We consider brine to be included in the latter category, because it contains no organic material.

5.2 Historical Review

Soft bottom benthic assemblages off the upper Texas coast have been little studied compared with many other areas of the United States. Prior to 1973, most benthic surveys were conducted using non-quantitative collecting gear (trawls, dredges), with no seasonal repetition of sampling. Soft bodied invertebrates were often ignored in favor of mollusks, whose shells are important to petroleum companies as indicators of geological strata (Ladd, 1951; Hedgpeth, 1953, 1954; Hildebrand, 1954; Hulings, 1955; Ladd, Hedgpeth and Post, 1957; Parker, 1960; Harper, 1970). The first attempt to gather seasonal data was made during the SEADOCK environmental impact study conducted by the Environmental Engineering

Department, Texas A&M University (Harper and Case 1975). The present study areas were included in the SEADOCK study area and limited baseline data are available from the latter study. Three recent qualitative studies of benthic assemblages have been conducted off the upper Texas coast in the general vicinity of Freeport; off Galveston (Henry, 1976; Harper, 1977a) and in the Buccaneer Field area 50 km south of Galveston (Harper, 1977b; Harper et al., 1981). Of these, only Henry collected monthly samples.

Historical data indicated that abundances of benthic organisms began to increase in early winter, attained maximum densities in spring, then declined through the summer, reaching lowest numbers in September or October; occasionally a small summer bloom occurred. However, relatively little was known of the seasonal changes or annual variability in composition of benthic communities off the upper Texas coast. The present study is unique. Monthly samples were collected for 4.5 years from two different habitats, a sandy bottom and a muddy bottom, allowing the investigators to study the changes in abiotic factors and community composition of the sites from year to year instead of trying to extrapolate data from relatively brief studies in several different study areas. In addition, sampling has continued on a quarterly basis for 1.5 years at the offshore site, increasing the data base on natural changes in population densities and species composition in the benthic assemblages.

There are virtually no data on the effects of pure brine on biological communities. Johnson (1974, 1977) conducted studies in two areas, Cedar Bayou (upper Galveston Bay) and the San Bernard River, where brine was being discharged. In both areas, water moved slowly and the dense brine formed a persistent stratified bottom layer that was occasionally displaced during high freshwater discharge. The San Bernard River site had maximum recorded bottom salinities of 18.9 o/oo, but the salinity was not detrimental to fish or invertebrates because more specimens were collected at the affected station than at a station 9 km downstream where the bottom salinity was much lower. The Cedar Bayou site, which received brine from salt dome cavern leaching, experienced bottom salinities as high as 118 o/oo, and the brine apparently limited penetration of fish and nektonic invertebrates into the affected area.

Most studies concerned with brine discharge have investigated the impact of oil field produced water or "bleedwater" brine, i.e. brine that is discharged into the environment after separating from the oil with which it was mixed when pumped to the surface. Separation is not 100% complete and some quantity of oil is also discharged. If the Bryan Mound salt dome is refilled with oil a second or third time, the disposed brine will probably, like bleedwater, contain oil. In shallow bodies of water, bleedwater oil becomes incorporated in the sediments, as was found in Louisiana (Mackin and Hopkins, 1962) and Texas (Mackin, 1971; Armstrong et al., 1979); oily bottoms contained depressed populations of benthic organisms. Such an effect has not yet been clearly demonstrated in offshore waters. The greater potential for mixing because of deeper water reduces the probability of oil being incorporated in the sediments. In Louisiana, studies comparing a production platform with a control area produced mixed results. Waller (1974) reported that oil field stations were less productive than control areas. However, Kritzler (1974), Farrell (1974) and Fish et al. (1974) found no differences in benthic fauna between production and control areas. Baker et al. (1981) conducted a 3 "season" (spring, summer, winter) study of the benthic biota associated with producing platforms off the Louisiana coast. Their data indicated that sublethal chronic exposure to hydrocarbons and trace metals was limited to within 500 m of a platform. They also emphasized that stress from abiotic variables, viz: hypoxia, Mississippi River outflow and tropical storms, caused benthic community instability and tended to mask effects due to platform production. Fitzhugh (1983) reanalyzed the polychaete data collected on the above study and determined that polychaete distribution was primarily influenced by depth and that platforms did not affect distribution. Harper et al. (1976) found oil in the sediments adjacent to one platform in Buccaneer Field, 50 km south of Galveston, that probably resulted from an accidental spill. The benthic assemblage at this site was quite depressed compared with nearby uncontaminated areas. In a subsequent study at the same location, depressed assemblages were found all around both platforms, but it was not clear whether the depression was caused by differences in the substrate or to discharges from the platforms (Harper, 1977b; Harper et al., 1981).

In the present study, the benthic assemblages displayed considerable seasonal abundance variability prior to diffuser start-up. The most extreme change occurred in May through July 1979 when the occurrence of hypoxic, hydrogen sulfide laden bottom water drastically reduced or eliminated the populations of many species (Harper and McKinney, 1980; Harper, McKinney, Salzer and Case, 1981). This extreme environmental perturbation created data analysis problems because seasonal signals tended to mask any effect due to brine disposal which began nine months later.

The diffuser began operating on March 10, 1980. An intensive study was conducted in March and April 1980. Discharge was intermittent during this time. Volumes were about 200,000 barrels/day, and no effects were detected (Harper and McKinney, 1981a). However, six months after the discharge rate was increased to 500,000 barrels/day, changes occurred in benthic abundances. Prior to September the nearfield abundances were significantly higher than farfield, but after September there were no significant differences. Furthermore, results of Duncan's multiple range test indicated a slight decrease in mean abundance in the nearfield area (Harper and McKinney, 1981b). In the following year, the nearfield stations again had significantly higher abundances than farfield stations (Harper and McKinney, 1982).

5.3 Materials and Methods

5.2.1 Study Area

The offshore site, where brine disposal occurs, was first sampled on December 2, 1977. The original sampling pattern consisted of 15 stations located on transects parallel with the shoreline, but also arranged in concentric circles centered around the presumptive discharge location (Figure 5-2). The diffuser was completed in September 1977. At that time it was determined that the center of the pattern was about 600 m seaward of the diffuser, and in October 1977 the entire station array was relocated so it centered on the diffuser.

At the same time four additional stations were added to the station pattern (Figure 5-3). The 19 stations were sampled monthly until February 24, 1982. In November a new sampling scheme was implemented. Seven new stations were added to the periphery of the study area, bringing the total number of stations to 26 (Figure 5-4). This station array was sampled quarterly (November, February, May and August in 1981 through 1983. Thus, there was a two-month overlap between the 19- and 26-station sampling; the

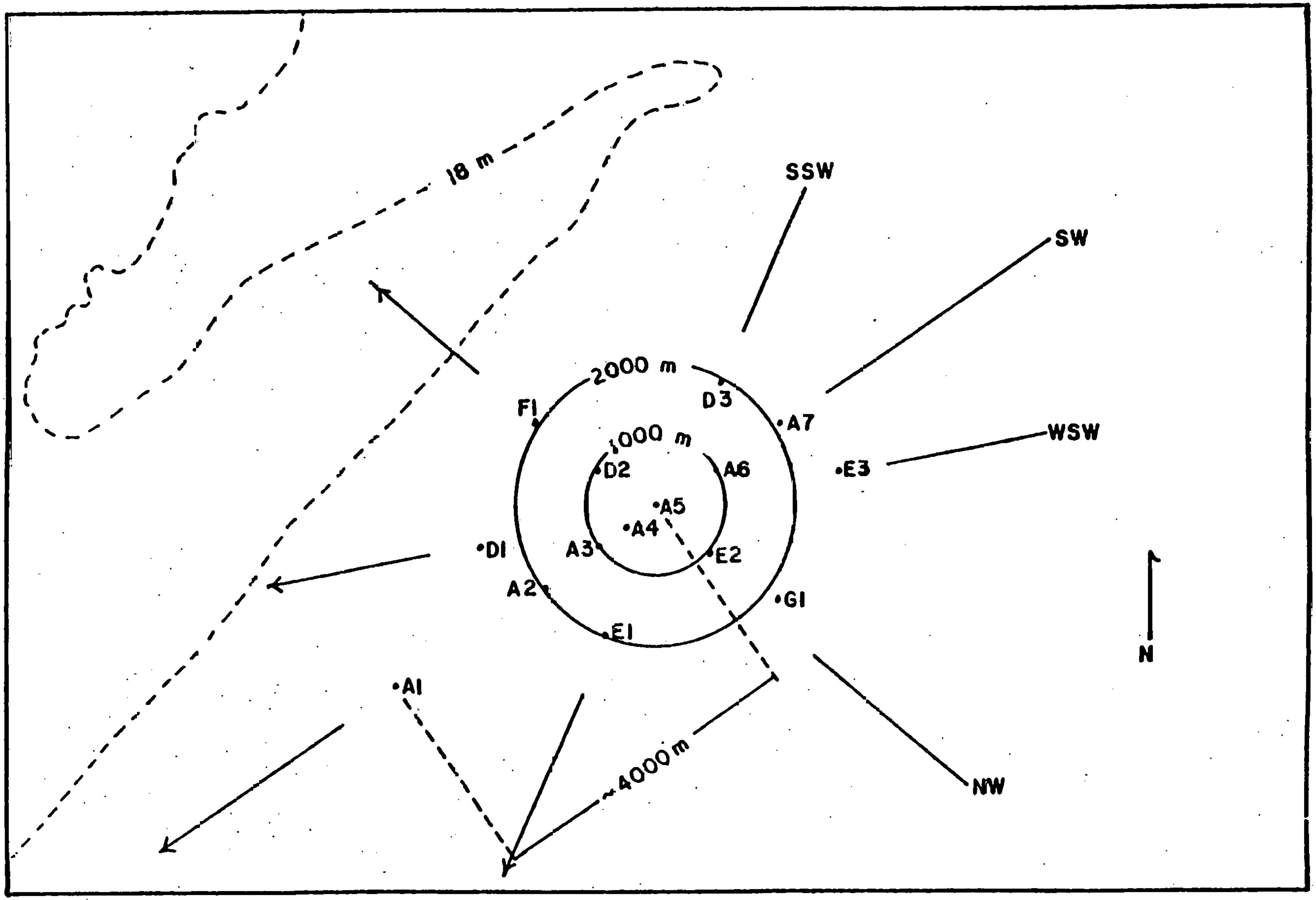


Figure 5-2. Chart of the offshore study area showing locations of the original 15 stations.

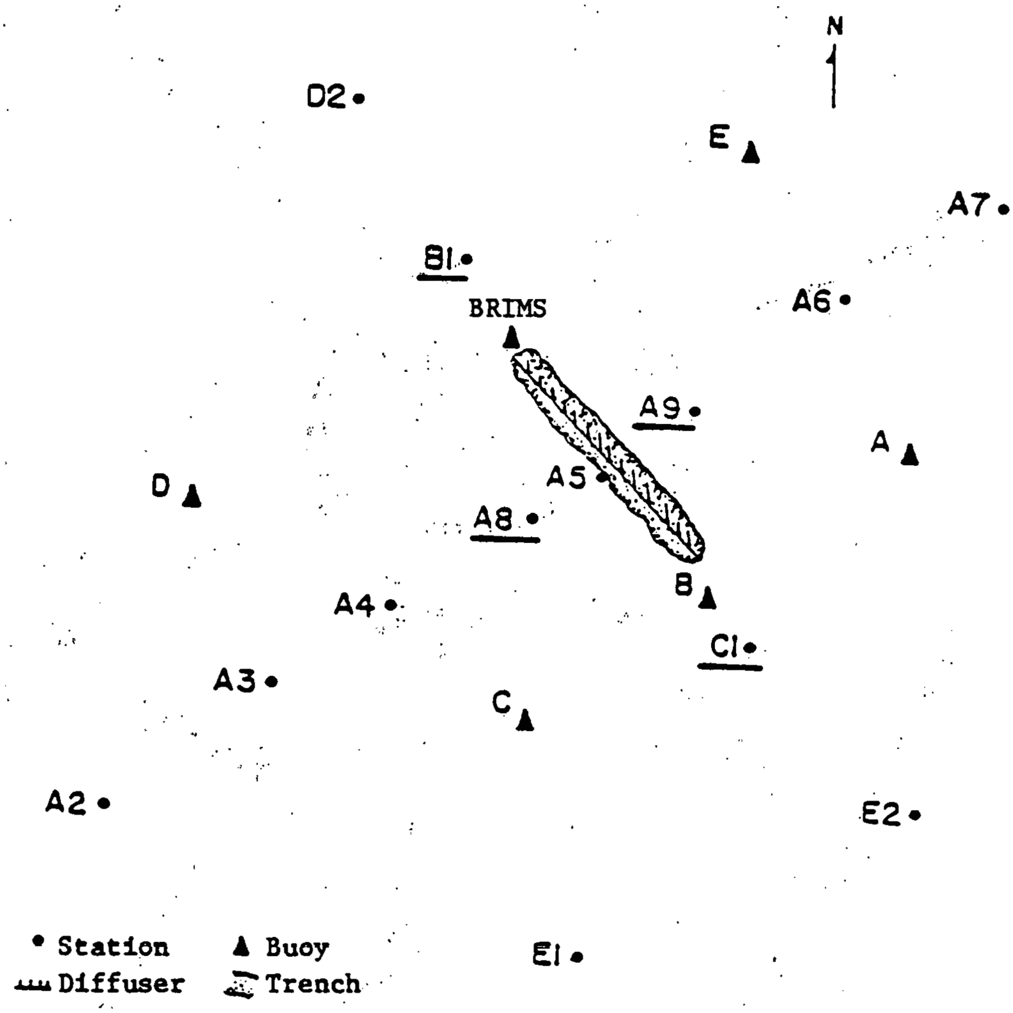


Figure 5-3. Details of the offshore study area showing the nearfield sampling stations in relation to the diffuser array in its trench. Buoys are indicated by solid triangles. Stations A8, A9, B1 and C1, which were added in October 1978, are underlined.

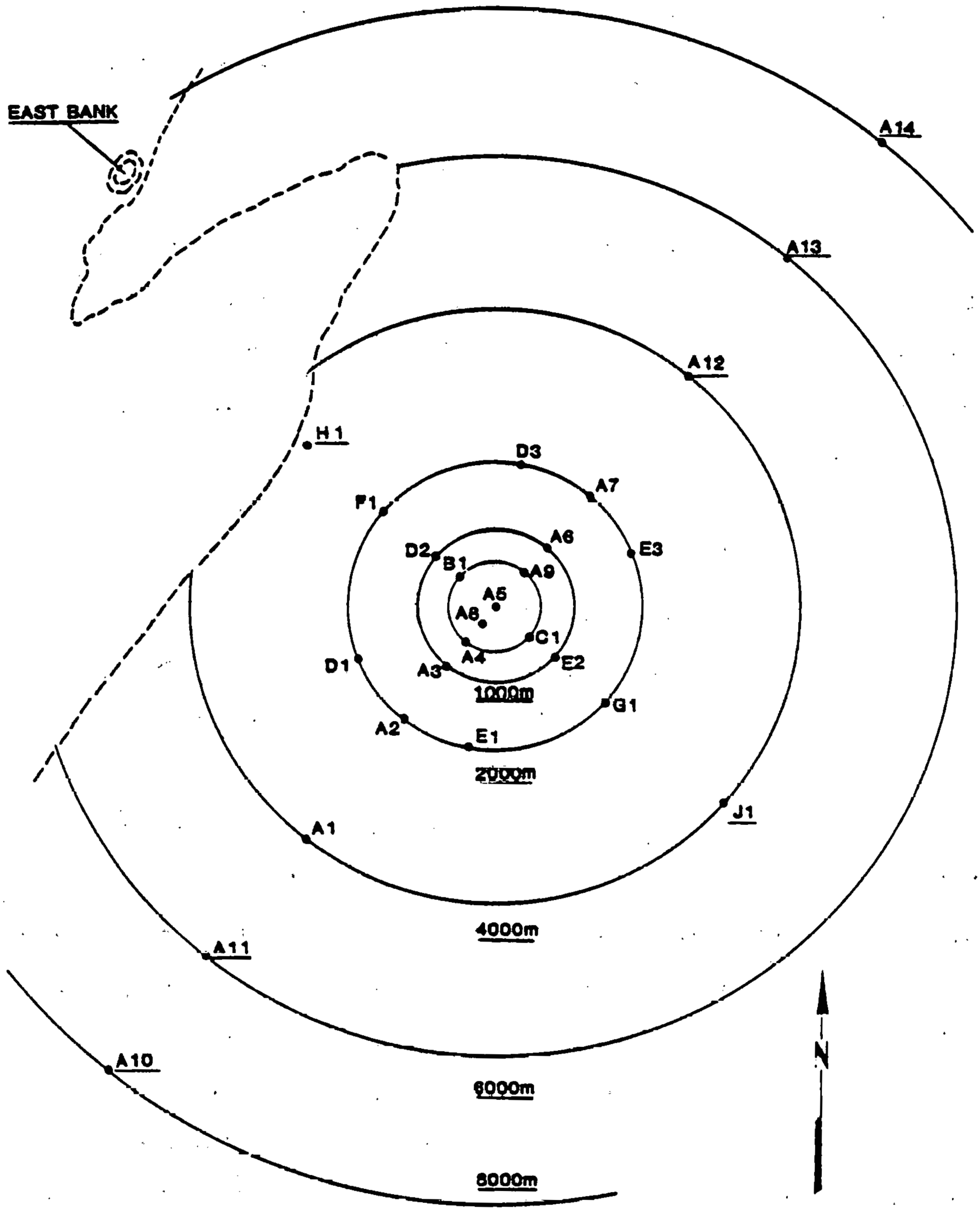


Figure 5-4. Chart of the offshore sampling area showing the 26-station quarterly sampling pattern. Underlined stations were first sampled in November 1981.

26-station cruise in November 1981 was followed by 19-station collections in December 1981 and January 1982 before the new quarterly sampling method was used exclusively. Coordinates of sampling locations are contained in Table 5-1.

5.3.2 Field Methods

Each station was sampled in triplicate by divers using Ekman grabs (232 cm^2 x 15 cm deep). The grabs were spaced at 1.5-meter intervals along a line having a small anchor at one end and a buoy at the other. When the vessel was on station, it was reversed and backed slowly as the samplers and divers descended to the bottom. This maneuver usually caused the grabs to spread apart when they landed. The line and buoy were cast loose from the vessel which then maintained station nearby until the divers surfaced. On the bottom each grab was carefully moved to an undisturbed location, pushed into the bottom and triggered. The divers manually closed the jaws, if necessary, and secured the vent flaps with an elastic band. Water samples were at first collected in a hand-carried plastic jar. Later, a Van Dorn water sampler attached to the diver's SCUBA tank was used to collect water samples immediately above the substrate. Divers also collected a sediment sample in a plastic jar and visually inspected the water and substrate, when possible, for unusual occurrences, evidence of brine, presence of organisms, etc.

When the divers surfaced, they and the samples were picked up by the vessel. The Ekman contents were placed in plastic containers and the sediment temperature was recorded. A description of the sediments, based on visual and textural examination, was recorded. Each sample was then washed separately on a 0.5-millimeter mesh sieve to remove sediments, and then the material remaining on the sieve was fixed in 5% seawater

Table 5-1. Coordinates of benthic sampling stations of the offshore and nearshore study area.

	Offshore			
	Pre-Oct. 1979		Post-Oct. 1979	
Station	Latitude (N)	Longitude (W)	Latitude (N)	Longitude (W)
A1	28°42'32"	95°16'29"	28°42'42"	95°16'38"
A2	28°43'12"	95°15'12"	28°43'27"	95°15'32"
A3	28°43'30"	95°14'49"	28°43'46"	95°15'03"
A4	28°43'38"	95°14'30"	28°43'58"	95°14'48"
A5	28°43'54"	95°14'15"	28°44'08"	95°14'28"
A6	28°44'10"	95°13'51"	28°44'28"	95°14'04"
A7	28°44'26"	95°13'09"	28°44'48"	95°13'35"
D1	28°43'24"	95°15'30"	28°44'03"	95°15'47"
D2	28°43'51"	95°14'32"	28°44'33"	95°14'57"
D3	28°44'32"	95°13'27"	28°45'06"	95°13'18"
E1	28°43'02"	95°14'42"	28°43'09"	95°15'19"
E2	28°43'37"	95°13'57"	28°43'41"	95°14'10"
E3	28°44'09"	95°13'57"	28°44'12"	95°13'18"
F1	28°44'32"	95°15'40"	28°44'59"	95°15'19"
G1	28°43'06"	95°13'00"	28°43'17"	95°13'47"
A8			28°44'05"	95°14'37"
A9			28°44'18"	95°14'18"
B1			28°44'20"	95°14'45"
C1			28°43'53"	95°14'23"
A10			28°41'39"	95°18'17"
A11			28°42'07"	95°17'32"
A12			28°45'31"	95°12'43"
A13			28°46'17"	95°11'48"
A14			28°48'06"	95°11'00"
H1			28°45'55"	95°15'50"
J1			28°42'34"	95°12'54"

	Nearshore	
Station	Latitude (N)	Longitude (W)
A1	28°48'00"	95°19'38"
A2	28°48'32"	95°18'40"
A3	28°48'38"	95°18'03"
A4	28°48'46"	95°17'45"
A5	28°48'58"	95°17'32"
A6	28°49'11"	95°16'53"
A7	28°49'22"	95°16'18"
D1	28°48'47"	95°18'58"
D2	28°49'20"	95°18'09"
D3	28°49'36"	95°16'11"
E1	28°48'16"	95°18'15"
E2	28°48'44"	95°17'17"
E3	28°49'09"	95°16'47"
F1	28°49'42"	95°18'39"
G1	28°48'28"	95°16'48"

formalin. The sediment sample was placed in a container.

The temperature and salinity of the bottom water sample were recorded as soon as the divers returned to the vessel. The temperature and salinity of a surface water sample were also recorded. Since October the dissolved oxygen (D.O.) content of at least the bottom water was measured. Prior to January 1979, temperature was measured with a Celsius thermometer, salinity with a refractometer and D.O. with a Hach kit. Since then a YSI Model 33 Temperature-Salinity-Conductivity meter, verified with a thermometer and refractometer, was used to determine termperature and salinity. D.O. was measured using a YSI Model 57 Dissolved Oxygen meter.

Pore water salinity was measured at the offshore site after the diffuser began operating (since March 10, 1980). Sediment samples were allowed to settle briefly after collection and the supernatant fluid was poured off to ensure the pore water would not be mixed with bottom water.

5.3.3 Laboratory Methods

Samples returned to the laboratory were allowed to fix at least 12 hours in seawater-formalin. Samples were then washed with fresh water on a 0.5-millimeter mesh sieve to remove formalin and remaining sediments. The material retained on the sieve was preserved in 70% rose bengal stained ethanol for at least 24 hours. Organisms were then removed, identified to lowest possible taxon and counted.

Sediment samples stood overnight allowing the sediments to settle and the pore water to collect as a supernatant fluid. Pore water salinities were then determined by refractometer. Sediments were then refrigerated at 4°C if not spread out to begin drying immediately. A portion of the dried sample was analyzed for grain size using methods of Folk (1980), including sieve analysis for the sand fraction and pipette analysis for silts and clays.

5.3.4 Data Analysis

Temperature, salinity and D.O. data collected from water and sediments were averaged for each cruise and each station. Sediment characteristics are presented in monthly Shepard diagrams. The discussion of abiotic factors will principally concern the sediment temperature, bottom and pore water salinity, bottom water D.O. and sediment characteristics because these are the factors directly affecting the benthos.

Biological data were analyzed in two ways. The first was descriptive, comparing total species and total abundances (per station or per cruise as appropriate, without extrapolation to numbers per m^2) and comparing the areal and seasonal distributions of total species and individuals within each site. The second method involved the use of cluster analysis (Bray-Curtis dissimilarity measure, flexible sorting, elimination of infrequently occurring species (those species comprising 95% of all individuals collected were retained)) following the methods of Clifford and Stephenson (1975), principal components analysis (PCA) using the same species as in cluster analysis and pooled data from each station at each site (see Clifford and Stephenson, 1975), discriminant analysis comparing abundances with abiotic variables, and ANOVA followed by Duncan's Multiple Range Test (MRT) to establish the hierarchy of means. The graphic output for cluster analysis included station group and species group dendrograms and two-way tables comparing co-occurrence of stations and species (only the former are illustrated). PCA displays were plots of each station location in space relative to the first three principal axes.

Duncan's MRT results displays were lists of stations ranked by mean diversity.

5.4 Results

5.4.1 Abiotic Characteristics of the Study Areas

5.4.1.1 Temperature

The water column at the offshore site was usually isothermal or nearly so (Table 5-2). During the spring warming period (March through May), bottom water warmed slower, and was usually 1 to 2°C cooler, than the surface. Stratification often kept bottom waters 1 to 2°C cooler during the summer (June through August). On occasion, usually following passage of a norther, the water was slightly warmer at the bottom than at the surface.

Sediment temperature changed more slowly than the bottom water indicating sediments act as a buffer against thermal shock from rapidly changing temperatures (Table 5-2). Sediment temperatures were up to 5°C cooler than surface waters during spring warming.

Seasonal sediment temperature changes were relatively similar between years (Figure 5-5). The coolest water temperatures were recorded in January and February, and the warmest in August through September. Temperatures increased gradually in the spring and decreased rapidly in the fall. The principal difference between years was the relatively mild winter of 1979 and 1980. No changes in the pattern occurred in 1982 through 1983.

Average bottom water temperatures since the diffuser began operating (March 1980 through August 1983) have been nearly uniform (Table 5-3; Harper and McKinney, 1982, 1983). There has been no indication of a temperature increase in the vicinity of the diffuser.

Table 5-2. Comparison of the average monthly temperature, salinity and dissolved oxygen of the water column, and the sediment temperature and pore water salinity (= sed.) at the offshore site. Data from stations A4, A5, A6, A8, A9, B1, C1 and E2 were deleted from salinity calculations after diffusion began.

Date	Temperature			Salinity			Dissolved Oxygen	
	Surface	Bottom	Sed.	Surface	Bottom	Sed.	Surface	Bottom
1977								
2 Dec	19.5	21.0	21.5	23.8	30.1			
1978								
4 Jan	14.2	14.5	15.0	33.5	33.9			
24 Feb	10.9	11.8	12.9	--	--			
17 Mar	14.0	14.0	14.0	32.3	35.7			
15 Apr	21.2	19.9	17.9	28.6	34.4			
24 May	26.4	24.8	23.2	30.2	34.9			
20 Jun	28.6	27.7	26.0	30.0	31.9			
17 Jul	30.7	27.0	25.4	31.1	35.1			
21 Aug	30.1	28.0	26.9	34.5	35.6			
27 Sep	28.1	28.6	27.4	31.5	32.0			
30 Oct	24.8	25.3	24.3	33.7	35.0		--	5.4
30 Nov	21.4	22.9	21.6	31.1	33.5		7.0	6.7
1979								
17 Jan	14.7	14.4	14.1	34.6	35.7		--	--
28 Jan	13.0	13.0	13.1	32.5	32.7		7.0	6.7
26 Feb	13.4	13.7	13.5	28.4	33.1		7.8	6.6
25 Mar	18.2	17.2	17.1	26.4	35.2		8.0	3.6
24 Apr	23.0	21.3	19.0	20.1	32.9		7.4	5.3
24 May	24.5	23.0	22.4	25.3	33.8		5.7	3.3
25 Jun	30.0	25.0	25.0	19.4	32.8		6.2	1.9
30 Jul	28.0	26.2	26.2	28.5	32.3		5.4	1.6
21 Aug	28.7	26.9	26.8	30.6	32.0		5.3	2.9
24 Sep	24.5	25.5	25.5	24.7	28.7		6.4	4.8
18 Oct	25.1	24.7	25.0	30.3	31.6		5.6	5.5
15 Nov	19.9	20.5	20.7	30.0	30.5		6.1	6.1
16 Dec	14.2	14.5	16.0	29.0	30.2		7.0	6.8
1980								
18 Jan	15.3	15.2	16.5	28.8	30.5		6.9	6.7
13 Feb	13.7	14.1	14.1	30.7	31.5		7.4	7.5
10 Mar	16.0	16.0	15.9	26.7	31.3		7.6	7.1
20 Mar	16.3	16.1	16.0	30.5	31.9		8.0	7.9
3 Apr	18.6	18.0	18.0	26.3	29.4	32.0	8.1	7.2
21 Apr	21.1	19.3	19.0	30.5	36.0	34.7	8.0	7.9
22 May	24.3	23.3	22.4	27.0	30.3	32.1	6.8	6.4
30 Jun	28.0	24.6	23.3	34.8	35.1	35.3	6.4	6.1
24 Jul	28.6	28.5	28.0	35.7	35.6	36.4	6.6	6.4
25 Aug	30.2	29.3	29.1	31.7	32.9	34.7	6.1	4.7
4 Sep	29.4	29.4	29.4	29.1	31.6	33.0	6.2	5.9
29 Sep	28.8	28.9	29.0	28.7	32.9	32.1	7.1	6.0
23 Oct	23.9	25.2	25.0	30.5	33.7	33.1	7.2	6.4
5 Dec	16.4	16.6	17.0	32.3	32.7	34.4	7.5	7.3
1981								
15 Jan	13.6	14.2	14.2	32.1	33.7	34.5	8.4	7.9
14 Feb	12.2	12.7	12.1	31.9	32.2	34.1	10.2	10.1
14 Mar	16.5	16.2	15.7	32.1	35.4	34.5	7.6	7.1
17 Apr	25.6	23.5	21.8	30.4	32.9	34.7	7.1	6.9
26 May	25.7	25.1	25.2	33.8	33.0	34.0	8.4	8.0
18 Jun	28.6	28.0	28.1	26.2	31.5	32.8	8.2	6.7
13 Jul	29.6	28.3	28.7	30.0	33.5	33.4	5.6	3.1
13 Aug	29.6	29.2	30.0	31.9	32.0	32.5	5.5	4.3
21 Sep	27.3	28.0	28.1	29.2	30.8	31.5	6.9	5.8
27 Oct	23.4	25.0	25.2	29.3	32.6	31.6	5.9	4.8
21 Nov	21.4	22.2	22.4	32.0	33.1	33.9	8.0	6.9
9 Dec	19.5	20.0	20.7	30.4	31.5	32.9	7.2	6.7
1982								
27 Jan	13.6	14.0	15.0	31.8	32.8	33.8	8.2	8.0
17 Feb	15.0	14.5	14.4	30.0	34.7	34.2	9.4	7.9
28 May	26.9	24.2	24.8	21.7	36.4	32.1	9.1	4.8
31 Aug	29.9	29.8	30.0	32.7	33.3	34.1	6.1	5.8
20 Nov	30.1	20.0	21.1	32.2	35.7	33.8	7.4	6.9
1983								
28 Feb	16.2	16.0	15.9	33.1	33.6	32.7	7.6	7.3
25 May	25.1	23.6	23.7	27.5	33.9	32.6	7.0	5.4
26 Aug	29.3	28.1	27.0	28.2	34.4	33.1	7.0	4.7

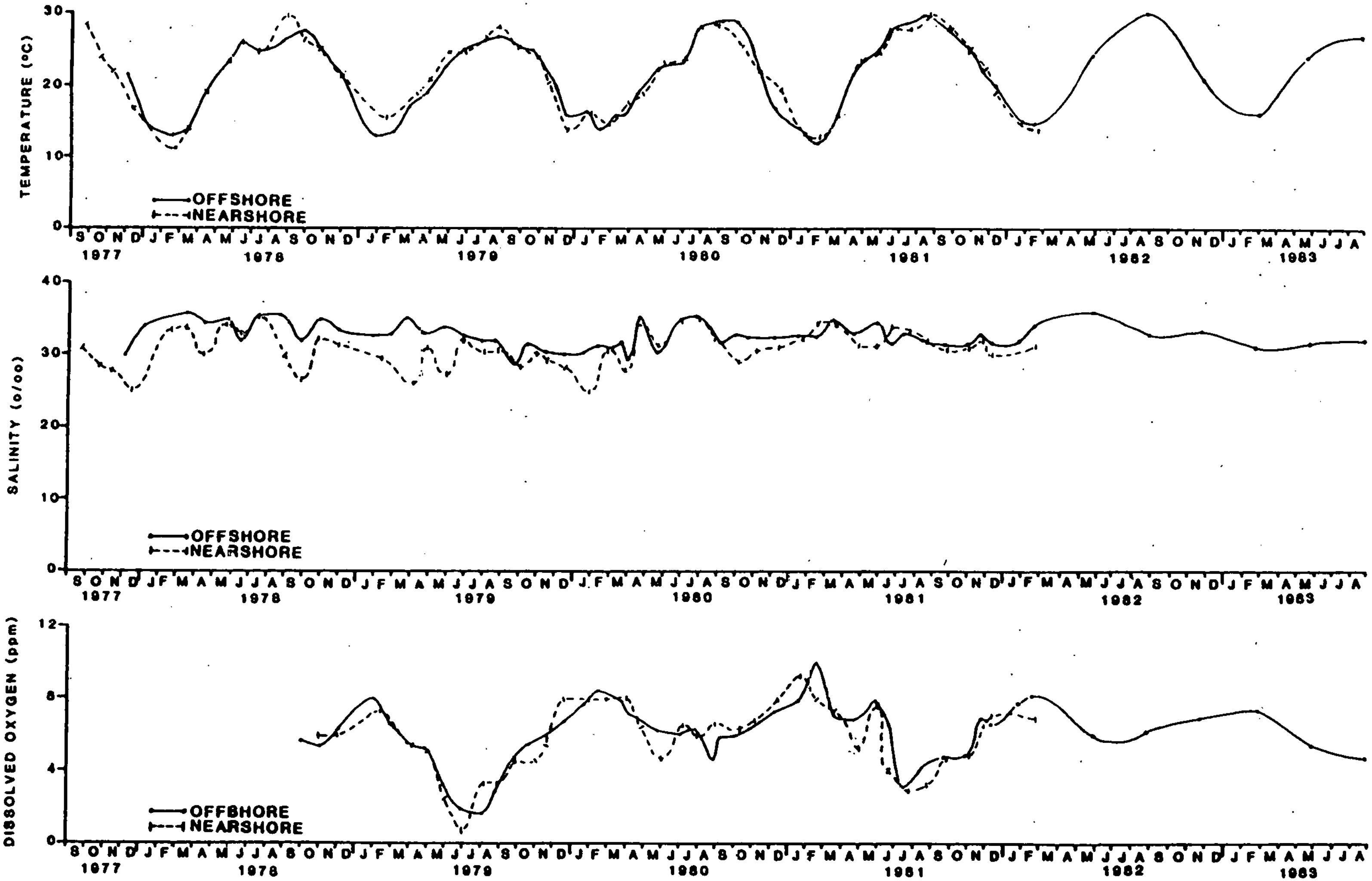


Figure 5-5. Sediment temperature, bottom water and dissolved oxygen trends at the offshore and nearshore study areas.

Table 5-3. Comparison of average bottom water temperature and salinity and pore water salinity at each station (quarterly data) during 600,000 barrels/day lower flow rate (December 1980 through November 1981) and 1,000,000 barrels/day higher flow rate (February 1982 through August 1983).

Station	Bottom Temp. Lower	Bottom Temp. Higher	Bottom Sal. Lower	Bottom Sal. Higher	Sed. Sal. Lower	Sed. Sal. Higher	Diss. Oxy. Lower	Diss. Oxy. Higher
500-m ring of stations								
A4	21.3	22.4	33.0	35.5	35.1	34.9	7.4	6.0
A5	21.3	22.3	34.5	36.0	36.2	35.8	7.4	6.2
A8	21.3	22.3	33.6	35.7	35.3	35.4	7.4	6.3
A9	20.9	22.7	34.1	34.8	35.4	34.4	7.4	6.4
B1	21.1	22.5	33.9	35.6	35.0	34.3	7.2	6.1
C1	21.3	22.4	33.7	34.9	35.4	34.7	7.3	6.1
1000-m ring of stations								
A3	21.3	22.3	33.1	35.1	34.2	34.3	7.3	6.0
A6	20.9	22.4	33.5	34.6	33.9	34.6	7.1	6.3
D2	21.1	22.4	33.1	34.2	34.0	32.8	7.4	6.0
E2	21.1	22.4	33.6	35.2	34.6	34.1	7.3	5.8
2000-m ring of stations								
A2	21.3	22.2	32.5	34.9	33.9	33.9	7.5	6.1
A7	20.8	22.1	32.4	34.4	33.4	32.9	7.4	6.1
D1	21.2	22.3	32.9	34.5	33.4	32.7	7.4	6.1
D3	21.2	22.2	32.9	34.2	34.0	32.8	7.2	6.1
E1	20.9	22.1	32.9	33.0	33.6	35.5	7.3	6.4
E3	21.4	22.4	32.7	35.1	33.2	33.5	7.2	5.9
F1	21.1	22.2	37.8	34.0	33.4	33.4	7.4	6.0
G1	21.0	22.4	32.5	35.2	34.5	33.3	7.2	5.9
4000-m ring of stations								
A1	21.2	22.2	33.0	34.8	33.2	32.8	7.4	6.3
A12		22.4		34.2		32.6		6.2
H1		22.4		34.5		32.9		6.3
J1		22.4		34.9		33.3		6.2
6000-m ring of stations								
A11		22.3		34.9		32.9		6.4
A13		22.3		33.6		32.9		6.2
8000-m ring of stations								
A10		22.6		34.3		32.8		6.2
A14		22.4		34.1		33.4		6.2

5.4.1.2 Salinity

Bottom water salinities at the offshore site were usually oceanic or sub-oceanic (30 to 36 o/oo); the lowest average salinity recorded was 28.7 o/oo (Table 5-2). Surface salinities were usually depressed at some time during the spring or summer (April through July) by local runoff or Mississippi River discharge (Kelly et al., 1982, 1983). Annual salinity trends were fairly similar in 1978, and 1980 through 1983 (Figure 5-5), with maximum salinity gradients of about 5 o/oo in those years (Table 5-2). In 1979, however, extremely high spring runoff rates depressed surface salinities to 19 to 20 o/oo, causing strong stratification (12 to 13 o/oo gradient) and contributed to the occurrence of hypoxia (Harper and McKinney, 1981a; Harper, McKinney, Salzer and Case, 1981). In the 1982 through 1983 bottom water salinities (peripheral stations) remained between 30 and 35 o/oo. Salinity gradients were about 3.0 o/oo in November and February, but increased to 4 to 5 o/oo in May and August as freshwater discharge reduced surface salinities to 27 to 28 o/oo.

Prior to diffuser operation, average bottom water salinities were uniform at the offshore site, but after diffusion began, there was an increase in nearfield salinities (Harper and McKinney, 1982). The average nearfield salinities continued to be elevated during the most recent year of study (Table 5-3). The areal extent of elevated bottom water salinities before and after the flow rate was increased to 1,000,000 barrels/day is compared in Figures 5-6, 5-7 and Table 5-3. Discharge was >600,000 barrels/day from November 1980 through December 1981 (5 quarterly cruises) and almost 1,000,000 barrels/day since January 1982 (7 quarterly cruises). Brine salinity was 240 to 260 o/oo during most of

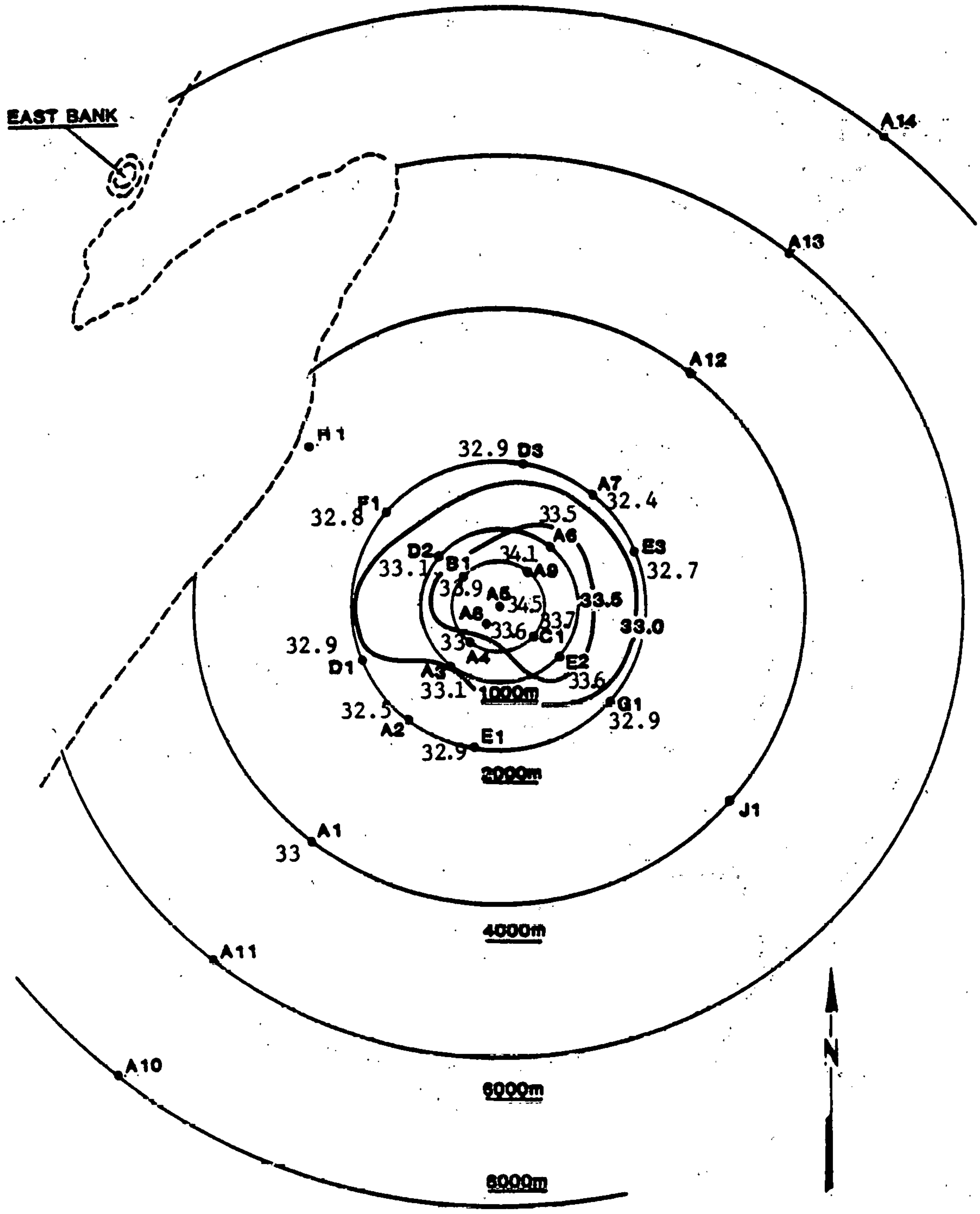


Figure 5-6. Areal distribution of average bottom water salinities during lower (~600,000 barrels/day) flow rate, December 1980 through November 1981.

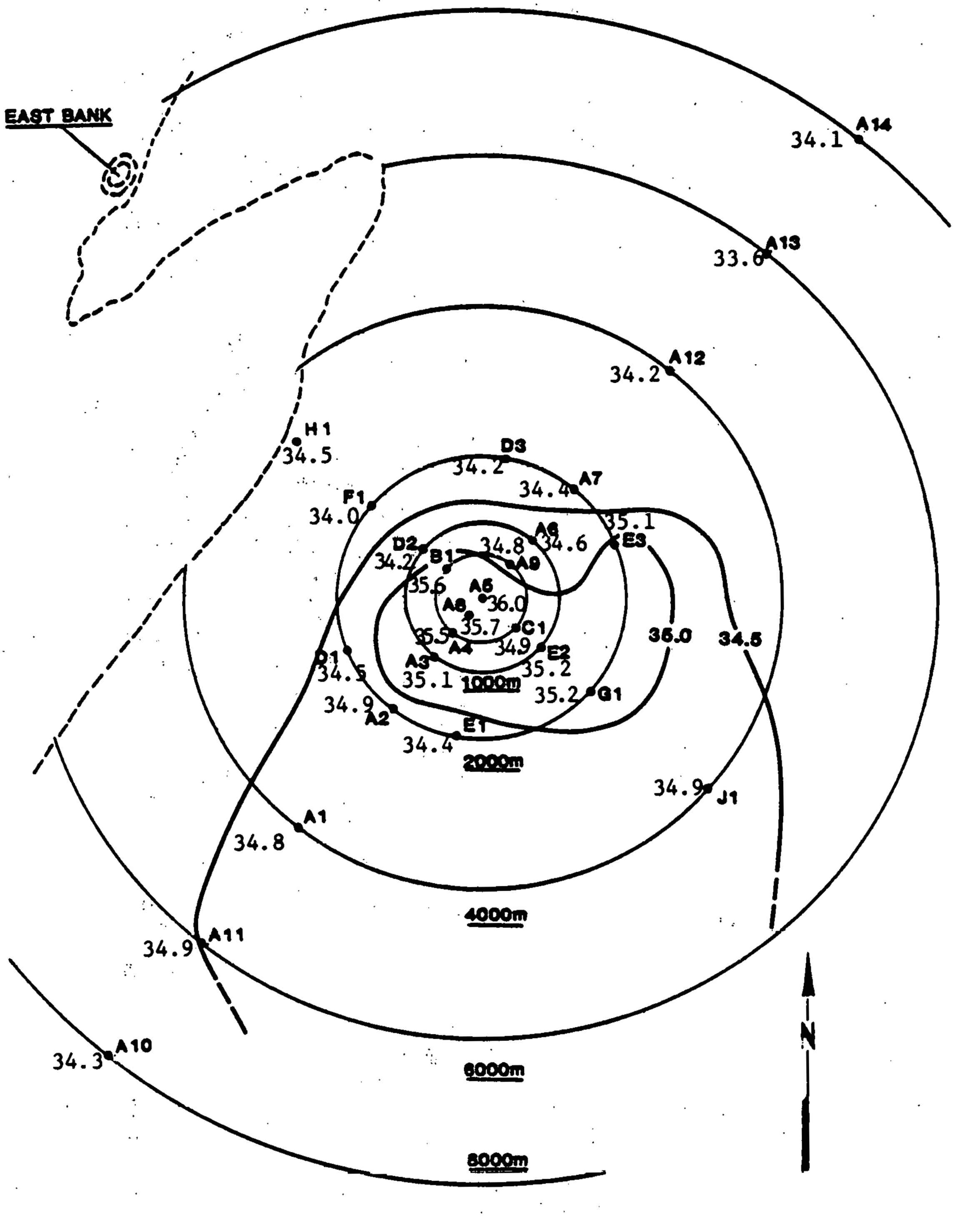


Figure 5-7. Areal distribution of average bottom water salinities during higher (1,000,000 barrels/day) flow rate, January 1982 through August 1983.

this time. The average densest part of the brine plume coverage appears to have trended toward the northeast through southeast, i.e. offshore. During the lower flow rate period, average ambient salinity was about 32.5 o/oo. Both the +1.0 and +0.5 o/oo isohalines were well inside the 2000-meter ring of stations (Figure 5-6). During the higher flow rate period, average ambient salinities were about 34.0 o/oo. The +1.0 isohaline extended beyond the 2000-meter ring of stations while the +0.5 o/oo isohaline appeared to extend a considerable distance southeast to southwest (Figure 5-7). Also, during the higher flow rate period, we recorded evidence that pools of higher density water separate from the plume. On November 20, 1982, the highest recorded bottom water salinity was 38 o/oo at station H1, the closest inshore. Salinities were 35 to 36 o/oo over most of the remainder of the study area. If brine is capable of being carried up a depth gradient toward shore, it is probable that all stations in the offshore study area are affected periodically, and that there are no true control areas available for comparison.

During prior studies pore water salinities have nearly always been higher than bottom water (Harper and McKinney, 1981b, 1982). However since the flow rate increased to 1,000,000 barrels/day, a reversal in salinity concentration has apparently occurred. During the lower flow rate period, pore water salinities were 1.5 to 3.0 o/oo higher than bottom water salinities, on the average. During the higher flow rate period, pore water salinities were 0.2 to 2.0 o/oo lower than bottom water, and were also, in some cases, slightly lower than equivalent pore water salinities during the lower flow rate period (Table 5-3). Slowey's data (1982; this volume: Ch. 3, Append. C) appear to agree with our observations. He recorded elevated pore water salinities from the latter half of 1980 through May of 1982. From August 1982 onward the pore water salinities decreased and were usually lower than, or very near, the bottom water salinities.

Areal extent of elevated pore water salinities appears to trend in the same directions, i.e. north and south, during both lower and higher flow rate periods (Figures 5-8 and 5-9). During the lower flow rate period, the +0.5 o/oo isohaline appears to have extended to the south to some unknown distance, while extending north to a little beyond the 2000-meter station (D3). The +2.0 o/oo isohaline was confined to within the 1000-meter ring of stations. During the higher flow rate period, the +0.5 o/oo isohaline shifted slightly, to the northeast, but covered approximately the same area, and appeared to extend toward the south. The +2.0 o/oo isohaline was confined to the 500-meter ring--a smaller areal coverage than during the prior period.

5.4.1.3 Dissolved Oxygen

Highest offshore D.O. values were recorded during winter months and lower values were recorded in summer when the water was warmer (Table 5-2). D.O. trends were similar annually (Figure 5-5). Lowest D.O. values were recorded in June and July 1979 concomitant with and following pronounced stratification due to low surface salinites (see above). The low D.O., combined with hydrogen sulfide production, caused extensive mortalities among the benthos (Harper et al., 1981).

Average D.O. values were similar at all offshore stations and there is no evidence that the diffuser altered the D.O. content of the bottom water at any station (Table 5-3).

Hypoxia was noted by the hydrographic task group in the summer of 1983. The timing of benthic cruises, however, was such that May samples

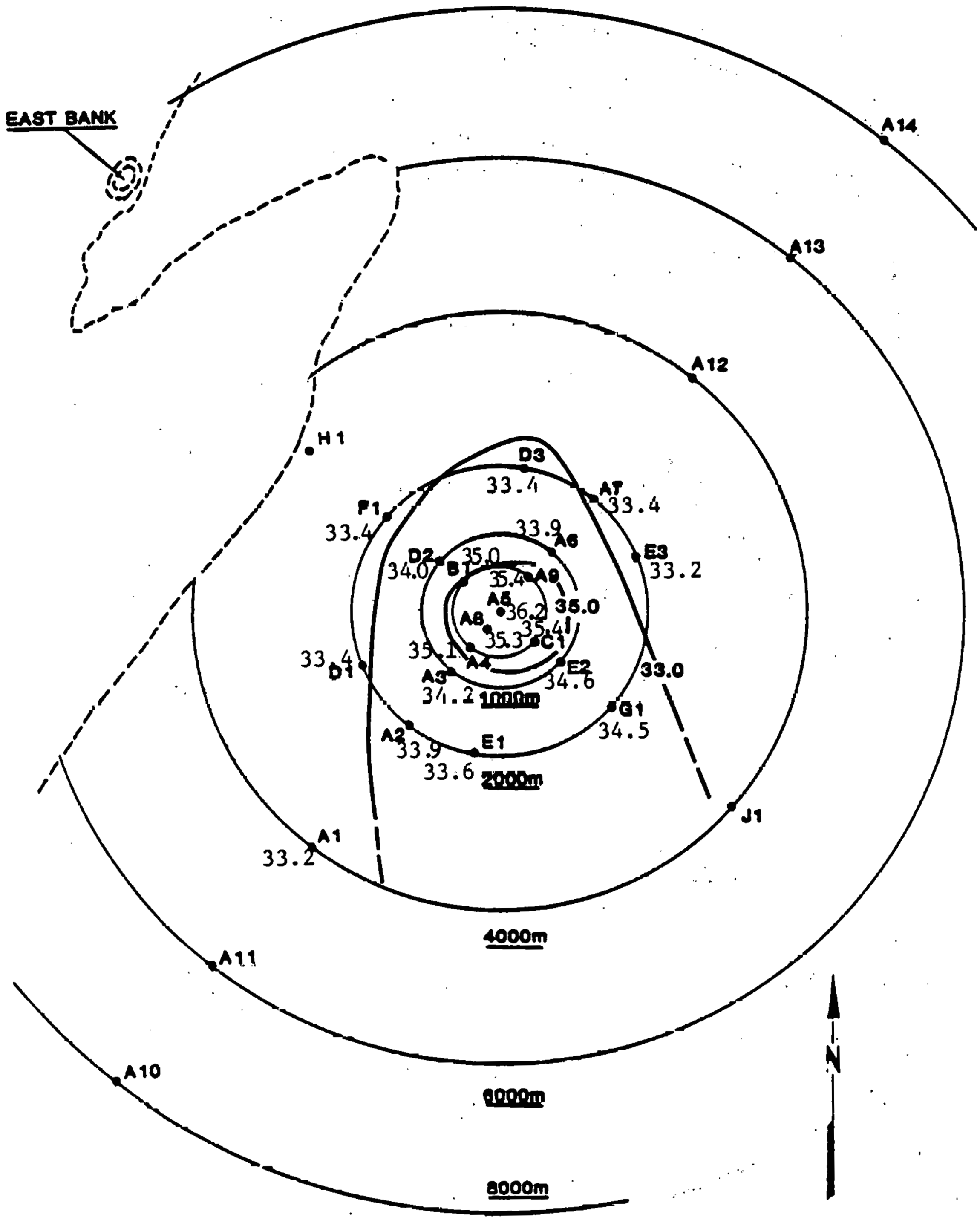


Figure 5-8. Areal distribution of average pore water salinities during lower (~600,000 barrels/day) flow rate, December 1980 through November 1981.

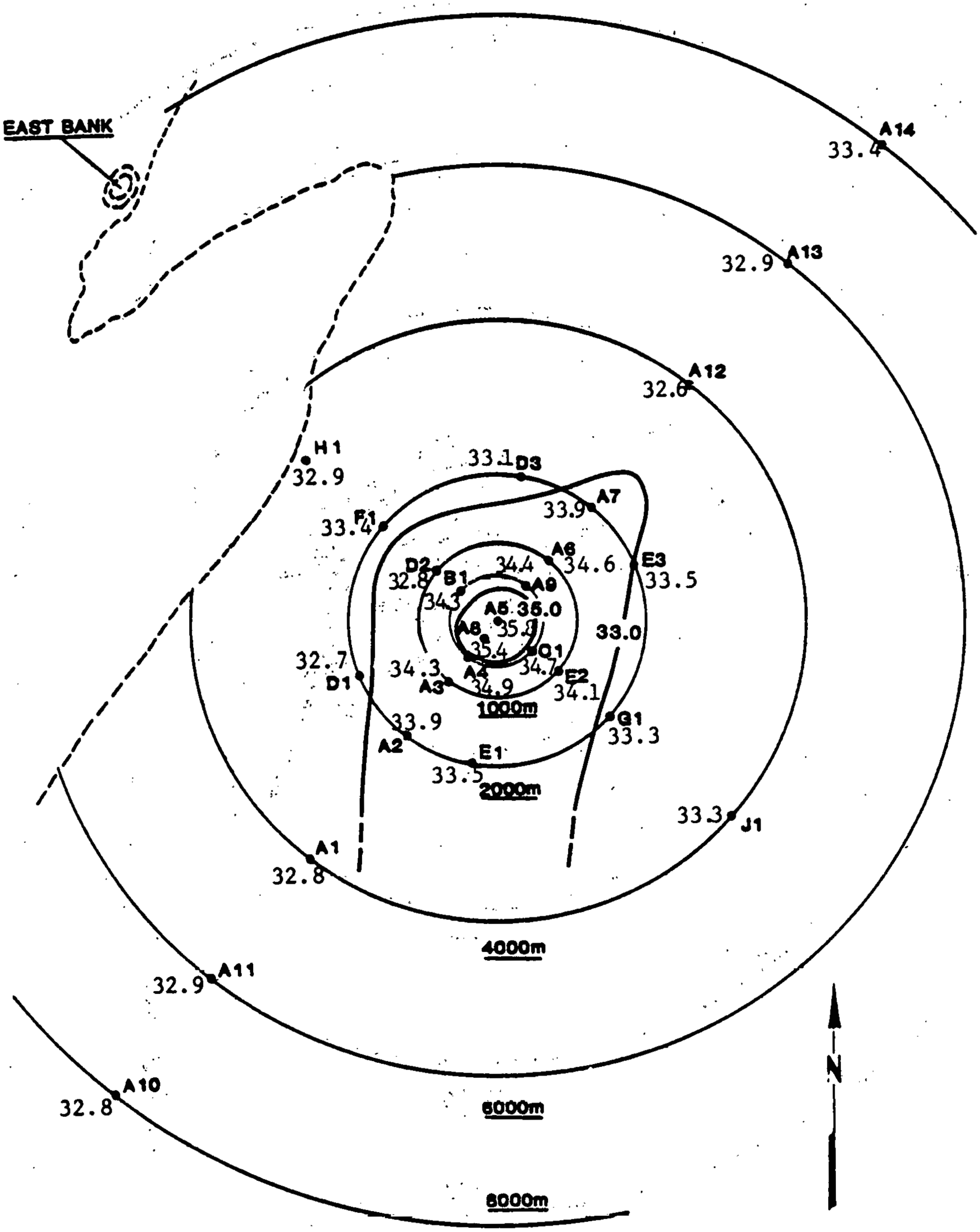


Figure 5-9. Areal distribution of average pore water salinities during higher (1,000,000 barrels/day) flow rater, January 1982 through August 1983.

were taken before and August samples were taken after the hypoxic occurrence.

5.4.1.4 Sediments

The average mean grain size was stable for much of the study period, ranging from 4.5 ϕ to 5.5 ϕ (Figure 5-10). An apparent decrease occurred in March 1980, and an apparent shift into the 6.5 to 7.0 ϕ range occurred in 1981, which continued through 1982. Sea conditions were relatively calm during most of 1981 and 1982 and it possible that accretion of fine sediments occurred. Grain size increased to 5.5 to 5.8 ϕ between November 1982 and May 1983. There was a sharp decrease to 7.9 ϕ in November 1983 possibly due to fine sediments stirred up by Hurricane Alicia in August settling to the bottom.

Shepard diagrams indicate that sediment characteristics varied from month to month at any given station (Harper and McKinney, 1982; Figure 5-11). The variability was also evident to the divers who often reported that the thickness of the fine surficial silt layer varied at any given station. The shift in grain size toward silt-clay composition is evident in the August diagram compared with previous quarterly collection data. In particular, note the shift in grain size from sand or muddy sand (November 1982 through May 1983) to silt-clay in August 1983 for stations A1, A10, A11 and D1.

5.4.2 Biological Characteristics of the Study Areas

5.4.2.1 Seasonal Trends of Diversity

Diversity trends (15-station data) followed a somewhat rhythmic pattern offshore (Figure 5-12); increased numbers of species occurred in spring (February through May) and fall (July through September). The

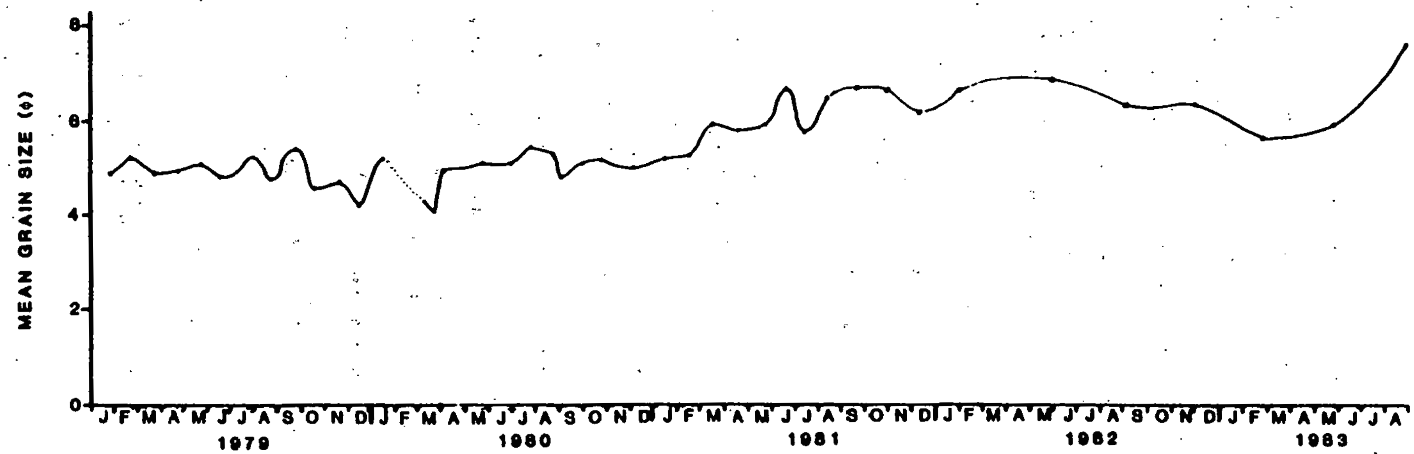


Figure 5-10. Temporal trends of averaged mean grain size at the offshore site.

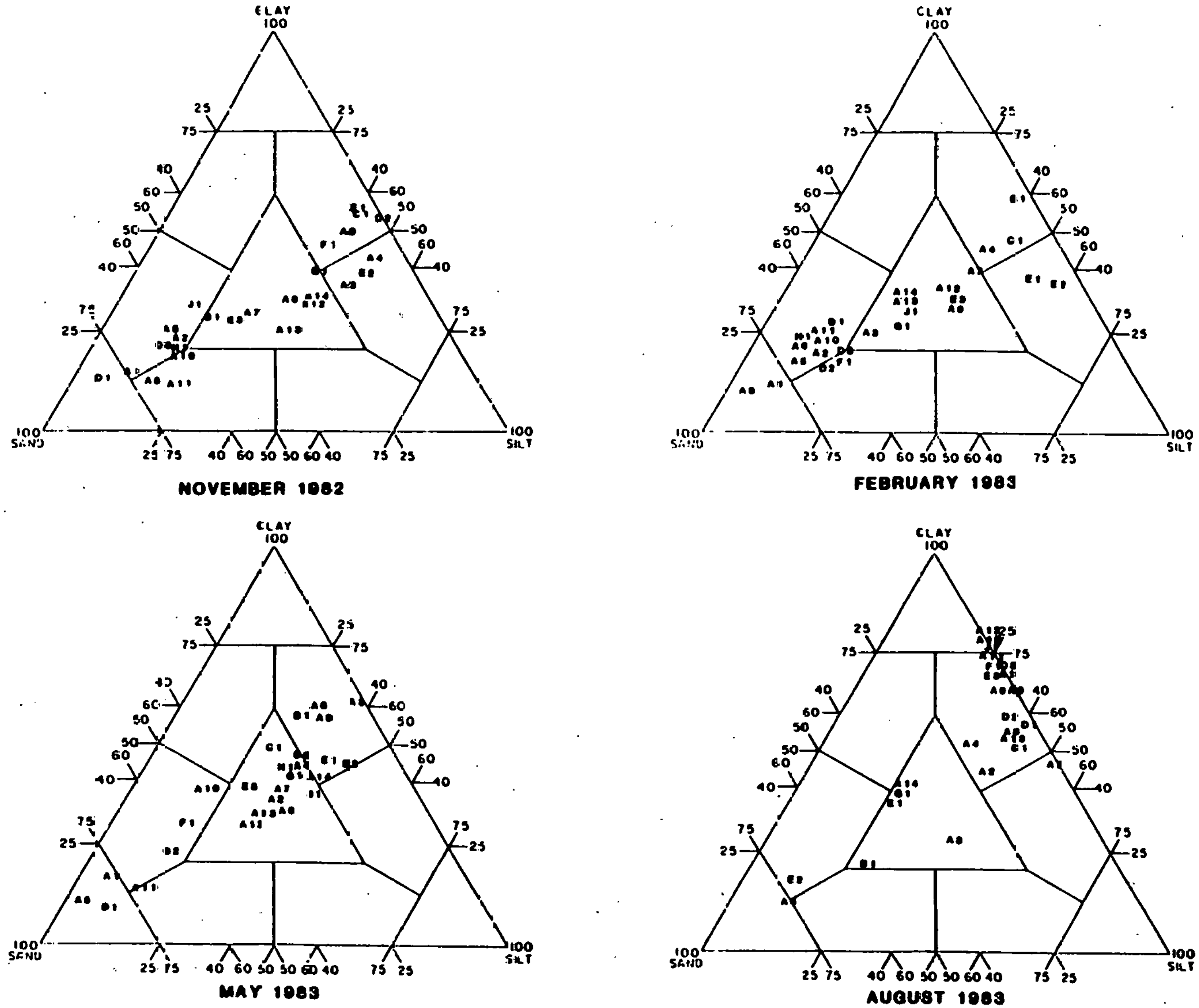


Figure 5-11. Shepard diagrams for 26-station quarterly sediment samples from November 1982 through August 1983.

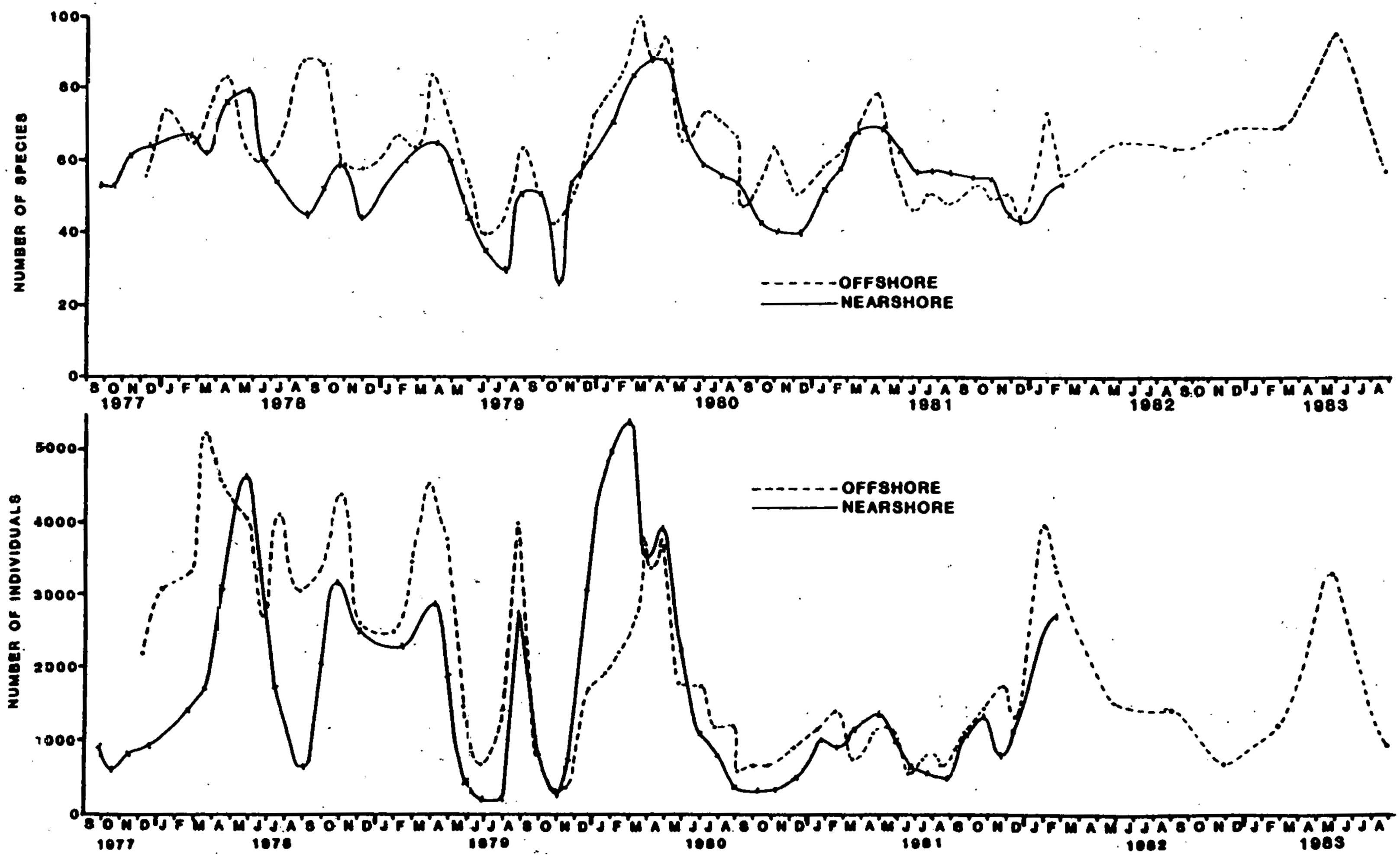


Figure 5-12. Comparison of temporal trends of total numbers of species and individuals for each cruise from September 1977 through August 1983.

largest numbers of species were collected during spring 1980, just prior to start-up of the diffuser. A decreasing trend, temporarily reversed in April, occurred after start-up. Neither the fall 1980 nor spring 1981 peaks were as high as corresponding peaks before the diffuser began operating. Following the increase in brine flow to 1,000,000 barrels/day, a gradual increase in numbers of species collected occurred, followed by an increase to 95 species in May 1983. This was the second highest number collected since the project began. Diversity then decreased through November 1983.

5.4.2.2 Seasonal Trends of Densities

Abundances of offshore benthic individuals fluctuated seasonally during 1977 through 1980, though density peaks did not always correspond exactly with diversity peaks (Figure 5-12). The lowest numbers of individuals were collected during and after hypoxia in 1979. In 1980, the spring peak density occurred just after the diffuser began operating. As with the numbers of species, a decreasing trend, temporarily reversed in April, occurred after the diffuser began operating. A sharp decrease occurred between August and September 1980 after brine output was increased. Neither the expected fall nor spring blooms occurred in 1980 and 1981. In fact, the abundance of benthos was quite depressed between September 1980 and December 1981. Total numbers of individuals collected during this period were always less than 2000 individuals, compared with the 4500 to 5000 individuals collected during spring blooms in prior years.

An abundance peak occurred in January 1982, corresponding with an increase in diversity. This peak was followed by a continual decline through November 1982. A spring bloom occurred in May 1983, in part resulting from a large population of ampeliscid amphipods. Following the May bloom, total abundances of benthos decreased to about 1000 individuals. Apparently the abundance pattern became more like the "expected" seasonal pattern in 1983, but still, the decreases in the fall-winter periods of 1982 and 1983 were greater than those in 1977 and 1978, prior to hypoxia and diffuser start-up.

5.4.2.3 Redox vs. Abundance Trends

The term oxidation is applied to the process in which oxygen is added to a substance. Conversely the loss of oxygen is termed reduction. The extent to which a substance can undergo oxidation - reduction processes depends upon the concentration of other oxidizing - reducing systems and their production in the area. Within a given area of the marine ecosystem, the proportion of oxidized to reduced components of particular system in relation to other systems constitutes the oxidation - reduction potential, or redox potential.

Redox potentials are measured in volts or millivolts (1 mv = 0.001 v). This gives a measure of the intensity of the electromotive force (E_h) and can either be positive or negative. A positive E_h value results from a state tending towards oxidation and a negative E_h value indicates a system causing reduction.

Oxygen in marine ecosystems produces a redox potential which is influenced considerably by temperature and the hydrogen ion concentration (pH). To adjust for these effects all E_h values given are standardized at a temperature of 25°C and pH 7.

The E_h of mud exposed to oxygenated water varies near +500 mv. Depending on the oxygen level at the water-sediment interface, this oxidized microzone may extend for several millimeters into the sediments or be completely absent. If the oxidized microlayer is absent the E_h values will approach zero or less. The less oxygen available in the sediments the lower the E_h value. Anaerobic bacteria exist where the E_h value is below -400 mv. Oxygen dependent animals are generally excluded from such a zone and are found where the E_h is no lower than -200 mv. Under extremely reduced conditions, hydrogen sulfide, a poison to aerobic organisms, is produced, and can rise above the substrate into the water column.

There appears to be a correlation between the abundances of benthic organisms and redox potential of the sediments. In Figure 5-13 the trends of mean E_h trends of diffuser area sediments (Slowey, this volume) are compared with mean abundances of benthos (15 station data). From August 1979 through mid-1980 abundances and E_h were both high. As densities of benthic organisms decreased in the latter part of 1980, the E_h became negative (reducing conditions). Both remained low through August 1983 with the exception of the positive spike in May 1983. These data were subjected to a regression analysis using E_h as the dependent variable (Figure 5-14). The correlation resulting from this analysis was 0.5924 with an F of 0.009. This moderately good correlation may be a result of the non-synoptic nature of the data. Better correlations were obtained when fewer data were used (see section 5.4.2.8.2).

It is quite probable that sediment E_h is dependent on the burrowing activities of infaunal benthos. Deep burrowers draw water into their burrows, bringing in food and/or oxygen. This oxygenates the sediments around the burrows. Shallower burrowing direct deposit feeders eat their way through the sediment, and, combined with the burrowing activities of surface deposit and filter feeders, cause sediment overturn, or

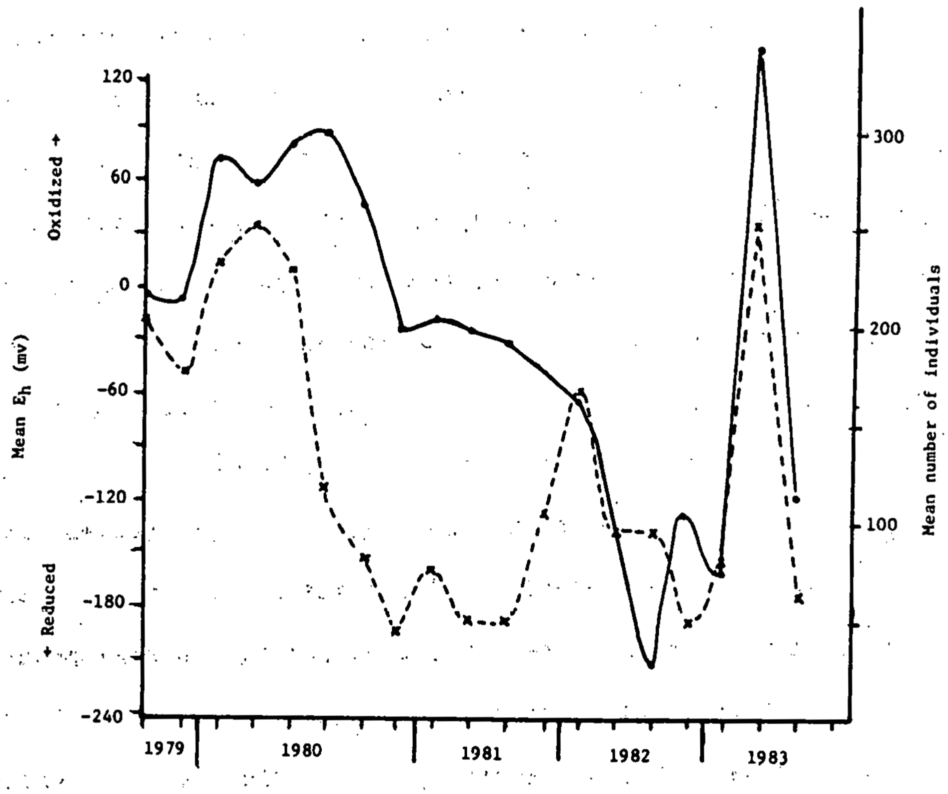


Figure 5-13. Comparison of temporal trends of mean E_h values (---) and mean abundance of benthic organisms (——).

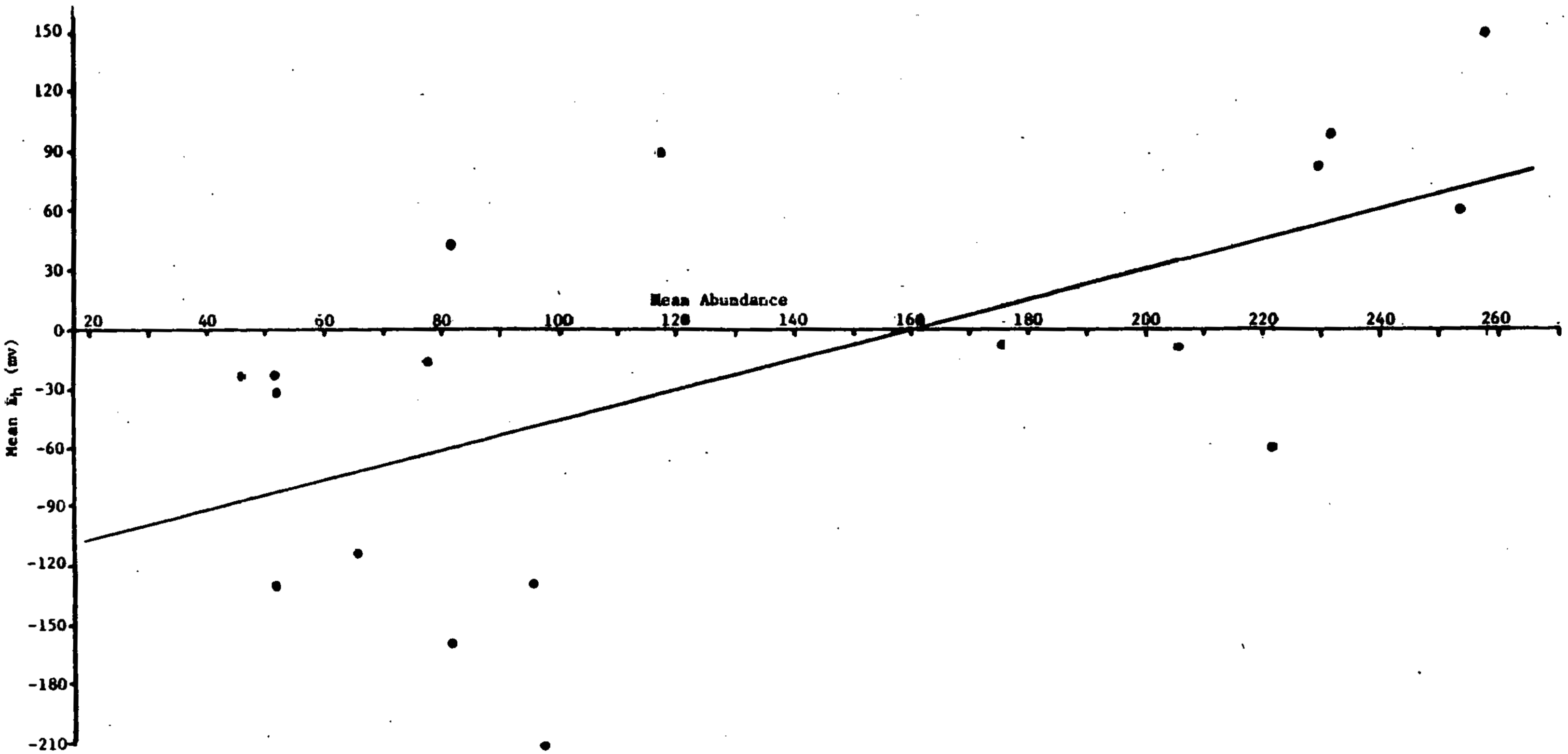


Figure 5-14. Regression analysis plot of mean E_h vs. mean abundance of benthic organisms.

bioturbation. These activities oxygenate the upper few centimeters of sediment and cause a typical brownish color of newly collected sediments.

It follows, then, that when organismal densities are high, bioturbational activity is more intense and E_h remains positive. Reduction of benthic abundances (as occurred in 1980-1981) reduces bioturbation, anaerobic bacterial activity increases (also a result of fewer bacterial being eaten by deposit feeders), and E_h becomes negative.

5.4.2.4 Areal Distribution of Diversity

In the 5 cruise lower flow rate period, the distribution of total numbers of species appears to have been fairly homogeneous (Figure 5-15). Most stations had 30 to 40 species during this time. Only the diffuser station (A5) had noticably more species--50.

In the 7 cruise higher flow rate period there were patches of stations, all but one, 2000 m or more from the diffuser with >60 species (Figure 5-16). The single exception was the diffuser station. Remaining stations had 40 to 50 species.

The distribution of average numbers of species per A transect station is shown in Figure 5-17. During both lower and higher flow rate periods, there was a peak at station A5 and depressed numbers of species immediately downcoast from the diffuser. Note the higher numbers of individuals toward the periphery of the study area.

5.4.2.5 Areal Distribution of Abundances

Areal abundance distribution data collected during the lower flow rate period (5 cruises) suggest three groups of stations, those with <300 total individuals, 300 to 500 individuals and >500 individuals (Figure 5-18). Greatest abundances were northeast (stations A9, A6 and A7) and

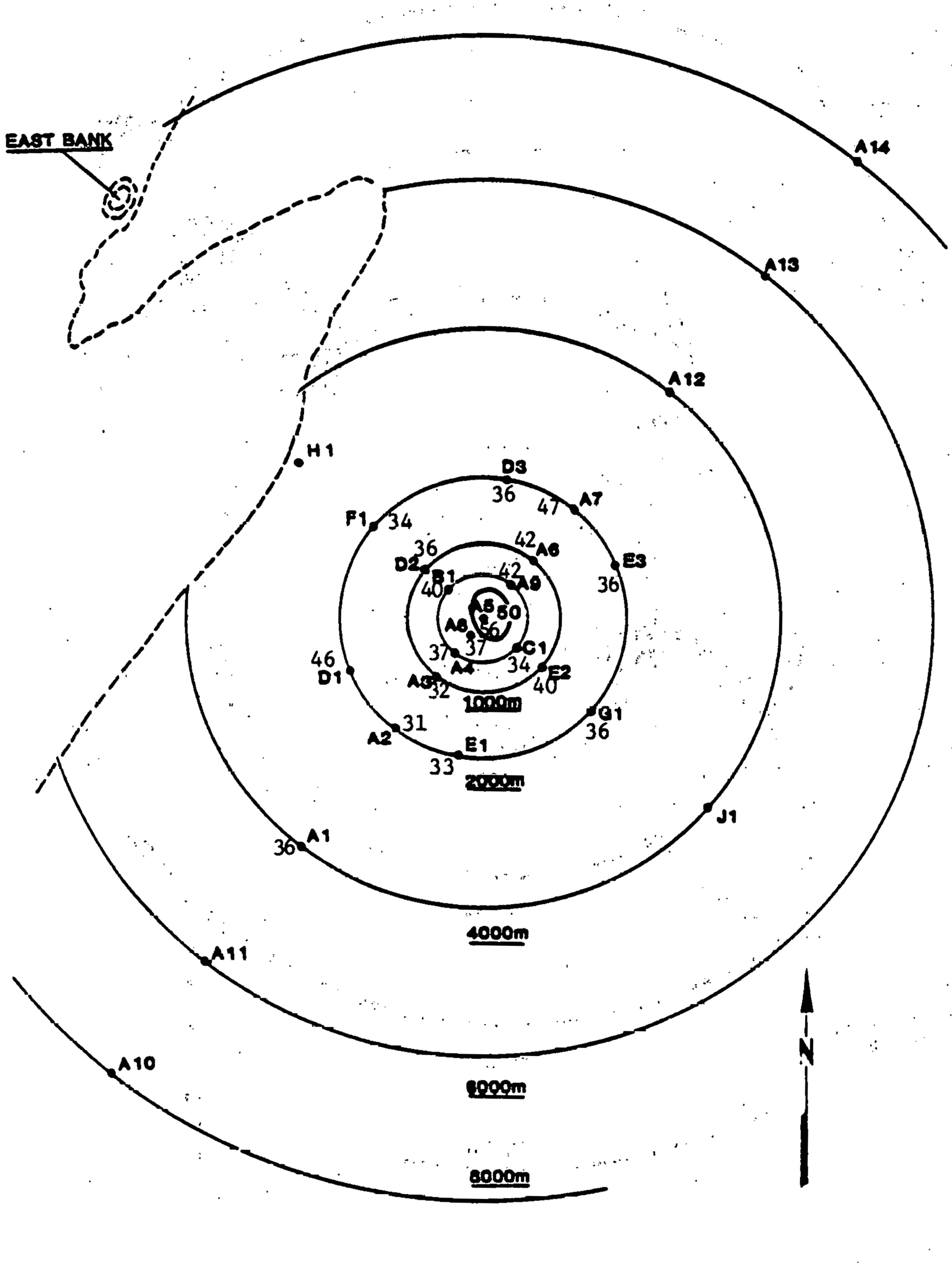


Figure 5-15. Areal distribution of total number of species during the lower flow rate (~600,000 barrels/day), December 1980 through November 1981.

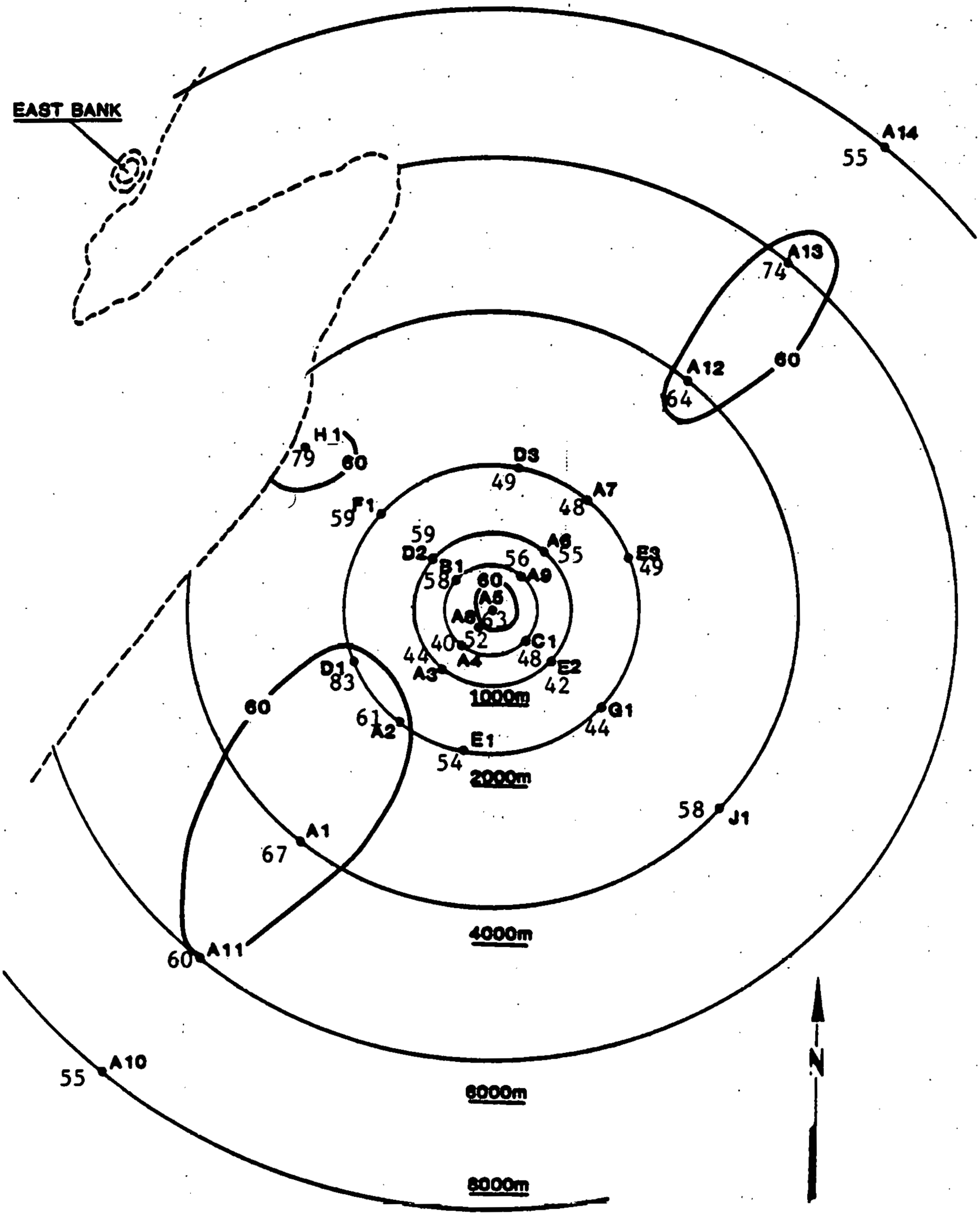


Figure 5-16. Areal distribution of total number of species during the higher flow rate (1,000,000 barrels/day), February 1982 through August 1983.

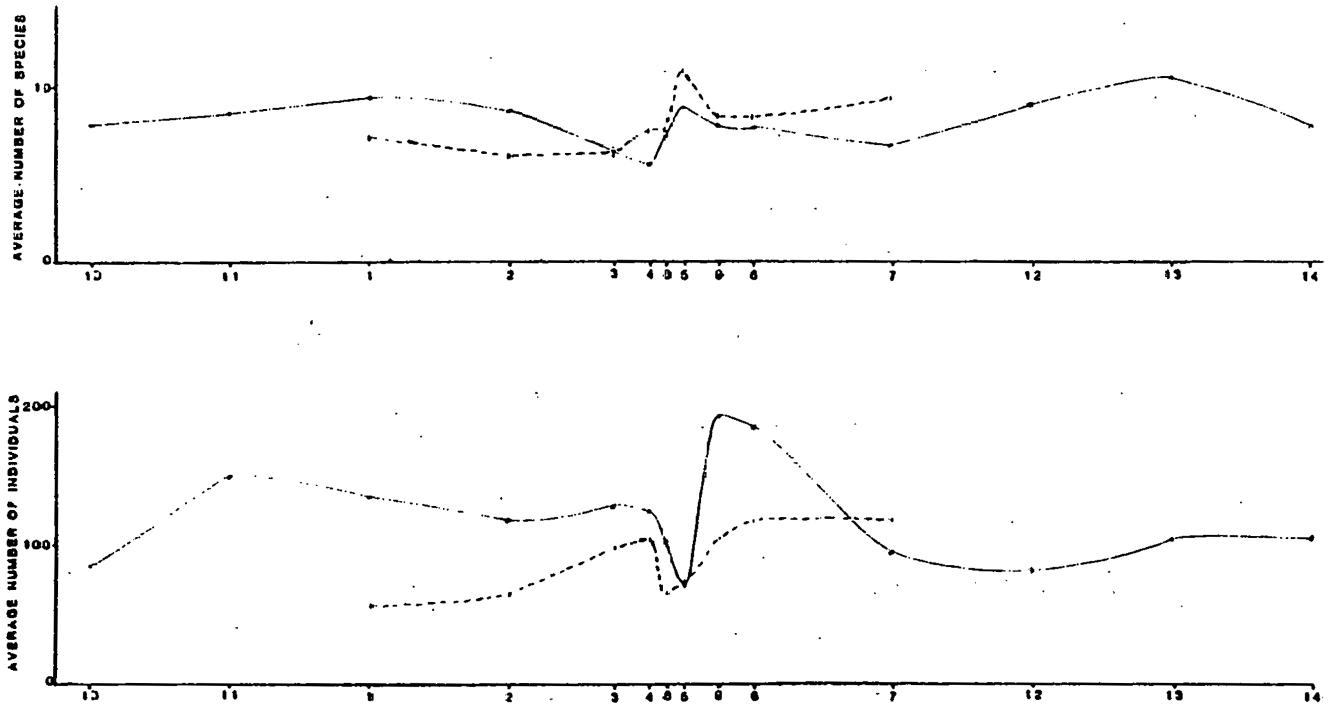


Figure 5-17. Average numbers of species and individuals at stations along transect A during lower flow rate (-----) and higher flow rate (———).

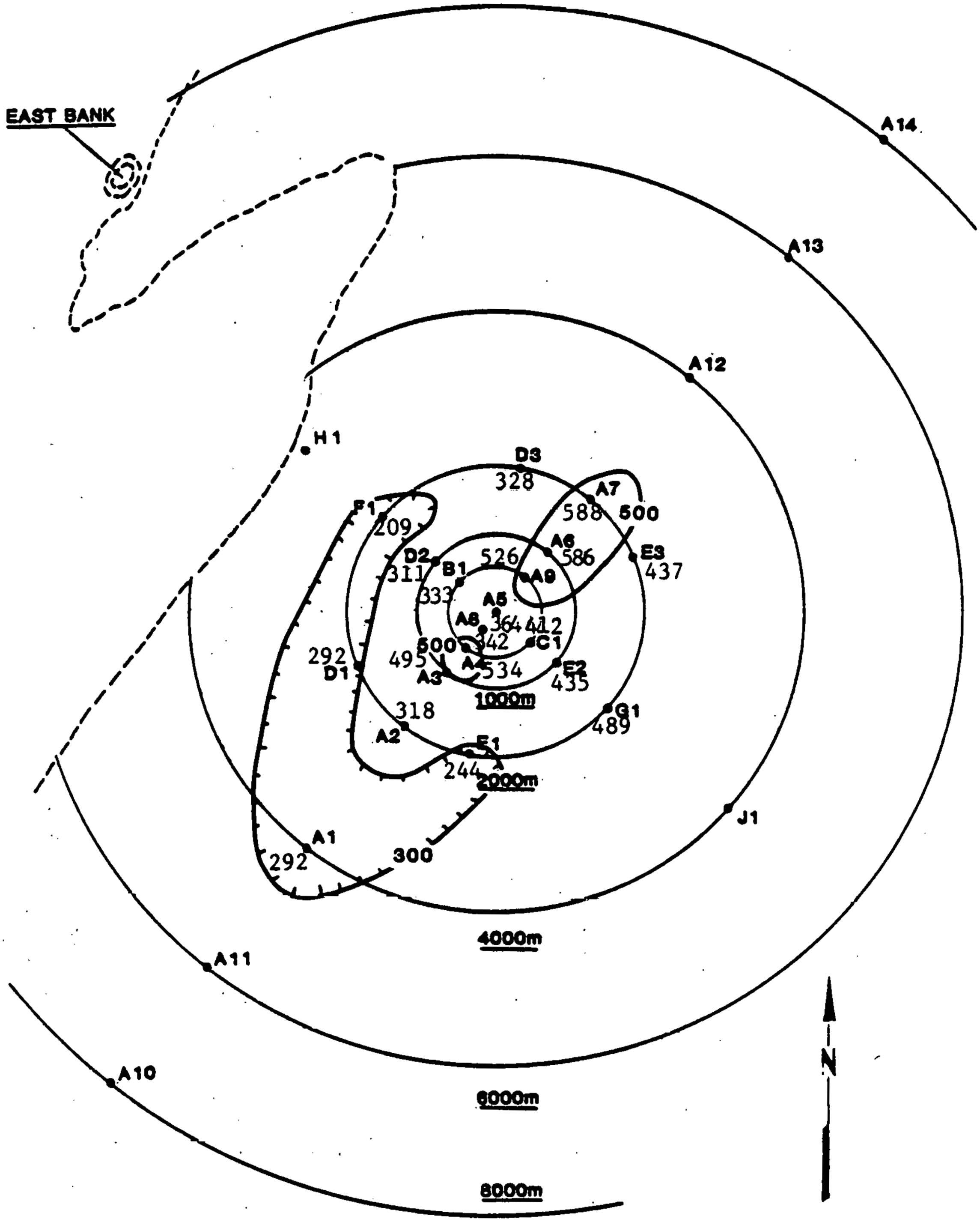


Figure 5-18. Areal distribution of total number of individuals during the lower flow rate (~600,000 barrels/day), December 1980 through November 1981.

southwest (A4) of the diffuser. A hook-shaped area of lower abundance lay toward the southern - western perimeter of the study area. Station A5, with 364 individuals, was included in the intermediate range of abundances.

The pattern was changed considerably during the higher flow rate period (Figure 5-19). Again, three somewhat arbitrary groups of stations could be established--those with <700 individuals, 700 to 1000 individuals and >1000 individuals. Greatest abundances were found in a crescent northeast - south of the diffuser in close proximity to the diffuser, and two isolated patches (A11 and H1). Stations with lower abundance did not occur together as they did during the lower flow rate period, but instead, occurred as 1 or 2 station patches. Station A5 had the second lowest number of individuals during the latter period.

Average numbers of individuals per A transect station clearly illustrate the depression in the vicinity of the diffuser, as well as the upcoast abundance peak (Figure 5-17). Note that during the lower flow rate period (which corresponds with the period of generally lower benthos abundances), two downcoast farfield stations had lower abundances than A5, whereas A5 had the lowest abundance during the higher flow rate period. It is also interesting to note that only station A5 had identical average abundances during the two periods.

5.4.2.6 Multivariate Analyses

Cluster analysis of quarterly data was performed on lower and higher flow rate data using 19 stations and on higher flow rate data using 26 stations (Figure 5-20). The lower flow rate (which coincided with low abundances) dendrogram shows nearfield and farfield stations intermixed with one another, with no apparent tendency for groups to form according

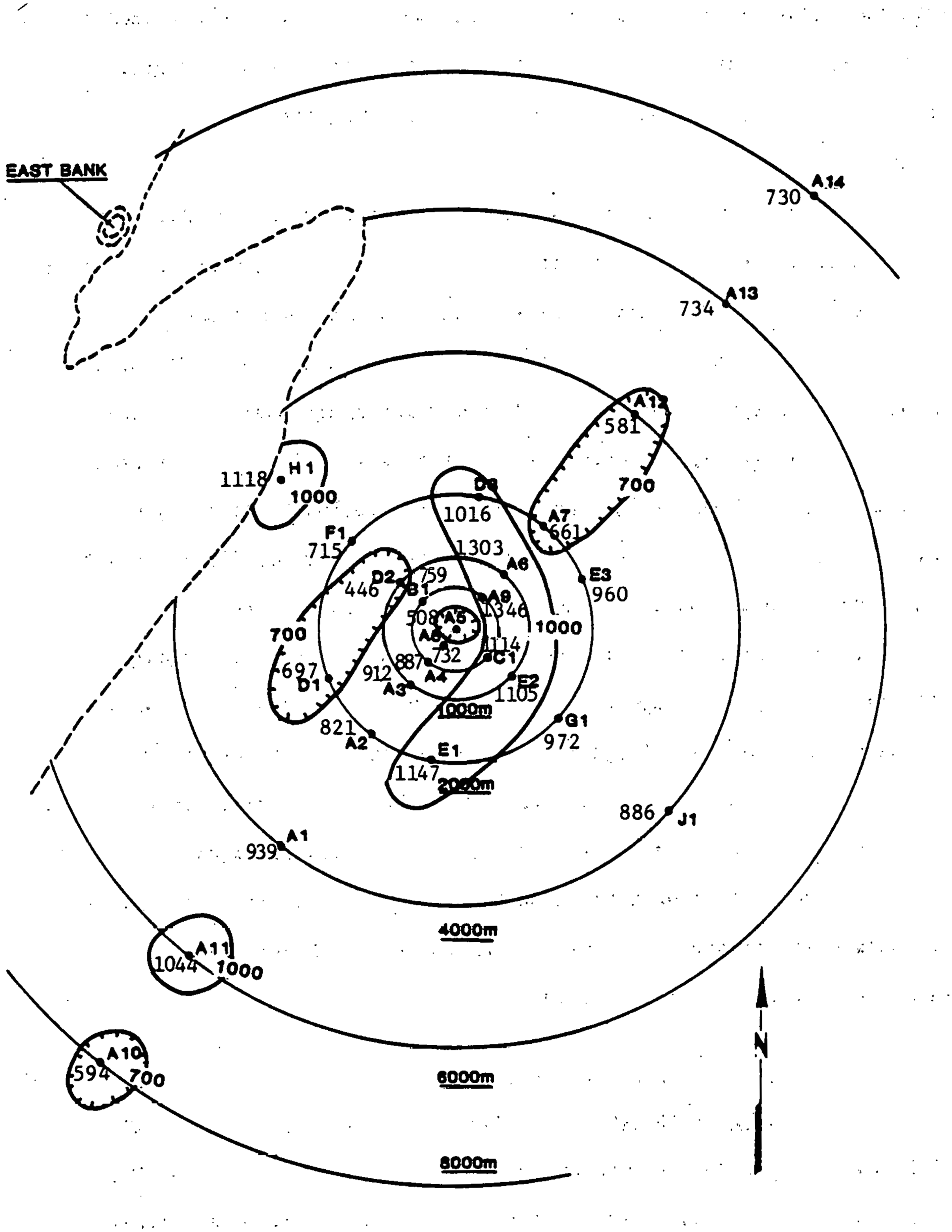
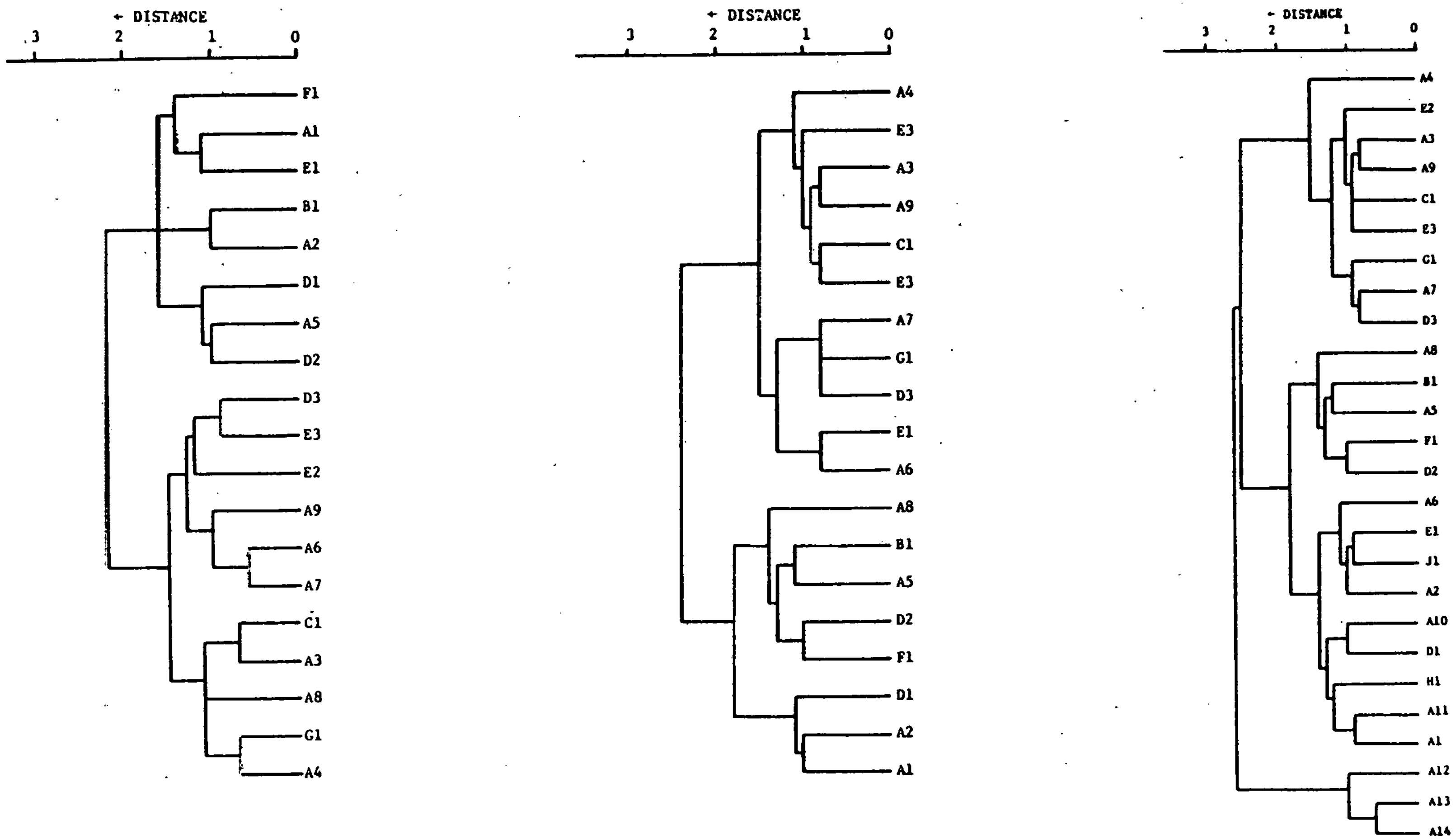


Figure 5-19. Areal distribution of total numbers of individuals during the higher flow rate (1,000,000 barrels/day), February 1982 through August 1983.



Lower Flow Rate
19 Stations

Higher Flow Rate
19 Stations

Higher Flow Rate
26 Stations

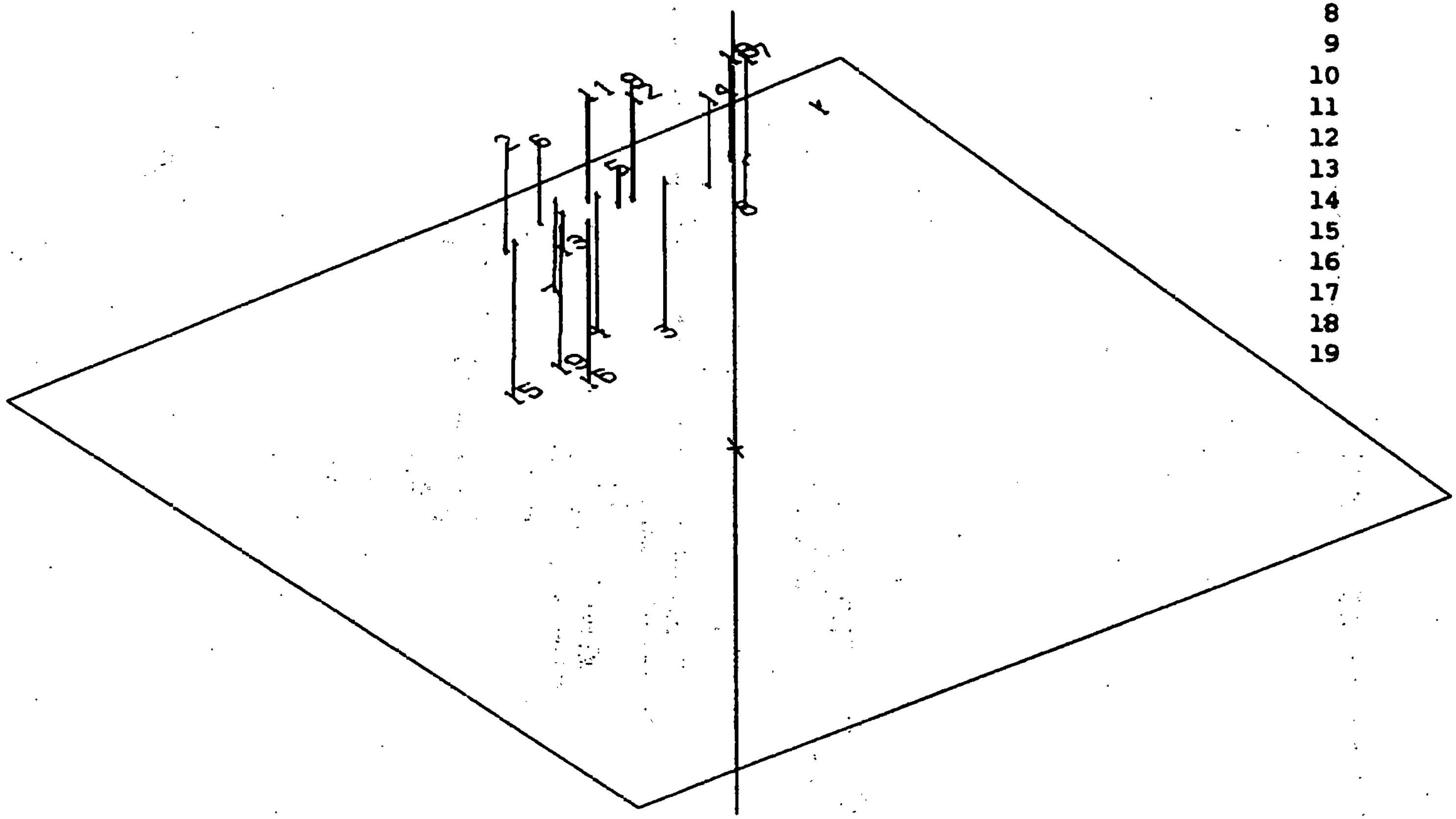
Figure 5-20. Station group dendrogram for lower flow rate 19-station data and higher flow rate 19- and 26-station data.

to proximity to the diffuser. Both higher flow rate dendrograms are similar. Nearfield stations A5, B1 and A8, and A9 and C1 clustered together, but were associated with intermediate and farfield stations. Also, all stations were fairly uniform in terms of similarity, suggesting that cluster analysis did not detect any effects due to brine.

Principal components analysis plots of lower (Figure 5-21) and higher (Figure 5-22) flow rate periods agreed with cluster analysis results. There was no tendency for nearfield stations to group out separately from the remainder of stations in the study area.

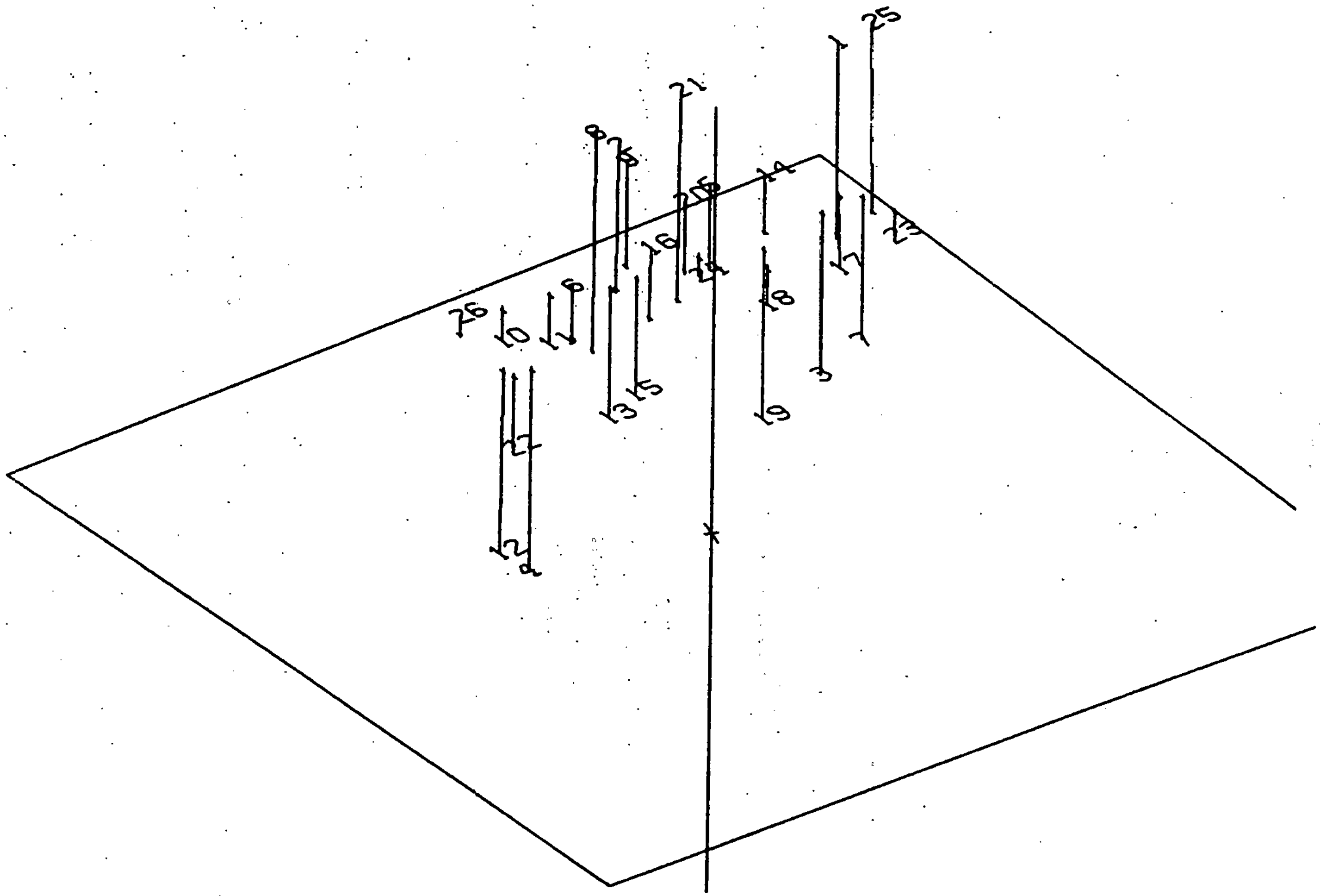
Discriminant analyses were performed on lower and higher flow rate abundance data (19-station data) using the following five abiotic variables: sediment temperature, salinity and mean grain size, and bottom water salinity and D.O. In both analyses, the first axis accounted for two-thirds of the variance in the system (Table 5-4). The most important abiotic variable was, however, different in the two analyses. During the lower flow rate period, sediment temperature accounted for 87% of the variance in axis 1, and thus accounted for a large proportion of the total variance in the system. Dissolved oxygen was important in axes 2 and 3, but only slightly more so than bottom salinity (axis 2) and mean grain size (axis 3). Overall, salinity appears to have been relatively unimportant.

During the higher flow rate period the primary variable in axis 1 was mean grain size (almost 55% of the variance) and the secondary variable was sediment temperature. Thus the most important variable in this system was much less dominant than the corresponding variable in the lower flow rate period. Pore water salinity appears to have been more important than in the previous period, accounting for about 51% of the variance in the



Number	Station
1	A1
2	A2
3	A3
4	A4
5	A5
6	A6
7	A7
8	D1
9	D2
10	D3
11	E1
12	E2
13	E3
14	F1
15	G1
16	A8
17	A9
18	B1
19	C1

Figure 5-21. Principal components analysis of quarterly data from the lower flow rate period, December 1980 through November 1981.



Number	Station
1	A1
2	A2
3	A3
4	A4
5	A5
6	A6
7	A7
8	D1
9	D2
10	D3
11	E1
12	E2
13	E3
14	F1
15	G1
16	A8
17	A9
18	B1
19	C1
20	A10
21	A11
22	A12
23	A13
24	A24
25	H1
26	J1

Figure 5-22. Principal components analysis of quarterly data from the higher flow rate period, February 1982 through August 1983.

Table 5-4. Comparison of discriminant analyses results from lower and higher flow rate periods. The heavy bar indicates the variable accounting for the largest amount of variance in that axis; the light bar indicates the variable accounting for the second largest amount of variance.

Percentage of variance in each axis

Axis	%	Axis	%
1	73.7	1	66.2
2	13.8	2	16.7
3	5.3	3	12.3
4	4.5	4	3.1
5	3.2	5	1.7

Percentage of variance/variable/axis - lower flow rate

Variable	1	2	3	4	5
Sed temp	78.0	5.0	6.6	2.9	2.5
D.O.	9.0	38.8	37.3	1.8	10.7
Pore sal	1.1	4.4	10.3	56.8	32.8
Bott sal	0.4	33.9	9.3	22.5	49.3
μ Grain	2.4	17.9	36.5	16.0	4.8

Percentage of variance/variable/axis - higher flow rate

Variable	1	2	3	4	5
μ Grain	54.8	27.9	2.5	12.1	1.6
Sed temp	20.6	8.8	62.4	3.6	5.7
Pore sal	3.2	50.6	1.1	11.9	28.6
Bott sal	7.5	0.4	4.3	70.3	13.7
D.O.	4.8	12.3	27.9	2.0	50.4

second axis. D.O. appears to have been the least important factor in the higher flow rate period.

Discriminant analysis suggests that, as in previous analyses, seasonal abiotic changes are tending to overshadow abundance changes caused by brine outflow. During the lower flow rate period, salinity was the important variable in axes 4 and 5 which accounted for relatively little (4.5% and 3.2%, respectively) of the variance in the system. During the higher flow rate period, salinity was somewhat more important, being the dominant variable in axis 2 (16.7% of the axis variance) and axes 4 and 5 (3.1% and 1.7%, respectively).

5.4.2.7 Statistical Analysis of Community Parameters

Previous statistical analyses of the various physical parameters affecting the benthos have indicated that changes in temperature, dissolved oxygen and, to some extent, salinity are strongly influenced by seasonal progression. These trends have tended to confuse analysis of brine effects within the study area. To minimize seasonality a number of approaches were used to separate seasonal from possible brine effects.

Quarterly data (November, February, May and August) from May 1980 forward were separated into control (D1, D3, A2, A7, G1, A6, and A3) and brine (A5, A4, A8, A9, B1, C1, and E2) stations. Choice of these station combinations was based on the results of past studies (Harper and McKinney, 1981b). These studies indicated that brine stations regularly fell within the brine plume and would therefore be more likely to reflect brine impact. Control stations were chosen because of their predisposal biologic and abiotic similarities to brine stations, proximity to their counterparts, and to have analyses based on equal numbers of stations (i.e. equivalent areal coverage, etc.). These data were then used to plot average numbers of individuals per meter squared over each of the quarterly periods (Figure 5-23). Using 95% confidence limits to define the range of variability it will be noted that although the brine means were always less than control means their range of variance overlapped in all cases. February and August were quarterly periods with widest intervals. May and November periods had considerably reduced ranges, and differences in controls and brines approached significance. To reduce the effects of this variance, particularly within the more variable quarters, a number of analytical techniques were used which reduced the effects of seasonality. Two aspects of community structure were emphasized for analysis: abundance and species diversity (H'). These two parameters are most readily comparable in analysis of the physical parameters affected by brine.

5.4.2.7.1 Salinity and Temperature Influences on Abundance

Regression models, using temperature and salinity observations, were run for several combinations of abiotic factors vs. biologic data. These models use recorded data to extrapolate to predicted values. Thus, maximum temperature and salinity values are above and below recorded values in all such figures. The data are presented as contour plots showing observed and predicted biologic data as functions of abiotic variables. The contour plots of benthic abundances relative to sediment temperature and salinity (Figure 5-24) indicate that the greatest numbers of individuals are found in a rather narrow salinity range (20 to 22 o/oo) but over a broad temperature range (8 to 36°C). Smallest abundances occurred in the highest salinity range. Bottom water data (Figure 5-25), conversely, indicated greater abundances over a broader salinity range (20

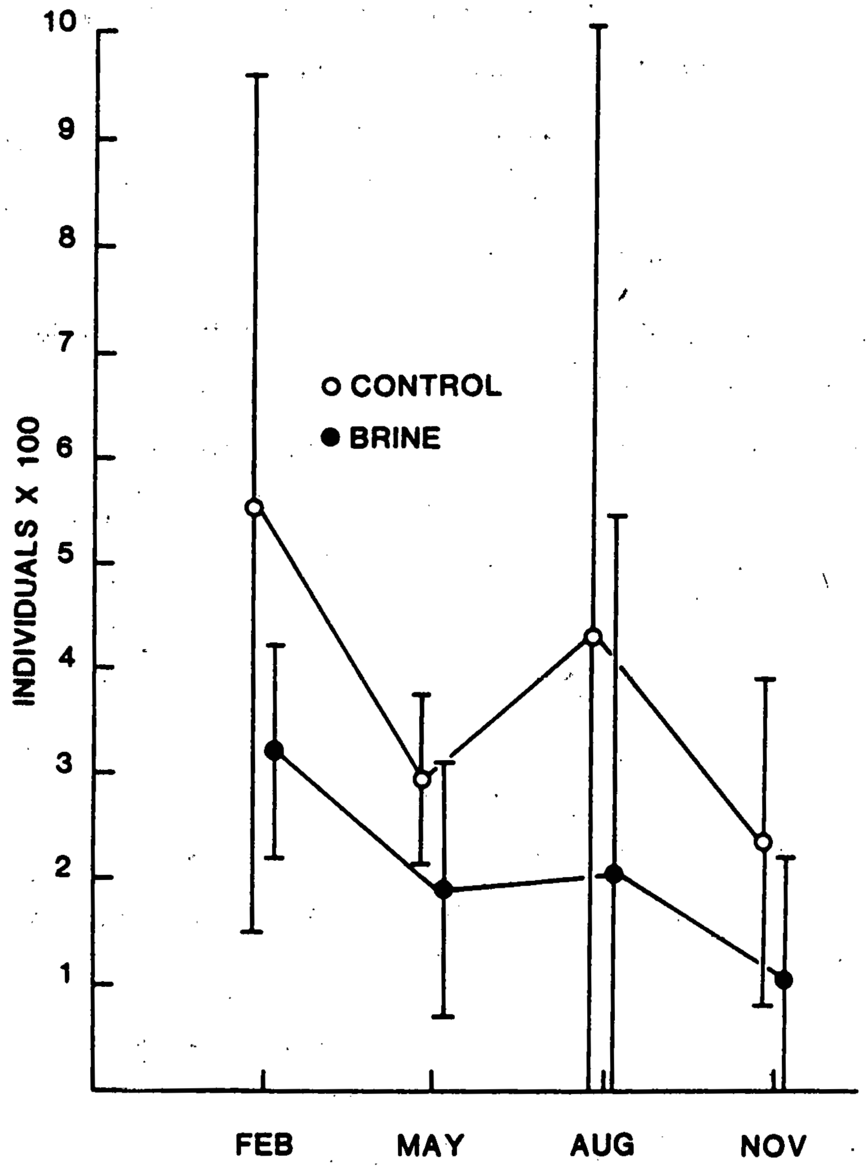


Figure 5-23. Compilation of postdisposal (May 1980 through Aug. 1983) abundances for selected brine (A5, A4, A8, A9, B1, C1 and E2) and control (D1, D3, A2, A7, G1, A6 and A3) stations. Bracketed lines delimit the 95% confidence limits at a = 0.05.

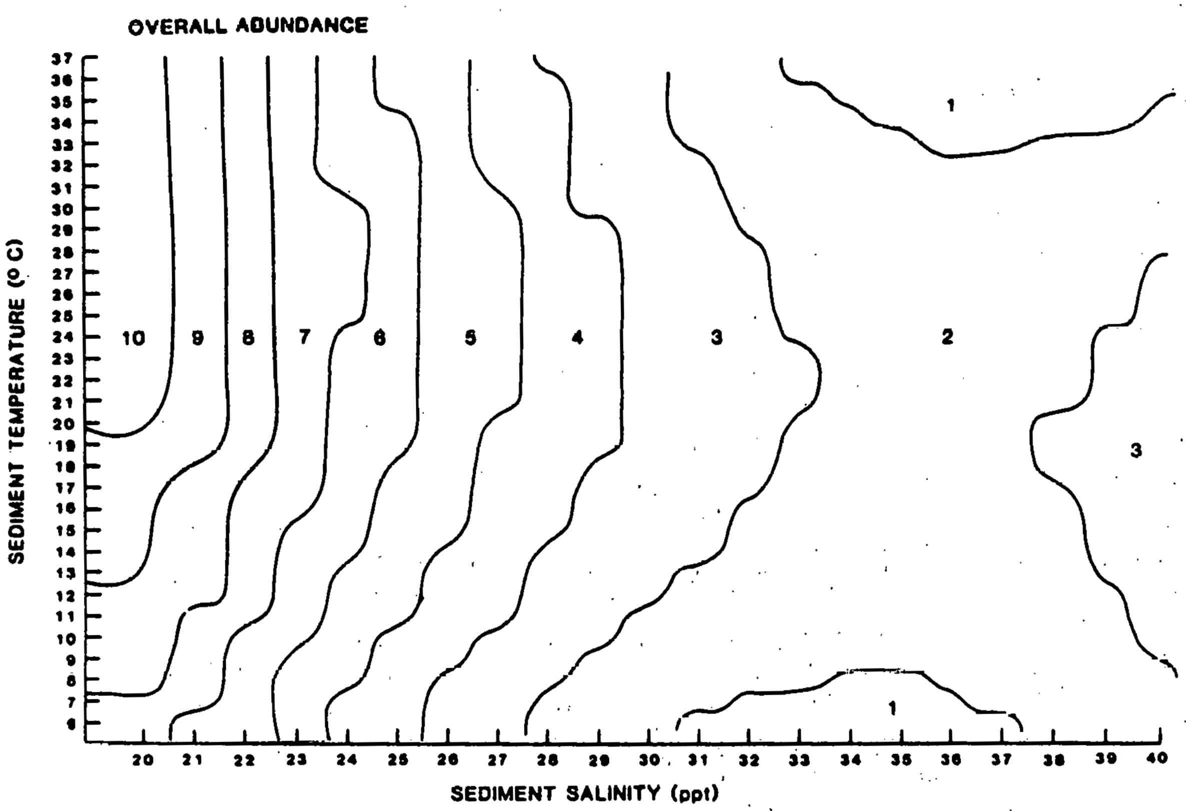


Figure 5-24. Contour plot of mean abundances over the range of sediment temperatures and salinities for the period of November 1982 to August 1983. The ten (10) delimits those temperatures and salinities in which mean abundances were the greatest. All rankings of contours are in descending order.

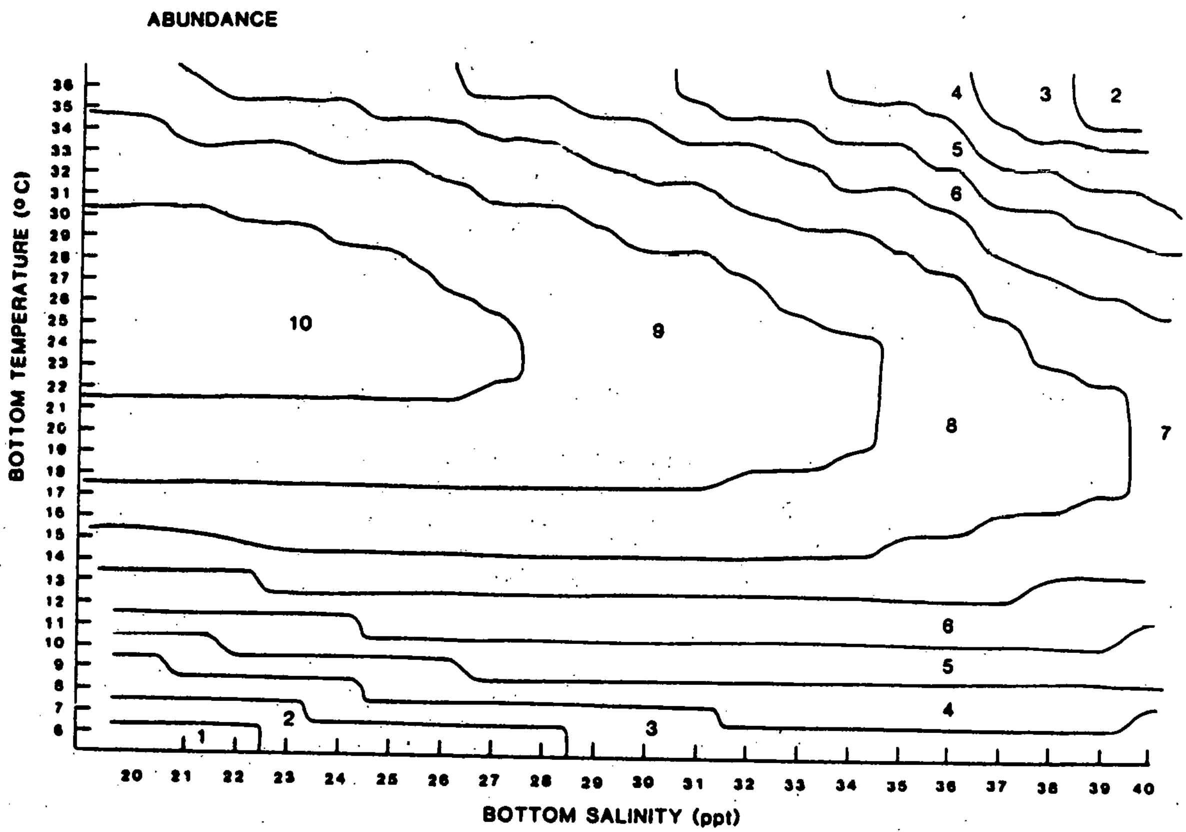


Figure 5-25. Contour plot of mean abundances over the range of bottom temperatures and salinities for the period of November 1982 to August 1983. The ten (10) delimits those temperatures and salinities in which mean abundances were the greatest. All rankings of contours are in descending order.

to 34 o/oo) and a more narrow temperature range (18 to 35°C). These trends were indicative of the relative stability of sedimentary salinities over time. Temperature appeared more seasonally responsive and less subject to fluctuation. Bottom salinity ranges appeared wider than that of sediment salinities due in part to brine plume influence, i.e. relative plume size, concentration, direction of flow, etc. Sediment salinities take longer to change because they respond more to the composition of the waters above the sediment than to rapid current shifts (Harper and McKinney, 1982).

5.4.2.7.2 Salinity and Temperature Influences on Species Diversity

As with abundance data Shannon diversity indices (H') were plotted against salinity and temperature gradients using a regression analysis model to produce a contour plot. The plot of all cruise data (November 1982 to August 1983) shows a rather limited range of high index concentrations (Figure 5-26). By plotting individual quarters, the influence of summer operative parameters becomes apparent. Hypoxic conditions developed in the study area during August. The effects were similar to those reported for the last hypoxic event: stratification of the water column, hypoxic bottom waters, dramatic decreases in benthos and nekton, etc. (Harper and McKinney, 1981b). Figure 5-27 contours, influenced by hypoxia, were similar to and a major influence on the overall contours (Figure 5-26). Contours of the other quarterly plots (Figures 5-28, 5-29 and 5-30) indicate a more seasonally influenced distribution. As temperatures increased with the season the highest levels of diversity moved with them over the entire range of salinities.

There were overriding seasonal influences on both abundances and

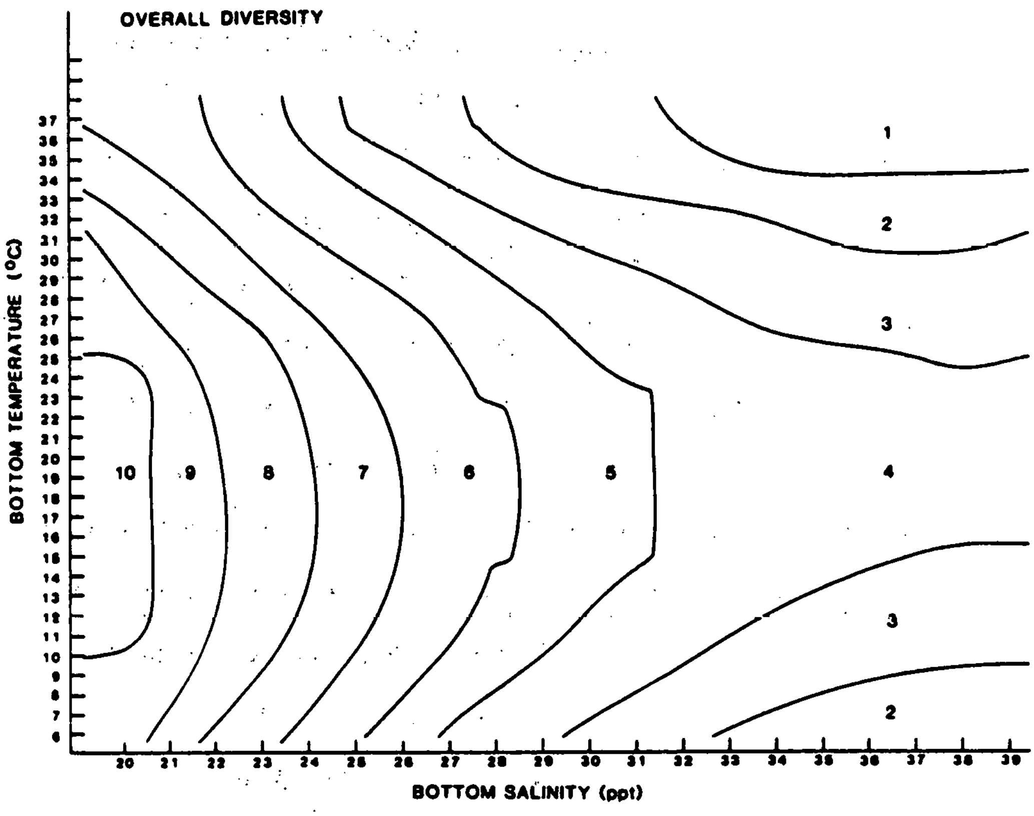


Figure 5-26. Contour plot of diversity indices over the range of bottom temperatures and salinities for the period of November 1982 to August 1983. The ten (10) delimits those temperatures and salinities in which diversity indices were greatest. All rankings of contours are in descending order.

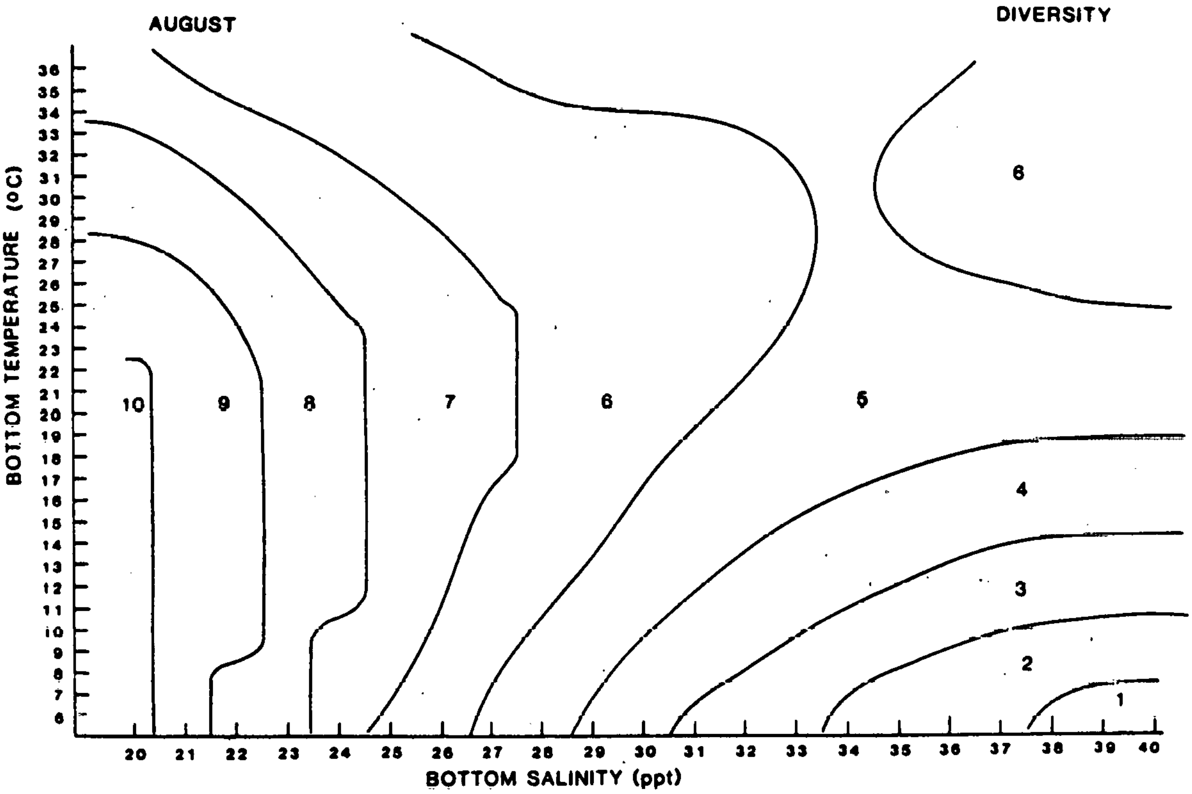


Figure 5-27. Diversity contours for August 1982. Numbers indicate the ranking of a particular contour as to range of diversity. Ten (10) delimits those temperature and salinity ranges in which the highest diversities (i.e. within stations) occurred. All rankings of contours are in descending order.

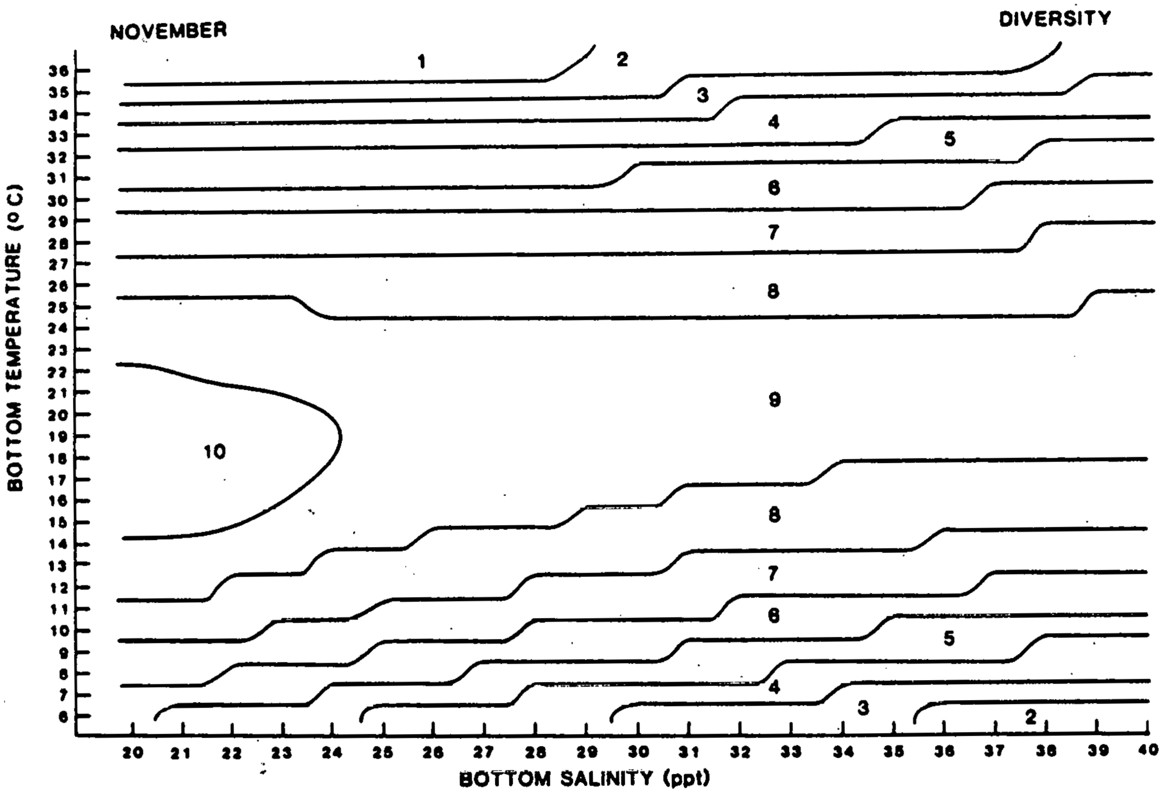


Figure 5-28. Diversity contours for November 1982. Numbers indicate the ranking of a particular contour as to range of diversity. Ten (10) delimits those temperature and salinity ranges in which the highest diversities (i.e. within stations) occurred. All rankings of contours are in descending order.

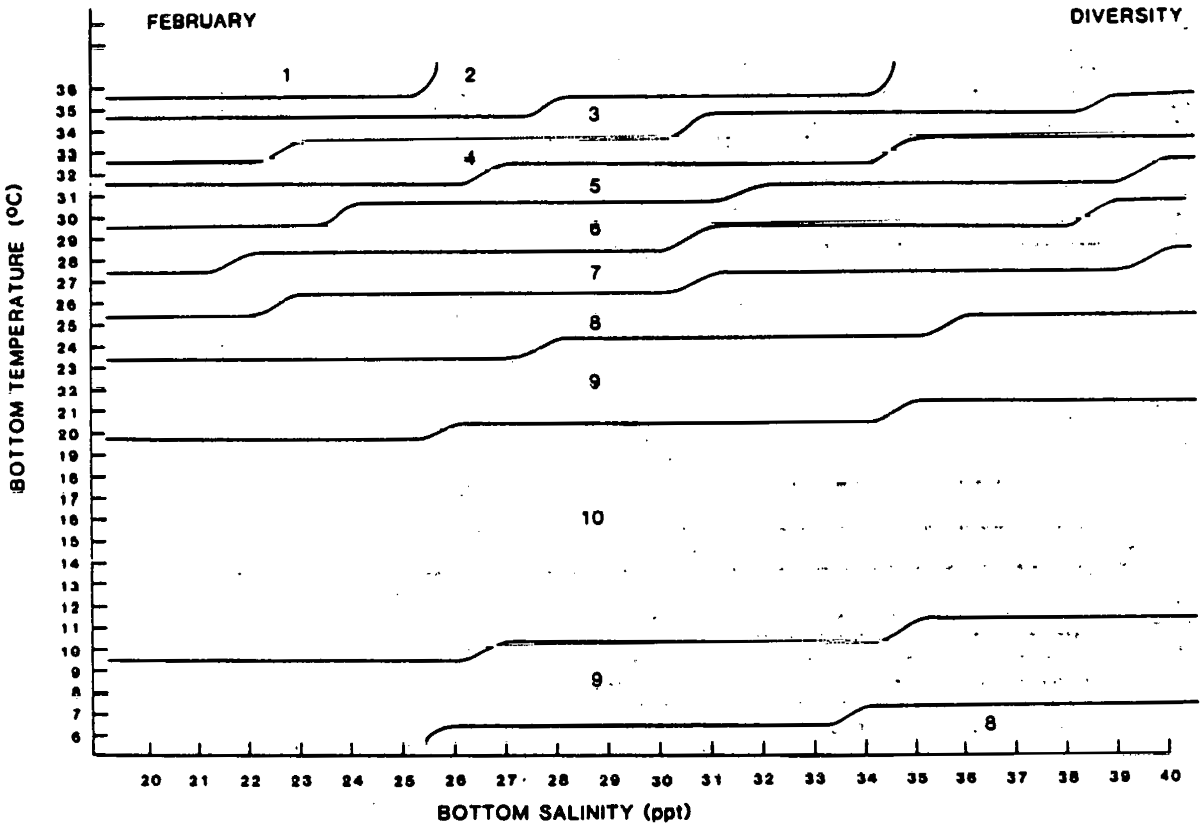


Figure 5-29. Diversity contours for February 1982. Numbers indicate the ranking of a particular contour as to range of diversity. Ten (10) delimits those temperature and salinity ranges in which the highest diversities (i.e. within stations) occurred. All rankings of contours are in descending order.

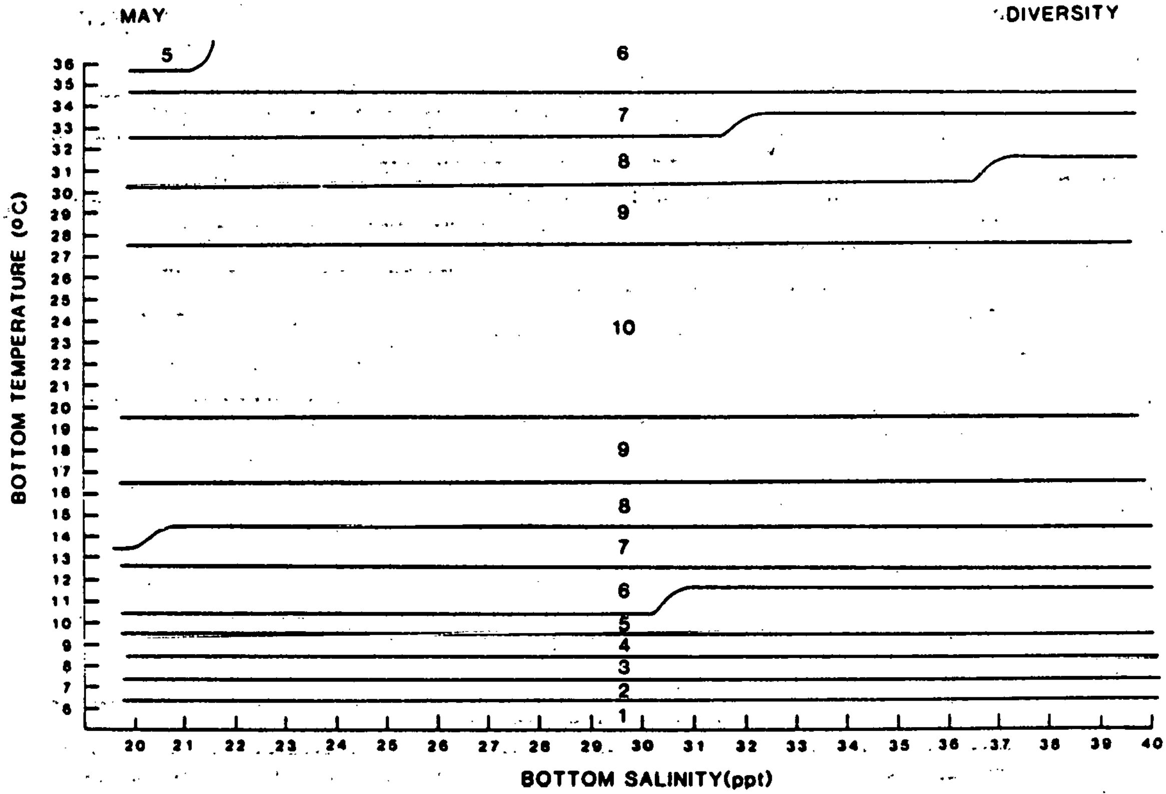


Figure 5-30. Diversity contours for May 1982. Numbers indicate the ranking of a particular contour as to range of diversity. Ten (10) delimits those temperature and salinity ranges in which the highest diversities (i.e. within stations) occurred. All rankings of contours are in descending order.

diversities when analyzed over time periods long enough for these patterns to develop. Analysis based on shorter time periods or based on physical parameters would therefore be more likely to show brine effects.

5.4.2.7.3 Salinity vs. Abundance/Diversity

Salinity data from each station and cruise were used to establish a range of salinity points against which abundance data could be analyzed. The resultant data were subjected to ANOVA procedures and Duncan's MRT. When all months (November 1982 to August 1983) were combined no significant differences in the abundance means were noted (PR > F = 0.87 at $\alpha = 0.05$). However, those stations with the greatest number of individuals were in the higher salinity ranges (37 to 38 o/oo). No significant differences were noted in analysis of individual quarters (PR > F = 0.29 in November, 0.91 in February, 0.41 in May and 0.41 in August at $\alpha = 0.05$).

Shannon diversity indices were calculated for station/cruise. These data were also compared with salinity ranges by ANOVA methods. When all months (November 1982 to August 1983) were combined no significant differences in abundances were noted (PR > F = 0.91 at $\alpha = 0.05$). No significant differences were noted when analyzed by quarters (Pr > F = 0.92 in November, 0.98 in February, 0.79 in May and 0.97 in August).

5.4.2.7.4 Distance vs. Abundance/Diversity

As previously described, the brine concentrations form a gradient (i.e. plume) from the diffuser. The plume extent and movement is controlled by currents and thus tends to sweep around the diffuser. Inclusion of benthic stations within this plume is dependent on current conditions, discharge rate, etc. Stations closer to the diffuser are more regularly and consistently impacted by brine than stations further away (due to plume movement and dilution). Benthic stations were therefore divided into a series of rings of increasing distance from the diffuser. Stations A4, A5, A8, A9, B1 and C1 were designated distance 1 (within 500 m). Stations A3, A6, D2 and E2 were designated distance 2 (1000-meter ring). Stations A2, A7, D1, D3, E1, E3, F1 and G1 were designated distance 3 (2000-meter ring). Stations A1, A12, H1 and J1 were designated distance 4 (4000-meter ring). Stations A11 and A13 were designated distance 5 (6000-meter ring), and stations A10, A14 were at distance 6 (8000-meter ring).

The initial analyses by ANOVA and Duncan's MRT's which combined all data indicated no significant differences in mean abundances from distance 1 (500 and less) to distance 6 (8000 m). At the $\alpha = 0.05$ level $Pr > F = 0.74$ (Figure 5-31). The 4000-meter ring (distance 4) had the greatest means followed by the 2000-meter, 1000-meter and 500-meter rings (none significantly different).

Analysis of individual quarters indicated that an effect associated with distance approached significance in the first half of the study year (Figure 5-31). In November of 1982, mean abundance at distances 6 (8000 m) and 4 (4000 m) were not significantly different from each other but were not truly significantly different from the other distances because of the overlap at distance 4. In February distances 4 and 5 were significantly different from each other, but again group overlap prevented establishment of distinctly significantly groups. In both November and February, diffuser stations were intermediate in mean abundances. ANOVA's for May and August, however, indicated no significant differences associated with distances.

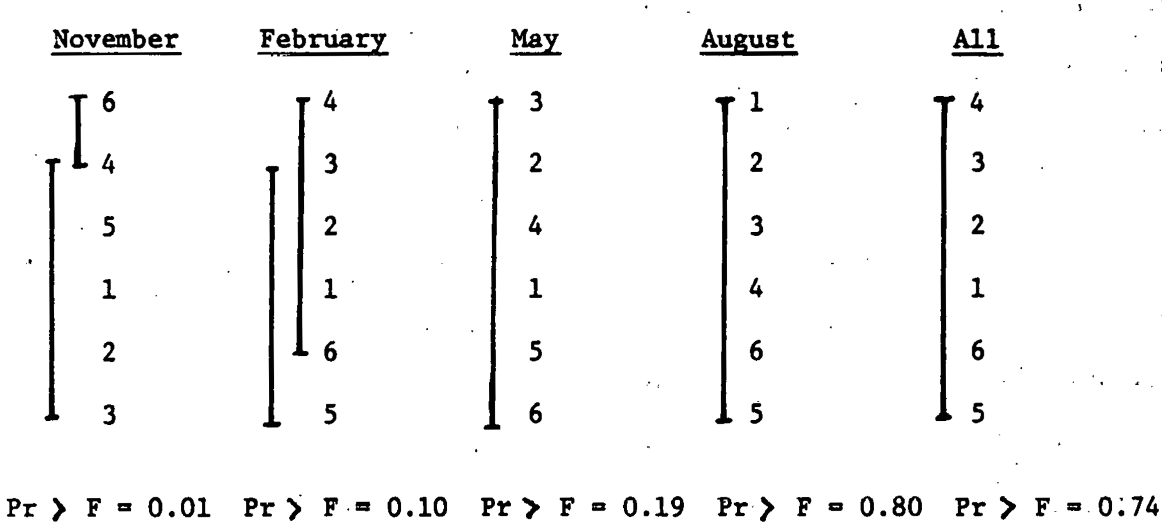


Figure 5-31. Results of Duncan's MRT's with abundance data. Numbers represent distances: 1 = 500 m or less, 2 = 1000,; 3 = 2000 m, 4 = 4000 m, 5 = 6000 m and 6 = 8000 m. *'s enclose those means which do not vary significantly ($\alpha = 0.05$).

If brine was adversely affecting benthic population levels in the immediate diffuser area, the inner rings should have had the lowest mean abundances. In actuality the farthest rings had lowest mean abundances in three of the four quarters. This may be a real low abundance or an artifact of both rings 5 and 6 having only two stations each. The only quarter in which these two rings were not at the bottom of the abundance hierarchy was November, the month with lowest overall abundances. The distance rankings are apparently not a function of sediment differences. Duncan's MRT comparing mean grain size vs. distance indicated there was no significant difference between distances.

In February and May quarters, months with greatest overall abundances, the inner ring of stations had the lowest mean abundance of the rings with at least four stations. The high abundances recorded in May were mostly due to large populations of the amphipod crustaceans, Ampelisca spp., a group noted for their sensitivity to pollution.

In August, it is probable that several factors caused an apparent reversal in the hierarchy, resulting in the inner ring distances having the greatest mean abundances. First, hypoxic or near-hypoxic D.O. values were detected by other investigators early in August. Based on past data (Harper and McKinney, 1980) this may have reduced the the benthic densities overall (and in fact, August total abundances were second lowest after November), reducing differences between distances. Also complicating the August data analysis was the passage of Hurricane Alicia on August 17, 1983. Because of the hurricane, diffuser operations were shut down for four days from August 17-20 and had not returned to pre-hurricane discharge rates when the sampling cruise occurred on 26 August. This reduction in output, coupled with a very evident shift in grain size to silt-clay at most stations, may have made the near-diffuser bottoms more hospitable for benthic species, at least temporarily.

Shannon diversity index (H') was also compared with distance using the same procedures as with abundance data (Figure 5-32). No significant differences were noted in November (PR > F = 0.17). Distance 1 (near-diffuser) stations, however, had the lowest average H' values. Distance 6 stations (8000 m) and distance 4 stations (4000 m) had the highest average indices. Within the remaining three quarters, means at the various distances approached significance, with truly significant groups being ruled out by group overlap. Distance 1 stations had the lowest H' in all analyses. The greatest H' usually occurred at the 4000-meter or 6000-meter stations.

ANOVA's of abundances and diversity over a range of salinities and distances indicated that H' may be the better indicator of brine impact if other analytical techniques ,i.e. cluster analysis, ordination, etc. indicate little differences in species composition between stations, and if sediments are relatively uniform. Diversity indices were depressed in the immediate area of the diffuser over the period of November 1982 through August 1983. A more detailed analysis of this community parameter would therefore be warranted.

5.4.2.7.5 Species Diversity and Taxonomic Composition

Species diversity, as expressed by the Shannon index, relates species richness as a function of occurrence, the resultant relationship being expressed as a single number. Some brine effect was detected in the diffuser stations which indicated an alteration in those relationships. Table 5-5 breaks the species composition of the ninety percentile group

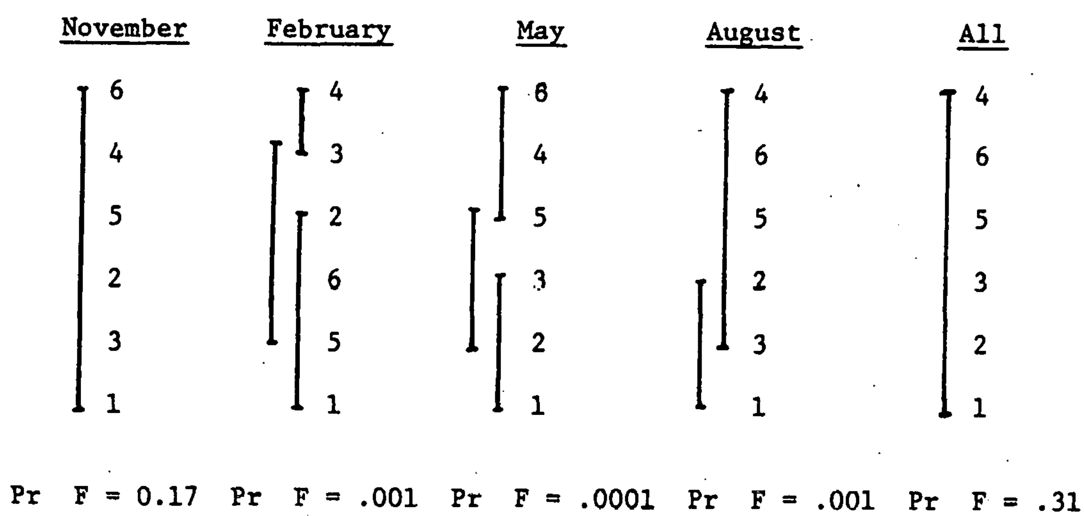


Figure 5-32. Results of Duncan's MRT's with Shannon's diversity indices. Numbers represent distances: 1 = 500 m or less, 2 = 1000 m, 3 = 2000 m, 4 = 4000 m, 5 = 6000 m and 6 = 8000 m. *'s enclose those means which are not significantly different (α = 0.05).

Table 5-5. Summary of taxonomic composition, 90 percentile group.

	Station	Total Taxa	Polychaeta	Crustacea	Mollusca	Other
Dec 1977 - Feb 1980 Predisposal Period	All	31	24	5	1	1
	Control	28	21	4	1	2
	Brine	26	17	5	1	1
May 1980 - Aug 1983 Postdisposal Period	All	31	21	6	1	3
	Control	31	20	7	1	3
	Brine	25	16	6	1	2
Feb 1981 - Nov 1982 Low Abundance Period	All	26	17	5	1	3
	Control	20	15	3	1	1
	Brine	27	18	5	1	3
Feb 1982 - Aug 1983 High Brine Flow Period	All	44	25	9	6	4
	Control	30	19	9	0	2
	Brine	18	13	2	1	2
Nov 1982 - Aug 1983 Current Report Period	All	41	28	7	3	3
	Control	28	21	3	0	4
	Brine	18	13	3	0	2

into major taxonomic units of Polychaeta, Crustacea and Mollusca. The ninety percentile group refers to those species whose occurrence accounts for 90% of those individuals collected in a specific period.

Species diversity based on these data were analyzed within various time periods using all stations, brine stations and control stations as subgroups. During the predisposal period (December 1977 to February 1980) brine and control stations were roughly equivalent in diversity. The 90% group for brine stations had 26 species and the control stations had 28 species. When all data were combined, 31 species comprised the 90% group. The combined postdisposal period (May 1980 to August 1983) showed little difference (from predisposal) in species diversity, i.e. 31 species in the combined 90% group. Control station species were somewhat greater (31 species) than brine stations (25 species).

When the postdisposal period was divided into sequences which reflected unusual seasonal trends and/or discharge activity, brine effects became more distinct. During February to November 1981 very low abundances occurred throughout the study area. During this period brine station had more species (27) in the 90% group than was recorded for control stations (20 species). This was the only period in which brine stations showed a higher diversity than controls. The February 1982 to August 1983 period, for example, was one in which control stations had 30 species and brine stations had only 18 species in the 90% group. This period also coincided with the increase of brine flow to the million barrel/day rate. Data from November 1982 to August 1983 (the current report period) also indicated the H' was reduced in the vicinity of the diffuser.

Changes in diversity are indicative of different species responses to changing conditions (biotic or physical parameters). An examination of the major taxa comprising the 90 percentile group is demonstrative of this point. Table 5-6 lists those polychaete species which occurred in the 90% group over the duration of the study. The top 15 species (P. pinnata through G. americana) have occurred with great regularity throughout the project. The majority of these species are surface and subsurface deposit feeders. Many of the less frequently occurring species (within the 90% group) were omnivores or carnivores. These species were chiefly responsible for the increase in species diversity at control stations (Table 5-5). Examples of these species include Pseudeurythoe ambigua, Sthenelais limicola, Diopatra cuprea, and Lumbrineris ernesti. A greater number of predators could be expected as a response to greater numbers of prey. As indicted by the distance analysis (of abundances) those stations with significantly greater mean abundances were outside the diffuser ring of stations. Even within the overall analysis of distance (November 1982 to August 1983) distances 2, 3 and 4 of (1000 to 4000 m) had the greatest mean numbers of individuals. Such a larger base population would support a larger number of predaceous species. This appeared to be the case in the study area and would explain an increasingly diverse community structure outside the immediate diffuser area.

Within the Crustacea (Table 5-7) some increase in species diversity could also be noted but their contribution to diversity analysis by ANOVA procedures appears limited. There have, however, been some species shifts within similar habitats. The Ampelisca species were a primary example. Ampelisca abdita, common through 1981, was replaced by Ampelisca agassizi in 1982. The general lack of Crustacea from August 1981 to February 1982 (Ampelisca included) coincided with the generally low abundance period.

Table 5-6. Commonly occurring polychaetes. The presence of a polychaete species in the 90 percentile (based on total species) during a quarterly sampling period as indicated by an X. F - February, M - May, A - August, N - November.

Species	1979				1980				1981				1982				1983		
	F	M	A	N	F	M	A	N	F	M	A	N	F	M	A	N	F	M	A
P. PINNATA	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
N. MICROMMA	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
M. PHYLLISAE	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
A. MACULATA	X		X	X	X		X	X	X		X	X	X	X	X	X	X	X	X
L. VERRILLI	X	X	X	X	X	X	X	X	X	X	X			X		X	X	X	X
C. DELTA	X		X	X	X	X	X	X	X	X	X		X	X		X	X	X	X
P. CRISTATA	X			X	X	X	X	X	X	X						X	X		
A. FINITIMA (cf)	X	X			X	X	X		X	X	X						X		
P. CIRROBRANCHIATA	X			X	X	X		X	X							X			
M. CALIFORNIENSIS				X	X	X	X	X	X	X	X			X		X	X	X	X
N. NIGRIPES				X	X	X	X			X	X	X		X		X	X	X	X
N. INCISA				X	X	X	X	X	X	X	X				X	X	X		
S. TENTACULATA				X			X				X	X	X	X	X	X		X	X
C. OCULATA		X			X	X				X						X	X		
G. AMERICANA		X			X	X			X		X					X		X	X
T. MARIONI					X	X		X	X		X					X	X		
P. PYGMAEA					X														
A. FRAGILIS					X	X	X	X			X			X		X			
S. LIMICOLA					X			X	X				X	X	X		X	X	
A. TAYLORI						X		X											
A. SIMPLEX						X													
L. ERNESTI						X	X	X	X	X	X			X	X	X	X	X	X
N. LAMELLOSA							X							X					
D. CUPREA									X	X					X	X	X	X	X
N. LATERICEUS										X									
M. CINCTA										X	X					X			
P. AMBIGUA																X		X	X
P. CIRRIFERA																X	X		
G. BREVIPALPA																X			
T. GRACILIS																X			
N. DAUERI																X			
C. TORQUATA																X			
A. JONESI																X			
G. SOLITARIA																		X	X

Table 5-7. Commonly occurring crustaceans. The presence of a crustacean species in the 90 percentile (based on total species) during a quarterly sampling period as indicated by an X. F - February, M - May, A - August, N - November.

Species	1979 F	1979 M	1979 A	1979 N	1980 F	1980 M	1980 A	1980 N	1981 F	1981 M	1981 A	1981 N	1982 F	1982 M	1982 A	1982 N	1983 F	1983 M	1983 A
A. ABDITA	X	X		X	X	X	X	X	X	X				X			X		
A. AGASSIZI	X	X					X		X	X				X	X	X	X	X	X
A. VERRILLI	X						X	X	X	X							X		
P. MACROMANUS	X																X		
PINNIXA B	X																		
P. SAYANA				X		X										X			
S. LOBATUS				X							X	X			X	X			
A. EVERMANNI				X			X	X			X				X	X	X		
PINNIXA (BUL ROS)										X					X				
M. EDWARDSI							X												
T. SIMILIS							X			X	X					X			
A. FLORIDANUS											X					X			
C. ACHERUSICUM																X			
L. SERRATORBITA																X			

Details of this period are discussed in other benthos sections and in previous reports (Harper and McKinney, 1983). Ampelisca will be discussed in detail in later sections.

The 90% group of Mollusca and Nemertinea are listed in Table 5-8. Nemertean species, which are major infaunal predators, responded to population levels much as did the predaceous polychaetes, i.e. cyclic with seasonal changes and differing concentrations of prey. Mollusca, with large numbers of planktonic larvae generally appeared in the 90% group if, and when, a large number of them settled within the sampling area.

Examination of all three tables listing 90% occurrences shows a steadily increasing number of species within these classifications. It is important to note that the November 1982 column, in all tables, was responsible for the addition of many species not seen before or since that quarter. Unusually low numbers of individuals were also noted during that period. The dominant species, while present, were greatly reduced in overall abundance. Some marginally numerous species (i.e. generally outside the 90% group) were included as a result. Nonetheless, an analysis of Control and Brine stations, as given previously in Table 5-5 shows that following brine discharge there has been a general and significant decrease in species diversity around the diffuser.

5.4.2.7.6 Responses to Brine by Taxonomic Groups

General responses of the major taxa within the study area (i.e. Polychaeta, Crustacea, and Mollusca) have been discussed in previous reports as well as preceding sections. The polychaetes and other vermiform organisms appear to be more resistant to pollution and/or environmental extremes than other groups (Harper and McKinney, 1981b). Individual species responses may differ as some can be adversely affected

Table 5-8. Commonly occurring nemertean and mollusks. The presence of nemerteans and mollusks species in the 90 percentile (based on total species) during a quarterly sampling period as indicated by an X. F - February, M - May, A - August, N - November.

	1979				1980				1981				1982				1983		
NEMERTEAN SPP.	F	M	A	N	F	M	A	N	F	M	A	N	F	M	A	N	F	M	A
C. LACTEUS	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NEMERTEA (Y.B.)	X			X	X		X			X	X			X		X	X	X	X
NEMERTEA (W.)				X	X		X			X	X					X			X
MOLLUSK SPP.																			
C. OPERCULATA			X												X				
C. BARRATTIANA			X	X															
A. AEQUALIS			X				X								X	X			
T. VERSICOLOR				X	X						X	X							
N. CONCENTRICA				X							X								
N. PUSILLA							X	X	X		X					X			
T. PROTEXTA														X		X	X		
N. ACUTA																X			
V. HELICOIDEA																X			
NUDIBRANCH (B.S.)																X			
BIVALVE (UNID.)																X			
L. PELLUCIDA																X			

while others respond positively (i.e. dramatic population increases = blooms) and have been labelled as indicator species. Mollusk larvae appear respond to increased salinity. The use of salinity gradients as a settling cue is well known among the Mollusca. This may be their chief response to brine in the study area (Harper and McKinney, 1980). The Crustacea are generally adversely affected by pollution and environmental extremes. They, as with some polychaetes, have been used as pollution indicators in numerous situations.

5.4.2.7.7 Crustacean Responses to Environmental Extremes

Although most of the crustacean populations within the study area appear to fluctuate with seasonal and environmental stress, the Amphipoda, *Ampelisca* specifically, respond more readily than do other taxa (Mackin 1971; Harper and McKinney 1980).

The *Ampelisca* within the study area were composed of a mixture of three species, *A. abdita*, *A. agassizi*, and *A. verrilli*, through 1980. Following the low abundance year of 1981 *A. agassizi* became the dominant *Ampelisca*. These shifts were due more to competition between these species than any other factor. All are colonial tube-dwellers which can form mats of tremendous area (hundreds of square meters). Competition for space is therefore keen and once a colony becomes established it tends to spread outward absorbing smaller adjacent colonies regardless of species. Samples can thus contain almost any combination of species although one would most likely dominate a specific area.

Because they are colonial and lack planktonic larvae, they tend to exhibit tremendous spring population increases (i.e. reproductive response) which provide adults for emigration to new areas, replacement of the overwintering population (their progenitors) and adults for a fall reproductive period. Such a population peak was first noted in the spring of 1979. Hypoxia during the summer of that year all but eliminated the Ampelisca. Recovery was prolonged because environmental factors (other, though minor, hypoxic events) as well as biotic factors (general population depression of 1981) in following years adversely affected these sensitive organisms.

Another population peak, similar in size to that of 1979, developed in the spring of 1983. The peak apparently occurred prior to the May quarterly sampling as populations appeared widely distributed and well established by May. The distribution of Ampelisca species for May is presented in Figures 5-33 and 5-34. The Ampelisca appeared concentrated in the ring of stations just outside of the diffuser area. Diffuser stations generally had population levels of an order of magnitude less than the immediate outer rings. Levels also dropped off with increasing distance from the diffuser (i.e., the more distant rings) but were not as low as at diffuser stations (Figure 5-35).

One factor considered contributory to such a distribution (other than brine influence) would be sediment preference. The Ampelisca appear to prefer the larger grain sizes (i.e. sand) over smaller more compact sediments. ANOVA and Duncan's MRT analysis of sediment/abundance data reflected the distributional pattern (Figure 5-36). Following a mild winter the seasonal increase in the benthos became apparent. In February, greatest numbers of individuals were found in the 6 to 8 ϕ silt stations polychaetes were the dominant taxon, subsurface deposit feeders and predatory species in particular. These organisms prefer silty-type sediments in general. Ampelisca agassizi was also quite numerous. By May

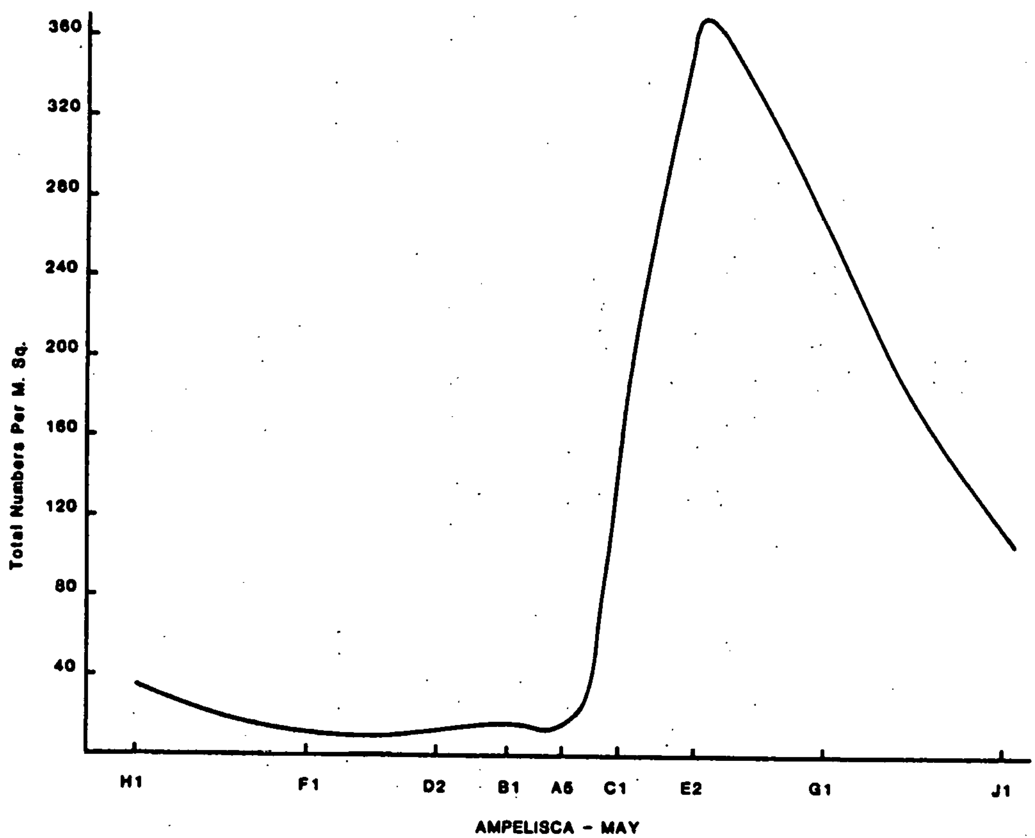


Figure 5-33. Total numbers of <u>Ampelisca</u> per square meter along the transect perpendicular to the shoreline.

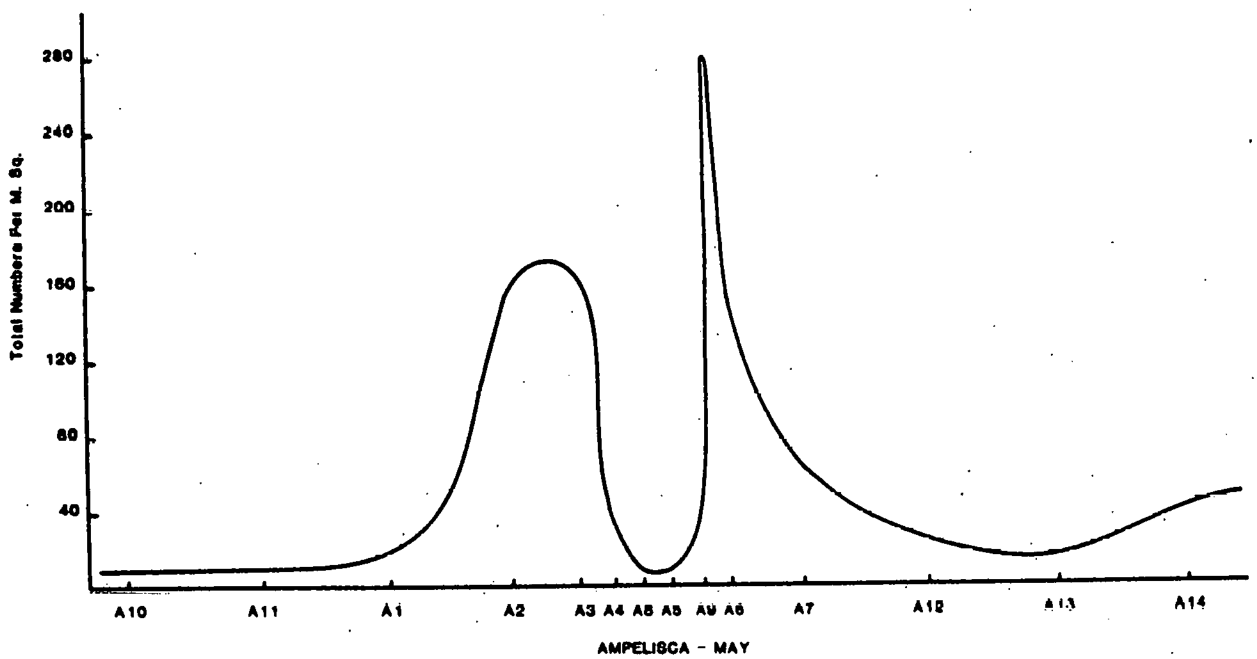


Figure 5-34. Total number of Ampelisca per square meter along the A transect for May 1983. The A transect is otherwise termed the longshore transect.

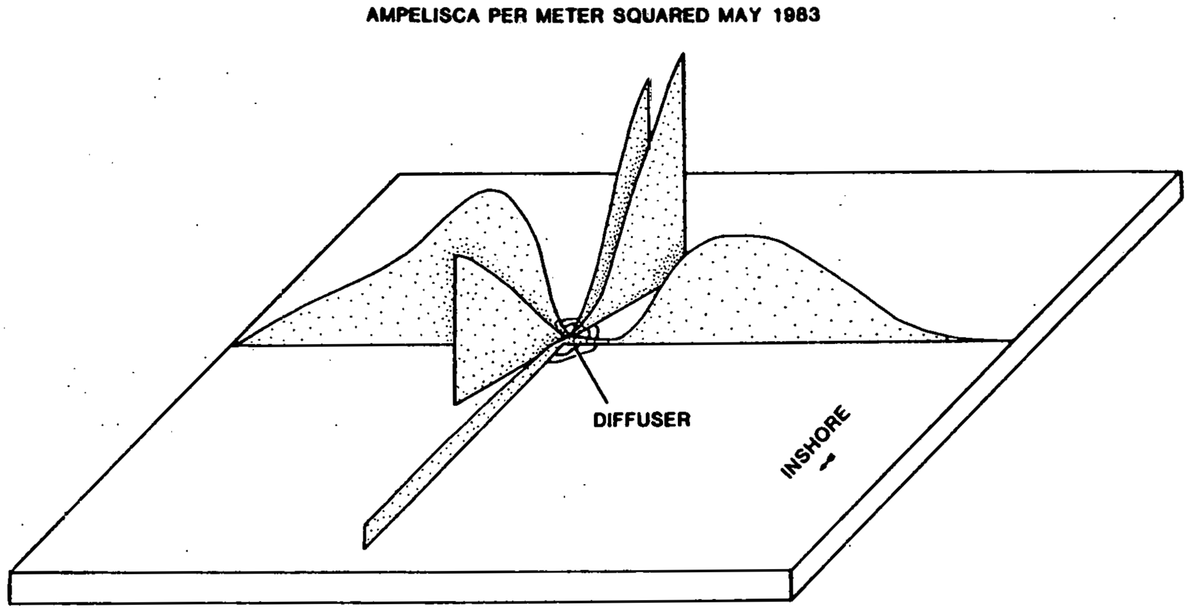


Figure 5-35. Graphic representation of Ampelisca abundances around the diffuser. Rings around the diffuser approximate the +3 and +4 bottom salinity contours.

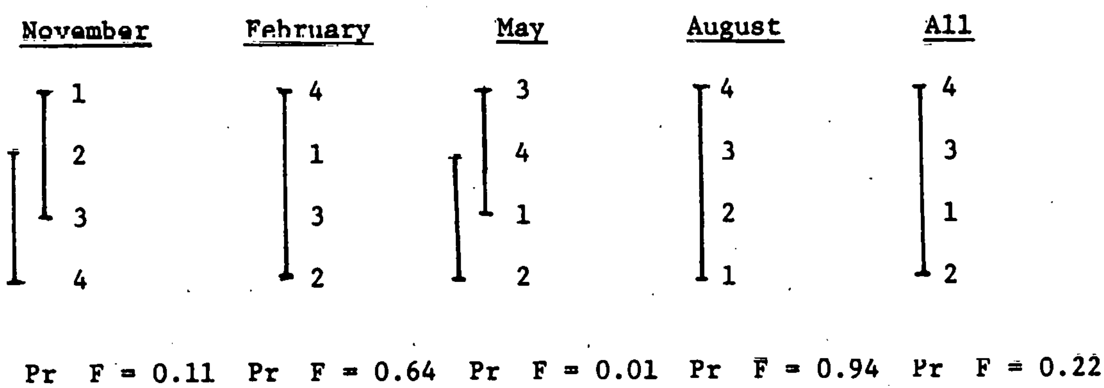


Figure 5-36. Results of Duncan's MRT's with mean grain sizes and abundances. Numbers represent phi size ranges: 1 = less than 4 (sand), 2 = 4 to 6 (silt), 3 = 6 to 8 (silt) and 4 = greater than 8 (clay).

greatest abundances were found in sandy sediments, concomitant with large numbers of A. agassizi (and to a lesser extent A. abdita) were the dominant species within the study area. Their large numbers as well as their preference for a more sandy sediment accounted for significantly greater abundances in these sediments, 4 ϕ or less (Figure 5-36).

Sediment preferences did not appear to overwhelm probable brine effects, however, as brine and control stations were similar in their mix of sediment types. Distance from the diffuser still showed significant impact on Ampelisca populations in the terms of a ring-like effect (Figure 5-35).

Unfortunately the persistence of such a pattern could not be followed throughout the summer because a major hypoxic event eradicated the amphipods prior to August sampling. When population levels are low brine effects are difficult to detect. However as population levels increase some depression in abundances of particular species can be noted. Such effects were obvious for the Ampelisca as well as an overall depression of species diversity around the diffuser.

5.4.2.8 Special Aspects of Community and Physical Parameters

Ongoing studies by other tasks have provided valuable data and information which have assisted in the analysis of brine effects on the benthos. These same data have also posed a number of questions concerning the effects of changing physical characteristics on community structure. Results of water and sediment quality studies have indicated that redox values have fluctuated greatly within the study area and two heavy metals, lead and cadmium, were present in greater concentrations around the diffuser than at control sites. Special cruises in summer 1983 by the hydrographic task group reported the recurrence of widespread hypoxic conditions in the Freeport, Texas area. All of these conditions have or could adversely affect the benthos within the study area. Some (i.e. heavy metal deposition) may have resulted from diffuser activity while others occurred as a result of natural processes (i.e. redox flux, hypoxia). Detection of problems resulting from diffusion of brine are, of course, a primary interest. Naturally occurring phenomena which stress the benthos are also important in the study of brine pollution effects. Any condition which regularly, or as a single event, stresses a community can vastly reduce its (the community) ability to successfully respond to pollution. The synergistic effects of natural stress and pollution can, in such cases, overwhelm a community which was, up to that time, handling either situation within the limits of normal fluctuation of abundance and species diversity. Acute sources of stress such as hypoxia may be relatively short in duration but long in recovery. Other stresses, such as heavy metal pollution, may be low in observable stress but chronic in long term effect. Each of the special topics will be addressed separately.

5.4.2.8.1 Hypoxia

As noted previously, the hydrographic task group found hypoxic conditions in the summer of 1983. Although no hypoxic D.O. readings were noted during the August benthos cruise the reduction in abundances were indicative of its effect. This hypoxic event was not as extensive as in 1979 (Harper and McKinney, 1980) but effects were similar. Crustacea, in particular, which were returning to pre-1979 levels, were virtually eliminated from the study area.

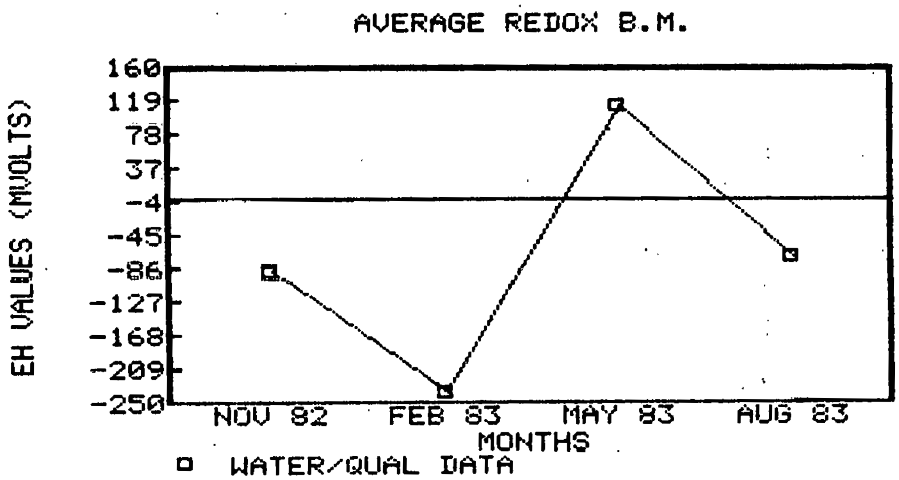
5.4.2.8.2 Redox Potential vs. Abundance

Correlations between redox potentials and abundances of organisms should be highly positive. This is certainly the case at the Bryan Mound site. Abundance of organisms at the control stations (A2, A3, A6, A7, D1, D3, G1), the brine stations (A4, A5, E2, A8, A9, B1, C1) and overall (26 stations), seem to fluctuate directly with the redox potential (Figures 5-37, 5-38 and 5-39). Abundances for all species, Amphipoda, and all species less the Amphipoda were plotted in these figures to negate any effect of the unusually large peak of Amphipoda during May. Redox correlations remained high regardless of species exclusions.

Correlation values between abundances of organisms and redox potentials were calculated and are presented in Table 5-9. A correlation value of +1 indicates a perfect positive correlation between the two factors. All correlation values between various abundance values were highly positively correlated with redox values. No significant differences were seen between correlations at brine stations and control stations. Fluctuating redox appears to be a factor at all stations regardless of other influences.

5.4.2.8.3 Lead Effects on Benthic Community Structure

The concentrations of lead (Pb) in marine sediments and their overlying waters have been monitored more carefully since the dangers of heavy metal ingestion by man were publicized in the early 1950's. Research has shown that all organisms tested to date are adversely affected by various concentrations of lead in the environment. Studies on a variety of marine taxa have been conducted to determine tolerance levels to lead and other heavy metals.



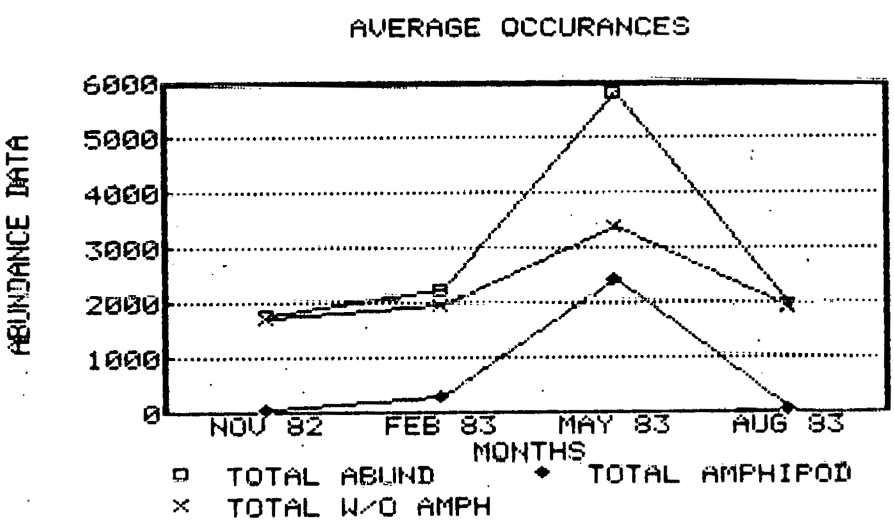
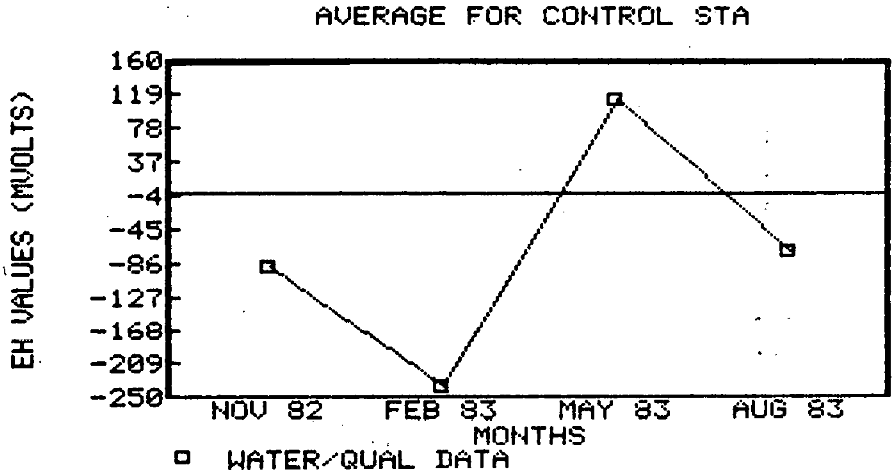


Figure 5-37. Comparison of redox (E_h) values and overall abundances at the Bryan Mound site. Abundance totals are given with and without Amphipoda which were the dominant species in May.



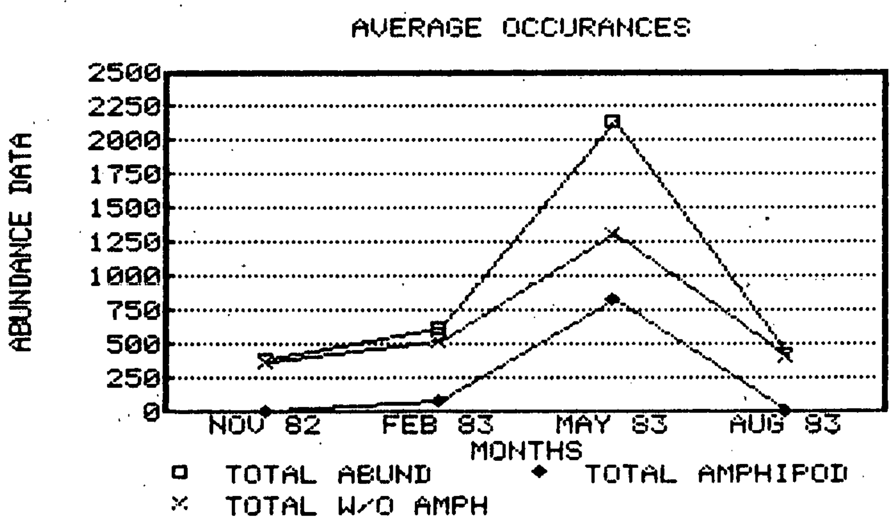


Figure 5-38. Comparison of redox (E_h) values and control station abundances at the Bryan Mound site. Abundance totals are given with and without Amphipoda which were the dominant species in May.

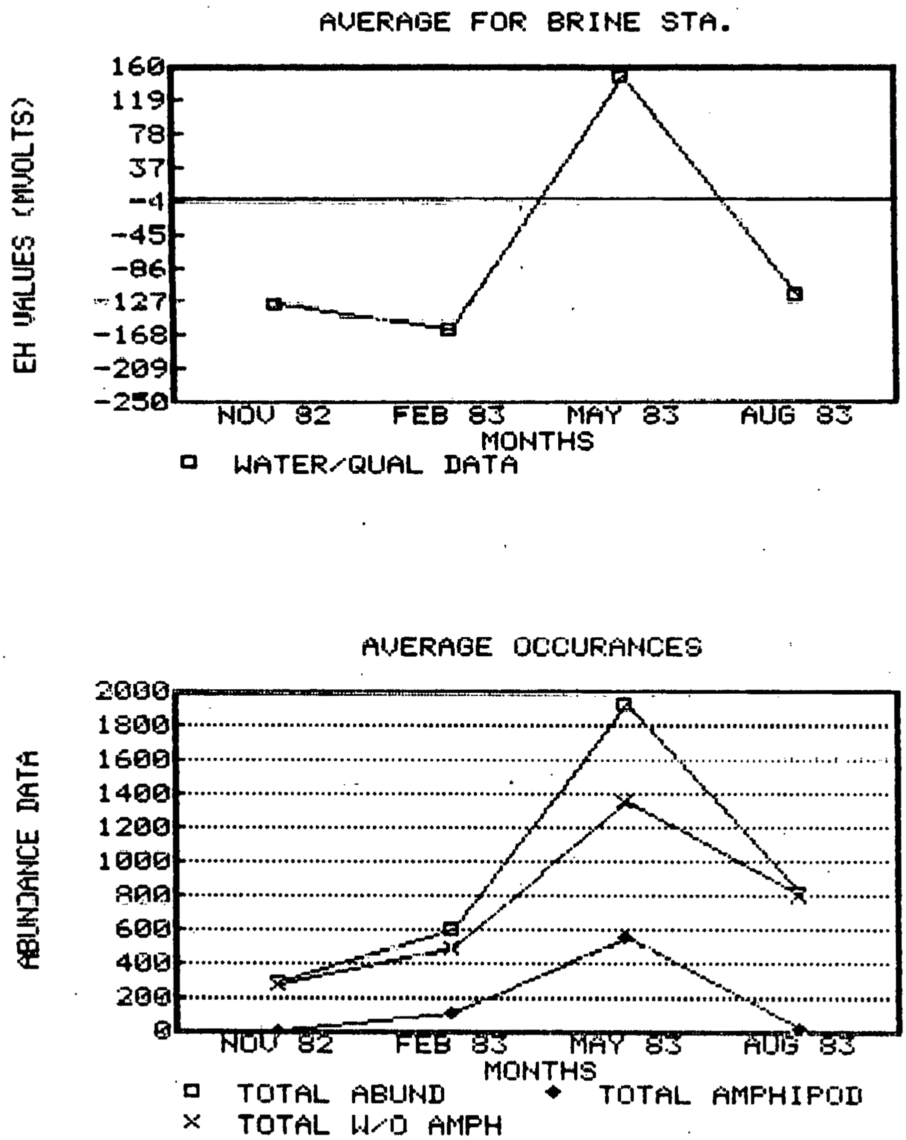


Figure 5-39. Comparison of redox (E_h) values and brine station abundances at the Bryan Mound site. Abundance totals are given with and without Amphipoda which were the dominant species in May.

Table 5-9. Correlation values between redox potential (E_h) and total abundances of various taxa. Brine stations include: A4, A5, E2, A8, A9, B1, and C1. Control stations include A2, A3, A6, A7, D1, D3, and G1. All stations include all quarterly stations.

Taxa		Control	Brine	All Stations
Total Abundance	Corr.	0.95	0.95	0.81
	Slope	0.135	0.192	0.061
	Inter	-190.87	-239.06	-249.59
Total Ampelisca	Corr.	0.89	0.96	0.77
	Slope	0.34	0.527	0.094
	Inter	-182.41	-154.03	-179.58
Total Amphipods	Corr.	0.81	0.99	0.80
	Slope	0.29	0.45	0.099
	Inter	-130.46	-112.44	-140.50
Total Abundance-Ampelisca	Corr.	0.77	0.90	0.81
	Slope	0.237	0.277	0.145
	Inter	-229.54	-269.43	-402.01
Total Abundance-Amphipod	Corr.	0.77	0.90	0.80
	Slope	0.249	0.277	0.152
	Inter	-233.96	-267.89	-415.06

All taxa do not share similar abilities to tolerate lead (Table 5-10). For example, the shrimp Pandalus montagui was able to tolerate lead at a concentration 10000 X greater than the amphipod Niphargoides maeticus. The two polychaetes listed differ by an order of magnitude, whereas the two mollusks are quite similar. Therefore, no one taxonomic class can be used to monitor environmental lead levels. Taxa at the generic or species level must be utilized in such monitoring programs.

Lead level build up in the sediments can occur in a number of ways. In soluble form in marine waters, lead can precipitate, be adsorbed on suspended sediment particles, or be absorbed and modified by marine organisms. Lead can also diffuse directly into or out of sediments as a direct result of concentration gradients between pore and bottom waters.

Both the Bryan Mound diffuser and control sites have shown an increase in lead concentrations in the sediments and in the overlying water (Slowey, 1982). Table 5-11 shows the lead concentration ranges and averages for the study site over a five year period. The values shown are quite low for sediment lead levels when compared to the delta region of the Mississippi River. Sedimentary cores from the delta region yielded values of 25 to 44 ppm (Windom and Duce, 1976), while Bryan Mound sediments ranged from 0.07 to 13.6 ppm.

No obvious effects on abundance or diversity have been observed on the benthic community at the Bryan Mound site to date, although levels are at the point where some organisms could be affected. If lead levels continue to increase a significant impact could be expected at some point in the future.

Table 5-10. LC_{50} for various exposure times and concentrations of Pb on adult marine organisms.

Group	Organism	Concentration (ppm)	Time	Author
Crustacea	PANDALUS MONTAGUI	375[a]	--	Portmann (1978)
	NIPHARGOIDES MAETICUS	0.03-0.06[a]	--	Patin et al. (1978)
Mollusca	CRASSOSTREA VIRGINICA	2.46	48h	Bryan (1976)
	CARDIUM EDULE	3.0[a]	48h	Calabrese et al. (1973)
Polychaeta	OPHRYOTROCHA LABRONICA	0.2-0.5[a]	48h	Patin (1982)
	NEREIS DIVERSICOLOR	7.5	192h	Bryan (1976)

[a]Concentration given for biological indicator of toxicity (changes in survival, abundance, fecundity, growth rates).

Table 5-11. Ranges and averages for Pb (ppm) at the diffuser study area (from Slowey 1981, 1982, 1983). # - lowest observed value to date; * - highest observed value to date.

Date	Range	Average (all stations)
August 1979	1.5 - 10.0	4.60
February 1980	#0.07 - 12.2	3.31
April 1980	1.6 - 9.8	4.40
June 1980	1.2 - 9.0	4.29
August 1980	2.9 - 8.6	5.25
October 1980	1.9 - 10.6	4.30
January 1980	1.2 - 12.3	6.92
March 1981	3.0 - 11.9	6.34
July 1981	2.0 - 9.8	6.02
November 1981	4.2 - 9.3	6.16
May 1982	5.8 - 12.2	7.43
August 1982	5.2 - 11.9	7.21
November 1982	5.2 - 10.6	8.28
February 1983	6.0 - 11.6	8.98
May 1983	6.0 - 10.4	7.33
August 1983	2.9 - 13.6*	8.32

5.4.2.8.4 Cadmium vs. Abundance

The effects of Cd on the benthos have been studied by many researchers resulting in data on assimilation, acute toxicity, and organism tolerance. Many animals have been tested under various concentrations of temperatures and salinities to monitor the effects of Cd. Table 5-12 gives a summary of some of this research. As one can observe from the data, cadmium is highly toxic and requires little concentration to cause death to the organism.

The presence of cadmium (Cd) as a marine pollutant became noticeable in the 1960's with the advent of human cadmium poisoning in Japan. A heavy metal such as Cd, with its low solubility and high toxicity, can be particularly dangerous to the marine benthos. Cadmium entering the water column does eventually reach the marine sediments. Precipitation, adsorption on suspended particles, and absorption by organisms account for the movement of Cd to the sediments. Ambient levels of Cd in marine sediments are usually very low, with average oceanic waters containing 0.05 ppb (Windom and Duce, 1976). Accumulation in sediments is evident though, as levels of 1.5 to 2.4 ppm are found in Mississippi River Delta sediments (Trefry and Presley, 1976).

The concentrations found at the Bryan Mound site are very low, ranging from 0.008 to 0.07 ppm. These concentrations are listed in Table 5-13. These cadmium levels represent lower levels than most researchers utilize even in the long term LC_{50} studies and are 21 times lower than the lowest level detected in the Mississippi Delta sediment samples.

No observed effect from cadmium has been noted at the Bryan Mound study site. Levels are still below the toxic range of most organisms. The situation does require monitoring as a continued increase in

Table 5-12. Lethal toxicity of Cd (Bryan, 1976).

Group	Species	LC_{50} (ppm) 24-hr	48-hr	96-hr	Minimum Observed LC_{50}: LC_{50}	Time (hr)	pH	°C	Conditions Form	Author
Molluscs	MYTILUS EDULIS	>200	165	2.5	–	–	S o/oo=20	20	Chloride	Eisler (1971)
Bivalves	MYA ARENARIA	>200	50	2.2	–	–	S o/oo=20	20	Chloride	Eisler (1971)
	CARDIUM EDULE	–	10-33	3.3	–	–	–	15	Chloride	Portman and Wilson (1971)
Crustaceans	CRANGON CRINGON	–	3.3-10	1.0	–	–	–	15	Chloride	Portman and Wilson (1971)
Shrimp	CRANGON SEPTEMSPINOSA	2.4	0.5	0.32	–	–	S o/oo=20	20	Chloride	Eisler (1971)
Crabs	PAGURUS LONGICARPUS	200	3.7	0.32	–	–	S o/oo=20	20	Chloride	Eisler (1971)
	CARCINUS MAENAS	100	16.6	4.1	–	–	S o/oo=20	20	Chloride	Eisler (1971)
Echinoderm	ASTERIAS FORBESI	12	1	0.82	–	–	S o/oo=20	20	Chloride	Eisler (1971)
Annelids	NEREIS VIVENS	25	25	11	–	–	S o/oo=20	20	Chloride	Eisler (1971)
	N. DIVERSICOLOR	–	–	–	10	816	50% = SW	13	Sulphate	Brown & Ahsanullah (1971)
	OPHRYOTROCHA LABRONICA	–	–	8	1	410	–	20	Sulphate	Brown & Ahsanullah (1971)

Table 5-13. Ranges and averages of Cd (ppm) at the diffuser study area (from Slowey 1981, 1982, 1983). # - lowest observed value to date; * - highest observed value to date.

Date	Range	Average (all stations)
August 1979	0.02 - 0.05	0.028
February 1980	0.01 - 0.04	0.022
April 1980	0.01 - 0.03	0.013
June 1980	0.01 - 0.04	0.019
August 1980	0.01 - 0.04	0.023
October 1980	#0.008 - 0.057	0.033
January 1981	0.01 - 0.05	0.031
March 1981	0.02 - 0.06	0.030
July 1981	0.02 - 0.06	0.028
November 1981	0.01 - 0.03	0.022
May 1982	0.01 - 0.07	0.050
August 1982	0.02 - 0.04	0.022
November 1982	0.01 - 0.02	0.016
February 1983	0.01 - 0.03	0.018
May 1983	0.01 - 0.05	0.018
August 1983	0.01 - 0.08*	0.025

concentration could eventually result in chronic effects.

5.5 Conclusions

The benthic study now has two years of quarterly data from 26 stations, including 7 collections made after the diffuser outflow rate was increased to 1,000,000 barrels/day. Analysis of the benthic data has shown:

1. The increased flow rate had no effect on either the near-bottom water temperature or dissolved oxygen concentrations. Nearfield station values of these characteristics were similar or identical to farfield values.
2. Both the bottom water and pore water salinities (averaged data) continued to be elevated about 2.0 o/oo in the nearfield region. We have consistently reported that pore water salinities were higher than bottom water, which we attributed to a slow rate of exchange between pore water and bottom water once a salinity build-up occurred in the sediments. Since the increase in brine output occurred, this pattern has reversed. Most stations had average pore water salinities of 0.2 to 2.0 o/oo lower than the overlying water. We also detected a tendency for the average increased salinity to be toward the southwest and/or offshore as indicated by the +0.5 o/oo isohaline.
3. Both the total numbers of species and individuals collected have returned to more "normal" levels in the study area as a whole. A spring peak, enhanced by large populations of ampeliscid amphipods, occurred in May, but population densities in November 1982 and February 1983 were still much lower than in years prior

to the occurrence of hypoxia (1979).

4. Total numbers of species at station A5 (diffuser) were higher than most other nearfield stations (and many farfield stations) in both the pre- and post-1,000,000 barrels/day brine flow periods. In contrast, the total abundances at station A5 were quite depressed (although not significantly so) compared with intermediate and farfield stations.

5. Cluster analysis and principal components analysis did not indicate any brine effect. Discriminant analysis indicated that sediment temperature and mean grain size accounted for most of the variance in the systems of pre- and post-increased flow rate, respectively.

6. Quarterly abundances over the entire project varied greatly at both control and brine stations. May and November showed the least variance.

7. Statistical analysis indicated that nearfield stations were intermediate in mean abundance compared with intermediate and farfield stations in November 1982 through May 1983. In August 1983, the greatest abundance occurred at nearfield stations. August. Species diversity around the diffuser remained lower than at control stations throughout the year (November excepted).

8. In general, the index of diversity has increased at control stations through the extent of the project. Brine stations, however remained unchanged for much of that time. H' was significantly reduced at brine stations following the increase in brine outflow.

9. Hypoxia was noted in the study area and it severely impacted the Crustacea.

10. Redox values and population levels were highly correlated: positive redox = increased abundances, negative redox = lower abundances.

11. Lead and cadmium have had no detectable impact as yet. The effects of increased concentrations or chronic exposure has not been determined.

12. Reduced species diversity in the benthos could determine the presence or absence of bottom feeding nektonic organisms. If the areal extent of this depressed species diversity is sufficient, reduced levels of commercially important species could result. Such an event would depend on several factors: 1) extent of impact; 2) feeding preferences of nekton (if any or if species specific); and 3) duration of impact. Present impacts appear limited to the immediate diffuser area.

CHAPTER 6

DATA MANAGEMENT

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6.1 Introduction

The principal responsibilities of the data management section are the maintenance of a centralized data storage and retrieval system, the protection of the data system, the transmission of validated data to the National Environmental Satellite Data and Information Service (NESDIS) in Washington, D.C., and programming support for project scientists and engineers. In order to meet these requirements the data management section must monitor and accurately document the flow of data from the initial sampling, through validation to its final transmission and storage.

6.2 Facilities

The SPR Project has at its disposal the facilities of Texas A&M University's Data Processing Center (DPC). It is equipped with an Amdahl 470 V/6-II and an Amdahl 470 V/8. The Amdahl processors are each configured with 16 data channels and a total of 20 megabytes of monolithic memory. The memory for each processor is prefixed with a high speed cache memory that is used to provide fast access to frequently used data instructions. The V/6 cache memory size is 32 kilobytes, and the V/8 size is 64 kilobytes.

Both Amdahl processors and all peripherals are combined into a loosely coupled, multiple processor complex that is connected to shared disks and tapes and is controlled by the IBM operating system MVS/JES3 (Multiple Virtual Storage/Job Entry Subsystem 3). The operating system controls the scheduling of all resources required for a job and provides the computer system operator with status information on the utilization and availability of these resources.

The following peripheral equipment is connected to the Amdahl processors:

52 STC 8650 Disk Drives (634 megabytes each)

1 CALCOMP 9-track Tape Drive (800/1600 bpi)

1 CALCOMP 7-track Tape Drive (200/556/800 bpi)

8 STC 3670 9-track Tape Drive (1600/6250 bpi)

1 DatagraphiX AutoCOM II Microfiche Printer

3 Versatec Plotters

1 Houston Instruments CP2-15/6 Four-Pen Drum Plotter

2 Xerox 9700 Electronic Printing Systems

WYLBUR, a text manipulation system developed at Stanford University, provides the major portion of the interaction between the computer systems and the data management section. It offers an on-line interactive capability for preparing and submitting jobs for execution.

6.3 Data Processing

Data are received from all components of the project (physical oceanography, biological oceanography, water chemistry, sediment chemistry, grain size, sea state) on formatted data sheets or on-line data files (e.g., physical oceanography). The data are stored as one or more data sets for each component of the project. In some cases, the raw data are processed by programs which arrange the data into a format compatible with existing files and programs.

After entering the data on-line, a cycle of validation is initiated through the appropriate principal investigator and the data management section to check for errors. With each cycle, the data are corrected by data management until they are error free. The data are then available for forwarding to NESDIS, statistical analyses and report generation (see Figure 6-1). The status of the data from each of the project's components is shown in Table 6-1.

Validated data are protected by an Access Control Facility (ACF2). The ACF2 protection system enables access to project data files to be specifically controlled by data management and personnel with project accounts. Flexibility in controlling the type of access permitted (reading from files or editing files) and the degree of access permitted (limited from a specific portion of a file to the entire contents of the account) enables the authorized use of project data to be selectively controlled. This system is particularly useful with large computer accounts in which numerous subaccounts (principal investigators and support personnel) are interactively maintained, as in the SPR project.

The data files are protected from inadvertent loss through a series of programs which copy the data to magnetic tape on a monthly basis. Two copies of the project's complete data files are maintained in a fire-proof vault. Documentation of the contents of the backup is kept by the data management section so that any data file which is lost (e.g., hardware failure, operator error) can be restored to on-line use.

6.4 Data Storage

Direct access storage of data is convenient for processing needs, but can lead to rather large disk storage requirements, particularly for data which is continuously collected (e.g., physical oceanography). The data

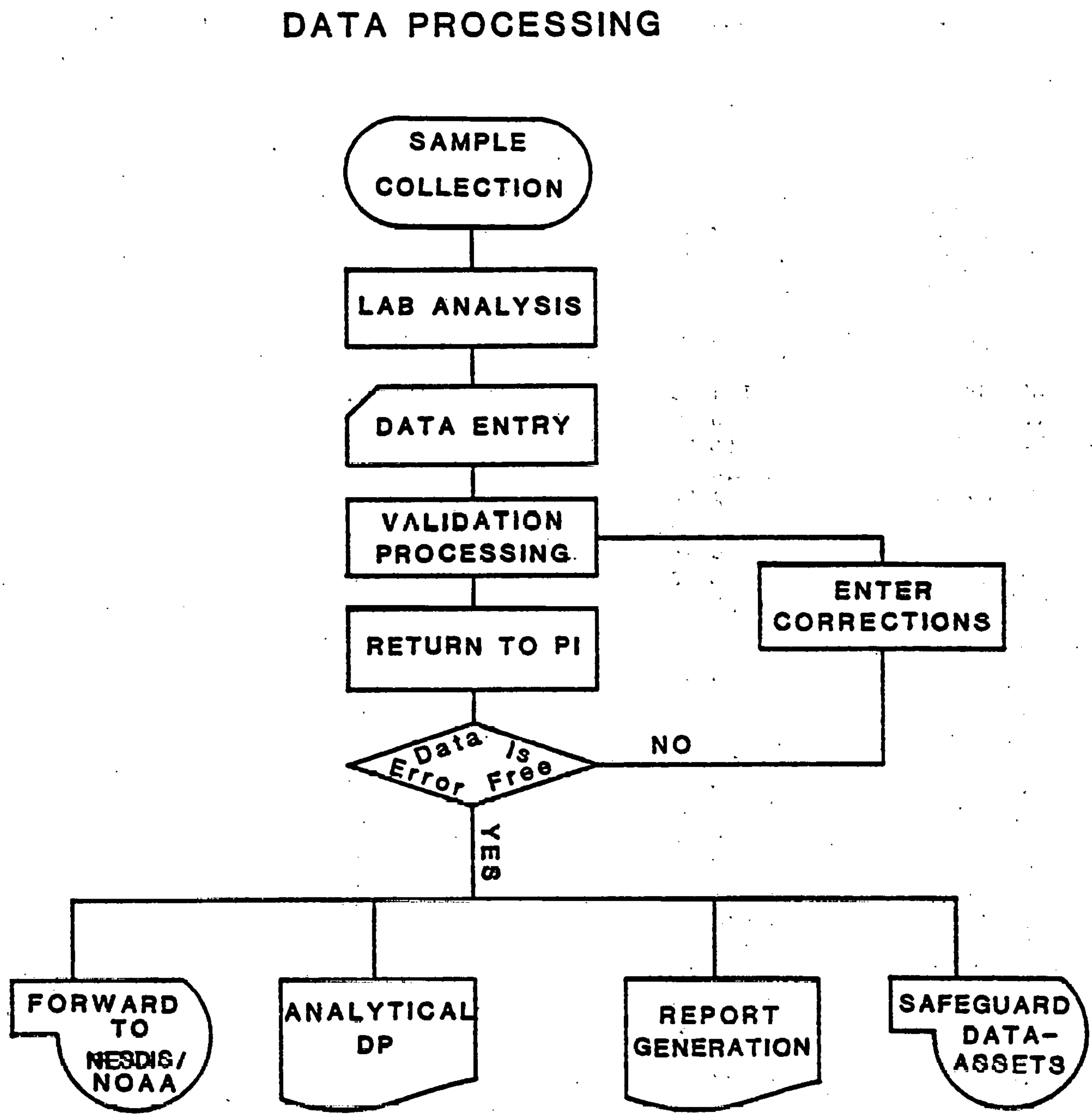

Figure 6-1. Flow chart of data processing activity.

Table 6-1. Cumulative status of project data sets as of November 10, 1983.

DATA SET: BENTHOS (5-MILE)

DATA SET NAME	CRUISE	CODED	VALIDATED	TRANSMITTED
BEN5.CRU01	22 SEP 77	X	X	X
BEN5.CRU02	14 OCT 77	X	X	X
BEN5.CRU03	11 NOV 77	X	X	X
BEN5.CRU04	15 DEC 77	X	X	X
BEN5.CRU05	20 FEB 78	X	X	X
BEN5.CRU06	15 MAR 78	X	X	X
BEN5.CRU07	14 APR 78	X	X	X
BEN5.CRU08	22 MAY 78	X	X	X
BEN5.CRU09	16 JUN 78	X	X	X
BEN5.CRU10	13 JUL 78	X	X	X
BEN5.CRU11	31 AUG 78	X	X	X
BEN5.CRU12	28 SEP 78	X	X	X
BEN5.CRU13	25 OCT 78	X	X	X
BEN5.CRU14	1 DEC 78	X	X	X
BEN5.CRU15	13 FEB 79	X	X	X
BEN5.CRU16	5 APR 79	X	X	X
BEN5.CRU17	26 APR 79	X	X	X
BEN5.CRU18	1 JUN 79	X	X	X
BEN5.CRU19	28 JUN 79	X	X	X
BEN5.CRU20	2 AUG 79	X	X	X
BEN5.CRU21	23 AUG 79	X	X	X
BEN5.CRU22	26 SEP 79	X	X	X
BEN5.CRU23	29 OCT 79	X	X	X
BEN5.CRU24	19 NOV 79	X	X	X
BEN5.CRU25	19 DEC 79	X	X	X
BEN5.CRU26	28 JAN 80	X	X	X
BEN5.CRU27	28 FEB 80	X	X	X
BEN5.CRU28	31 MAR 80	X	X	X
BEN5.CRU29	23 APR 80	X	X	X
BEN5.CRU30	28 MAY 80	X	X	X
BEN5.CRU31	2 JUL 80	X	X	X
BEN5.CRU32	24 JUL 80	X	X	X
BEN5.CRU33	27 AUG 80	X	X	X
BEN5.CRU34	8 OCT 80	X	X	X
BEN5.CRU35	4 NOV 80	X	X	X
BEN5.CRU36	12 DEC 80	X	X	X
BEN5.CRU37	21 JAN 81	X	X	X
BEN5.CRU38	18 FEB 81	X	X	X
BEN5.CRU39	17 MAR 81	X	X	X
BEN5.CRU40	27 APR 81	X	X	X
BEN5.CRU41	27 MAY 81	X	X	X
BEN5.CRU42	22 JUN 81	X	X	X
BEN5.CRU43	20 JUL 81	X	X	X
BEN5.CRU44	20 AUG 81	X	X	X
BEN5.CRU45	22 SEP 81	X	X	X

Table 6-1. Continued.

BEN5.CRU46	28 OCT 81	X	X	X
BEN5.CRU47	23 NOV 81	X	X	X
BEN5.CRU48	10 DEC 81	X	X	X
BEN5.CRU49	24 FEB 82	X	X	X

DATA SET: BENTHOS (10-MILE)

DATA SET NAME	CRUISE	CODED	VALIDATED	TRANSMITTED
BEN10.CRU01	2 DEC 77	X	X	X
BEN10.CRU02	4 JAN 78	X	X	X
BEN10.CRU03	24 FEB 78	X	X	X
BEN10.CRU04	17 MAR 78	X	X	X
BEN10.CRU05	15 APR 78	X	X	X
BEN10.CRU06	24 MAY 78	X	X	X
BEN10.CRU07	20 JUN 78	X	X	X
BEN10.CRU08	17 JUL 78	X	X	X
BEN10.CRU09	21 AUG 78	X	X	X
BEN10.CRU10	27 SEP 78	X	X	X
BEN10.CRU11	30 OCT 78	X	X	X
BEN10.CRU12	30 NOV 78	X	X	X
BEN10.CRU13	28 JAN 79	X	X	X
BEN10.CRU14	26 FEB 79	X	X	X
BEN10.CRU15	25 MAR 79	X	X	X
BEN10.CRU16	24 APR 79	X	X	X
BEN10.CRU17	24 MAY 79	X	X	X
BEN10.CRU18	25 JUN 79	X	X	X
BEN10.CRU19	30 JUL 79	X	X	X
BEN10.CRU20	21 AUG 79	X	X	X
BEN10.CRU21	24 SEP 79	X	X	X
BEN10A.CRU22	18 OCT 79	X	X	X
BEN10A.CRU23	15 NOV 79	X	X	X
BEN10A.CRU24	16 DEC 79	X	X	X
BEN10A.CRU25	18 JAN 80	X	X	X
BEN10A.CRU26	13 FEB 80	X	X	X
BEN10A.CRU27	10 MAR 80	X	X	X
BEN10A.CRU28	20 MAR 80	X	X	X
BEN10A.CRU29	3 APR 80	X	X	X
BEN10A.CRU30	21 APR 80	X	X	X
BEN10A.CRU31	22 MAY 80	X	X	X
BEN10A.CRU32	30 JUN 80	X	X	X
BEN10A.CRU33	24 JUL 80	X	X	X
BEN10A.CRU34	25 AUG 80	X	X	X
BEN10A.CRU35	4 SEP 80	X	X	X
BEN10A.CRU36	29 SEP 80	X	X	X
BEN10A.CRU37	22 OCT 80	X	X	X
BEN10A.CRU38	5 DEC 80	X	X	X
BEN10A.CRU39	15 JAN 81	X	X	X
BEN10A.CRU40	14 FEB 81	X	X	X

Table 6-1. Continued.

BEN10A.CRU41	14 MAR 81	X	X	X
BEN10A.CRU42	17 APR 81	X	X	X
BEN10A.CRU43	26 MAY 81	X	X	X
BEN10A.CRU44	18 JUN 81	X	X	X
BEN10A.CRU45	13 JUL 81	X	X	X
BEN10A.CRU46	13 AUG 81	X	X	X
BEN10A.CRU47	21 SEP 81	X	X	X
BEN10A.CRU48	27 OCT 81	X	X	X
BEN10B.CRU49	21 NOV 81	X	X	X
BEN10A.CRU50	9 DEC 81	X	X	X
BEN10A.CRU51	27 JAN 82	X	X	X
BEN10B.CRU52	17 FEB 82	X	X	X
BEN10B.CRU53	28 MAY 82	X	X	X
BEN10B.CRU54	31 AUG 82	X	X	X
BEN10B.CRU55	20 NOV 82	X	X	X
BEN10B.CRU56	18 FEB 83	X	X	X
BEN10B.CRU57	25 MAY 83	X	X	X
BEN10B.CRU58	26 AUG 83	X	X	11/83

DATA SET: BENTHIC SEDIMENT ANALYSIS (10-MILE)

DATA SET NAME	CRUISE	CODED	VALIDATED	TRANSMITTED
BEN10.PHI01	28 JAN 79	X	X	X
	26 FEB 79	X	X	X
	25 MAR 79	X	X	X
	24 APR 79	X	X	X
	24 MAY 79	X	X	X
	25 JUN 79	X	X	X
	30 JUL 79	X	X	X
	21 AUG 79	X	X	X
	24 SEP 79	X	X	X
	18 OCT 79	X	X	X
	22 MAY 80	X	X	X
	15 NOV 80	X	X	X
	16 DEC 80	X	X	X
	18 JAN 80	X	X	X
	10 MAR 80	X	X	X
	20 MAR 80	X	X	X
	3 APR 80	X	X	X
	21 APR 80	X	X	X
BEN10.PHI02	22 MAY 80	X	X	X
	30 JUN 80	X	X	X
	24 JUL 80	X	X	X
	25 AUG 80	X	X	X
	4 SEP 80	X	X	X
	29 SEP 80	X	X	X
	23 OCT 80	X	X	X

Table 6-1. Continued.

	5 DEC 80	X	X	X
	15 JAN 81	X	X	X
	14 FEB 81	X	X	X
BEN10.PHI03	14 MAR 81	X	X	X
	17 APR 81	X	X	X
	26 MAY 81	X	X	X
	18 JUN 81	X	X	X
	13 JUL 81	X	X	X
	13 AUG 81	X	X	X
BEN10.PHI04	21 SEP 81	X	X	
	27 OCT 81	X	X	
	21 NOV 81	X	X	
	17 FEB 82	X	X	
	28 MAY 82	X	X	
	20 AUG 82	X	X	

DATA SET: NEKTON

DATA SET NAME	CRUISE	CODED	VALIDATED	TRANSMITTED
NEK.CRU01	1 OCT 77	X	X	X
NEK.CRU02	4 NOV 77	X	X	X
NEK.CRU03	3 DEC 77	X	X	X
NEK.CRU04	20 FEB 78	X	X	X
NEK.CRU05	21 MAR 78	X	X	X
NEK.CRU06	14 APR 78	X	X	X
NEK.CRU07	8 MAY 78	X	X	X
NEK.CRU08	14 JUN 78	X	X	X
NEK.CRU09	15 JUL 78	X	X	X
NEK.CRU10	15 SEP 78	X	X	X
NEK.CRU11	11 OCT 78	X	X	X
NEK.CRU12	13 OCT 78	X	X	X
NEK.CRU13	1 DEC 78	X	X	X
NEK.CRU14	13 DEC 78	X	X	X
NEK.CRU15	24 FEB 79	X	X	X
NEK.CRU16	12 MAR 79	X	X	X
NEK.CRU17	5 APR 79	X	X	X
NEK.CRU18	20 APR 79	X	X	X
NEK.CRU19	14 MAY 79	X	X	X
NEK.CRU20	6-10 JUN 79	X	X	X
NEK.CRU21	21-24 JUN 79	X	X	X
NEK.CRU22	5-9 JUL 79	X	X	X
NEK.CRU23	19-22 JUL 79	X	X	X
NEK.CRU24	22-25 AUG 79	X	X	X
NEK.CRU25	22-25 SEP 79	X	X	X
NEK.CRU26	2-6 OCT 79	X	X	X
NEK.CRU27	16-19 OCT 79	X	X	X
NEK.CRU28	3-6 NOV 79	X	X	X
NEK.CRU29	15-18 NOV 79	X	X	X

Table 6-1. Continued.

NEK.CRU30	1-4 DEC 79	X	X	X
NEK.CRU31	14-19 DEC 79	X	X	X
NEK.CRU32	3-6 JAN 80	X	X	X
NEK.CRU33	16-20 JAN 80	X	X	X
NEK.CRU34	4-11 FEB 80	X	X	X
NEK.CRU35	15-20 FEB 80	X	X	X
NEK.CRU36	5-8 MAR 80	X	X	X
NEK.CRU37	19-23 MAR 80	X	X	X
NEK.CRU38	24-25 MAR 80	X	X	X
NEK.CRU39	27-28 MAR 80	X	X	X
NEK.CRU40	1-5 APR 80	X	X	X
NEK.CRU41	8-9 APR 80	X	X	X
NEK.CRU42	14-15 APR 80	X	X	X
NEK.CRU43	16-20 APR 80	X	X	X
NEK.CRU44	5-10 MAY 80	X	X	X
NEK.CRU45	19-22 MAY 80	X	X	X
NEK.CRU46	2-6 JUN 80	X	X	X
NEK.CRU47	19-24 JUN 80	X	X	X
NEK.CRU48	7-11 JUL 80	X	X	X
NEK.CRU49	21-24 JUL 80	X	X	X
NEK.CRU50	5-15 AUG 80	X	X	X

DATA SET: NEKTON

DATA SET NAME	CRUISE	CODED	VALIDATED	TRANSMITTED
NEK.CRU51	16 AUG 80	X	X	X
NEK.CRU52	26-29 AUG 80	X	X	X
NEK.CRU53	7-11 SEP 80	X	X	X
NEK.CRU54	22-25 SEP 80	X	X	X
NEK.CRU55	6-9 OCT 80	X	X	X
NEK.CRU56	20-31 OCT 80	X	X	X
NEK.CRU57	3-5 NOV 80	X	X	X
NEK.CRU58	18-21 NOV 80	X	X	X
NEK.CRU59	1-4 DEC 80	X	X	X
NEK.CRU60	15-19 DEC 80	X	X	X
NEK.CRU61	6-13 JAN 81	X	X	X
NEK.CRU62	21-24 JAN 81	X	X	X
NEK.CRU63	2-8 FEB 81	X	X	X
NEK.CRU64	16-19 FEB 81	X	X	X
NEK.CRU65	2-6 MAR 81	X	X	X
NEK.CRU66	16-19 MAR 81	X	X	X
NEK.CRU67	7-10 APR 81	X	X	X
NEK.CRU68	20-23 APR 81	X	X	X
NEK.CRU69	4-8 MAY 81	X	X	X
NEK.CRU70	19-27 MAY 81	X	X	X
NEK.CRU71	2-9 JUN 81	X	X	X
NEK.CRU72	15-19 JUN 81	X	X	X

Table 6-1. Continued.

NEK.CRU73	1-8 JUL 81	X	X	X
NEK.CRU74	20-24 JUL 81	X	X	X
NEK.CRU75	3-9 AUG 81	X	X	X
NEK.CRU76	16-20 AUG 81	X	X	X
NEK.CRU77	11-13 NOV 81	X	X	X
NEK.CRU78	11-13 FEB 82	X	X	X
NEK.CRU79	17-19 MAY 82	X	X	X
NEK.CRU80	9-11 AUG 82	X	X	X
NEK.CRU81	8-10 NOV 82	X	X	X
NEK.CRU82	8-9 FEB 83	X	X	X
NEK.CRU83	19-22 MAY 83	X	X	X
NEK.CRU84	01-02 SEP 83	X	X	11/83

DATA SET: NEKTON WEIGHT

DATA SET NAME	CRUISE	CODED	VALIDATED	TRANSMITTED
NEK.WEIGHT77	11-13 NOV 81	X	X	X
NEK.WEIGHT78	11-13 FEB 82	X	X	X
NEK.WEIGHT79	17-19 MAY 82	X	X	X
NEK.WEIGHT80	9-11 AUG 82	X	X	X
NEK.WEIGHT81	8-10 NOV 82	X	X	X
NEK.WEIGHT82	8-9 FEB 83	X	X	X
NEK.WEIGHT83	19-22 MAY 83	X	X	X
NEK.WEIGHT84	01-02 SEP 83	X	X	11/83

DATA SET: OVER-THE-SIDE-MEASUREMENTS

DATA SET NAME	CRUISE	CODED	VALIDATED	TRANSMITTED
OTS.CRU01	15 SEP 77	X	X	X
	20 OCT 77	X	X	X
	17 NOV 77	X	X	X
	18 DEC 77	X	X	X
	2 FEB 78	X	X	X
	25 FEB 78	X	X	X
	23 MAR 78	X	X	X
	19 APR 78	X	X	X
	25 MAY 78	X	X	X
	20 JUN 78	X	X	X
	18 JUL 78	X	X	X
	30 AUG 78	X	X	X
	17 SEP 78	X	X	X
	16 OCT 78	X	X	X
	17 NOV 78	X	X	X
	18 DEC 78	X	X	X
	12 FEB 79	X	X	X
	11 MAR 79	X	X	X

Table 6-1. Continued.

	13 APR 79	X	X	X
	25 MAY 79	X	X	X
	1 JUN 79	X	X	X
	14 AUG 79	X	X	X
	6 SEP 79	X	X	X
	5 OCT 79	X	X	X
	14 NOV 79	X	X	X
OTS.CRU02	4 DEC 79	X	X	X
	7 DEC 79	X	X	X
	6 JAN 80	X	X	X
	26 JAN 80	X	X	X
	6 FEB 80	X	X	X
	22 FEB 80	X	X	X
OTS.CRU03	25 MAR 80	X	X	X
	18 APR 80	X	X	X
	9 MAY 80	X	X	X
	11 JUN 80	X	X	X
	27 JUN 80	X	X	X
	9 JUL 80	X	X	X
	14 AUG 80	X	X	X
	27 AUG 80	X	X	X
	11 SEP 80	X	X	X
OTS.CRU04	9 OCT 80	X	X	X
	31 OCT 80	X	X	X
	20 NOV 80	X	X	X
	6 DEC 80	X	X	X
	16 DEC 80	X	X	X
	9 JAN 81	X	X	X
OTS.CRU05	26 JAN 81	X	X	X
	9 FEB 81	X	X	X
	24 FEB 81	X	X	X
	16 MAR 81	X	X	X
	31 MAR 81	X	X	X

DATA SET: OVER-THE-SIDE-MEASUREMENTS

DATA SET NAME	CRUISE	CODED	VALIDATED	TRANSMITTED
OTS.CRU06	13 APR 81	X	X	X
	29 APR 81	X	X	X
	26 MAY 81	X	X	X
	10 JUN 81	X	X	X
	19 JUN 81	X	X	X
	8 JUL 81	X	X	X
	28 JUL 81	X	X	X
	7 AUG 81	X	X	X
	20 AUG 81	X	X	X

Table 6-1. Continued.

OTS.CRU07	3 SEP 81	X	X	X
	7 OCT 81	X	X	X
	3 NOV 81	X	X	X
	2 DEC 81	X	X	X
	5 JAN 82	X	X	X
OTS.CRU08	19 FEB 82	X	X	X
	8 MAR 82	X	X	X
	14 APR 82	X	X	X
	3 MAY 82	X	X	X
	1 JUN 82	X	X	X
	8 JUL 82	X	X	X
	3 AUG 82	X	X	X
OTS.CRU09	7 SEP 82	X	X	X
	5 OCT 82	X	X	X
	2 NOV 82	X	X	X
	1 DEC 82	X	X	X
OTS.CRU10	4 JAN 83	X	X	X
	3 FEB 83	X	X	X
	10 MAR 83	X	X	X
	11 APR 83	X	X	X
	5 MAY 83	X	X	X
	9 JUN 83	X	X	X

DATA SET: ENDECO - BRYAN MOUND RUTHERFORD AT

	TYP	PERIOD	COLL	INIT PROC	VAL	TRANS
AT106239	105	23 JUN 79 - 16 JUL 79	X	X	X	
AT107169	105	16 JUL 79 - 2 AUG 79	X	*	X	R
AT108029	105	2 AUG 79 - 17 AUG 79	X	X	X	X
AT609299	174	29 SEP 79 - 17 OCT 79	X	X	X	X
AT610179	174	17 OCT 79 - 5 NOV 79	X	X	X	X
AT611059	174	5 NOV 79 - 30 NOV 79	X	X	X	X
AT111309	105	30 NOV 79 - 1 DEC 79	X	X	X	X
AT612019	174	1 DEC 79 - 15 DEC 79	X	X	X	X
AT612159	174	15 DEC 79 - 15 JAN 80	X	X	X	X
AT601150	174	15 JAN 80 - 10 MAR 80	X	X	X	X
AT603100	174	10 MAR 80 - 24 APR 80	X	X	X	
AT605260	174	26 MAY 80 - 26 JUN 80	X	X	X	
AT606260	174	26 JUN 80 - 16 JUL 80	X	X	X	R
AT607160	174	16 JUL 80 - 7 AUG 80	X	X	X	R
AT608180	174	18 AUG 80 - 18 SEP 80	X	X	X	R
AT609180	174	18 SEP 80 - 23 OCT 80	X	X	X	X
AT610230	174	23 OCT 80 - 12 DEC 80	X	**	X	X
AT612120	174	12 DEC 80 - 22 JAN 81	X	X	X	X
AT601221	174	22 JAN 81 - 20 FEB 81	X	X	X	X
AT702201	174	20 FEB 81 - 7 MAR 81	X	**	X	X

Table 6-1. Continued.

AT603201	174	20 MAR 81 - 21 APR 81	X	***		
AT604211	174	21 APR 81 - 12 MAY 81	X	**	X	2/82
AT705121	174	12 MAY 81 - 10 JUN 81	X	**	X	2/82
AT606291	174	29 JUN 81 - 29 JUL 81	X	X	X	2/82
AT607291	174	29 JUL 81 - 17 AUG 81	X	X	X	2/82
AT608251	174	25 AUG 81 - 23 SEP 81	X	*	X	
AT609231	174	23 SEP 81 - 29 OCT 81	X	X	X	
AT610291	174	29 OCT 81 - 03 DEC 81	X	X		

METER SITE DISCONTINUED

DATA SET: ENDECO - BRYAN MOUND RUTHERFORD AM

	TYP	PERIOD	COLL	INIT PROC	VAL	TRANS
AM107169	105	16 JUL 79 - 2 AUG 79	X	X	X	X
AM108179	105	17 AUG 79 - 29 SEP 79	X	X	X	X
AM609299	174	29 SEP 79 - 19 OCT 79	X	X	X	X
AM610199	174	19 OCT 79 - 5 NOV 79	X	X	X	
AM611059	174	5 NOV 79 - 30 NOV 79	X	X	X	R
AM611309	174	30 NOV 79 - 15 DEC 79	X	X	X	X
AM612159	174	15 DEC 79 - 15 JAN 80	X	X	X	X
AM601150	174	15 JAN 80 - 10 MAR 80	X	X	X	X
AM603100	174	10 MAR 80 - 24 APR 80	X	X	X	10/80
AM605260	174	26 MAY 80 - 26 JUN 80	X	X	X	R
AM606260	174	26 JUN 80 - 16 JUL 80	X	X	X	R
AM607160	174	16 JUL 80 - 7 AUG 80	X	X	X	R
AM108070	105	7 AUG 80 - 18 AUG 80	X			
AM608180	174	18 AUG 80 - 18 SEP 80	X	X	X	R
AM609180	174	18 SEP 80 - 23 OCT 80	X	X	X	12/80
AM610230	174	23 OCT 80 - 12 DEC 80	X	**	X	X
AM612170	174	17 DEC 80 - 22 JAN 81	X	X	X	X
AM601221	174	22 JAN 81 - 20 FEB 81	X	X	X	X
AM602201	174	20 FEB 81 - 20 MAR 81	X	**	X	2/82
AM603201	174	20 MAR 81 - 21 APR 81	X	X	X	2/82
AM604211	174	21 MAR 81 - 12 MAY 81	X	X	X	2/82
AM605121	174	12 MAY 81 - 10 JUN 81	X	**	X	2/82
AM606291	174	29 JUN 81 - 29 JUL 81	X	X	X	2/82
AM607291	174	29 JUL 81 - 25 AUG 81	X	X	X	2/82

METER SITE DISCONTINUED

Table 6-1. Continued.

DATA SET: ENDECO - BRYAN MOUND RUTHERFORD AB

	TYP	PERIOD	COLL	INIT PROC	VAL	TRANS
AB106239	105	23 JUN 79 - 16 JUL 79	X	X	X	X
AB107169	105	16 JUL 79 - 2 AUG 79	X	X	X	X
AB108029	105	2 AUG 79 - 17 AUG 79	X	X	X	X
AB608179	174	17 AUG 79 - 29 SEP 79	X	X	X	X
AB609299	174	29 SEP 79 - 17 OCT 79	X	X	X	X
AB610179	174	17 OCT 79 - 8 NOV 79	X	***		
AB611089	174	8 NOV 79 - 30 NOV 79	X	X	X	X
AB611309	174	30 NOV 79 - 15 DEC 79	X	X	X	X
AB612159	174	15 DEC 79 - 15 JAN 80	X	X	X	X
AB601150	174	15 JAN 80 - 10 MAR 80	X	X	X	X
AB603100	174	10 MAR 80 - 24 APR 80	X	X	X	X
AB605260	174	26 MAY 80 - 26 JUN 80	X	X	X	12/80
AB606260	174	26 JUN 80 - 16 JUL 80	X	X	X	R
AB607160	174	16 JUL 80 - 7 AUG 80	X	X	X	X
AB708070	174	7 AUG 80 - 11 AUG 80	X	X	**	X
AB608180	174	18 AUG 80 - 18 SEP 80	X	X	X	X
AB609180	174	18 SEP 80 - 23 OCT 80	X	X	**	
AB610230	174	23 OCT 80 - 12 DEC 80	X	X	***	
AB612120	174	12 DEC 80 - 22 JAN 81	X	X	X	6/81
AB601221	174	22 JAN 81 - 20 FEB 81	X	X	X	6/81
AB602201	174	20 FEB 81 - 20 MAR 81	X	X	X	2/82
AB603201	174	20 MAR 81 - 21 APR 81	X	X	X	2/82
AB604211	174	21 APR 81 - 12 MAY 81	X	X	X	2/82
AB705121	174	12 MAY 81 - 10 JUN 81	X	**	X	2/82
AB606291	174	29 JUN 81 - 29 JUL 81	X	X	X	2/82
AB607291	174	29 JUL 81 - 17 AUG 81	X	X	X	2/82
AB608251	174	25 AUG 81 - 23 SEP 81	X	X	X	2/82
AB609231	174	23 SEP 81 - 29 OCT 81	X	X	X	2/82
AB610291	174	29 OCT 81 - 03 DEC 81	X	X		

METER SITE DISCONTINUED

DATA SET: ENDECO - BRYAN MOUND RUTHERFORD BT

	TYP	PERIOD	COLL	INIT PROC	VAL	TRANS
BT106239	105	23 JUN 79 - 16 JUL 79	X	X	X	X
BT107169	105	16 JUL 79 - 2 AUG 79	X	X	X	X
BT108029	105	2 AUG 79 - 18 AUG 79	X	X	X	X
BT108189	105	18 AUG 79 - 10 SEP 79	X	X	X	X
BT109109	105	10 SEP 79 - 29 SEP 79	X	*		
BT609299	174	29 SEP 79 - 17 OCT 79	X	X	X	X
BT610179	174	17 OCT 79 - 8 NOV 79	X	X	X	X

Table 6-1. Continued.

BT611089	174	8 NOV 79 - 1 DEC 79	X	***		
BT612019	174	1 DEC 79 - 15 DEC 79	X	X	X	X
BT612159	174	15 DEC 79 - 24 JAN 80	X	X	X	X
BT601240	174	24 JAN 80 - 10 MAR 80	X	X	X	
BT603100	174	10 MAR 80 - 19 APR 80	X	X	X	X
BT604190	174	19 APR 80 - 26 MAY 80	X	X	X	X
BT605260	174	26 MAY 80 - 8 JUL 80	X	X	X	X
BT607080	174	8 JUL 80 - 19 JUL 80	X	X	X	X
BT609030	174	3 SEP 80 - 2 OCT 80	X	X	X	X
BT610020	174	2 OCT 80 - 3 NOV 80	X	X	X	X
BT611030	174	3 DEC 80 - 12 DEC 80	X	X	X	X
BT612120	174	12 DEC 80 - 14 JAN 81	X	X	X	X
BT601141	174	14 JAN 81 - 20 FEB 81	X	X	X	X
BT602201	174	20 FEB 81 - 20 MAR 81	X	X	X	X
BT603201	174	20 MAR 81 - 21 APR 81	X	X	X	X
BT604211	174	21 MAR 81 - 6 MAY 81	X	X	X	1/82
BT605061	174	6 MAY 81 - 9 JUN 81	X	X	X	1/82
BT606091	174	9 JUN 81 - 29 JUN 81	X	X	X	1/82
BT606291	174	29 JUN 81 - 29 JUL 81	X	X	X	1/82
BT607291	174	29 JUL 81 - 26 AUG 81	X	X	X	1/82

METER SITE DISCONTINUED

DATA SET: ENDECO - BRYAN MOUND RUTHERFORD BM

	TYP	PERIOD	COLL	INIT PROC	VAL	TRANS
BM609109	174	10 SEP 79 - 29 SEP 79	X	X		
BM609299	174	29 SEP 79 - 17 OCT 79	X	X		
BM610179	174	17 OCT 79 - 8 NOV 79	X	X	***	
BM611089	174	8 NOV 79 - 1 DEC 79	X	X	**	X
BM612019	174	1 DEC 79 - 15 DEC 79	X	X	X	X
BM612159	174	15 DEC 79 - 24 JAN 80	X	X	X	X
BM601240	174	24 JAN 80 - 10 MAR 80	X	X	X	X
BM603100	174	10 MAR 80 - 19 APR 80	X	X	X	X
BM604190	174	19 MAY 80 - 26 JUN 80	X	X	X	X
BM605260	174	26 JUN 80 - 8 JUL 80	X	X	X	X
BM607080	174	8 JUL 80 - 19 JUL 80	X	X	X	X
BM609030	174	3 SEP 80 - 2 OCT 80	X	X	X	X
BM610020	174	2 OCT 80 - 3 NOV 80	X	X	X	
BM611030	174	3 NOV 80 - 12 DEC 80	X	X	X	X
BM612120	174	12 DEC 80 - 14 JAN 81	X	X	X	
BM601141	174	14 JAN 81 - 20 FEB 81	X	X	X	R
BM602201	174	20 FEB 81 - 6 MAR 81	X	X	***	
BM603201	174	20 MAR 81 - 21 APR 81	X	X	X	1/82
BM604211	174	21 APR 81 - 6 MAY 81	X	X	X	1/82
BM605061	174	6 MAY 81 - 9 JUN 81	X	*	X	1/82

Table 6-1. Continued.

BM606091	174	9 JUN 81 - 29 JUN 81	X	X	X	1/82
BM606291	174	29 JUN 81 - 29 JUL 81	X	X	X	1/82
BM607291	174	29 JUL 81 - 26 AUG 81	X	X	X	1/82

METER SITE DISCONTINUED

DATA SET: ENDECO - BRYAN MOUND RUTHERFORD BB

	TYP	PERIOD	COLL	INIT PROC	VAL	TRANS
BB106239	105	23 JUN 79 - 16 JUL 79	X	X	X	X
BB107169	105	16 JUL 79 - 2 AUG 79	X	X	X	X
BB108029	105	2 AUG 79 - 18 AUG 79	X	X	X	X
BB108189	105	18 AUG 79 - 10 SEP 79	X	X	X	X
BB609109	174	10 SEP 79 - 29 SEP 79	X	X	X	X
BB609299	174	29 SEP 79 - 17 OCT 79	X	X	X	X
BB610179	174	17 OCT 79 - 8 NOV 79	***			
BB611089	174	8 NOV 79 - 1 DEC 79	X	X	X	X
BB612019	174	1 DEC 79 - 15 DEC 79	X	X	X	X
BB612159	174	15 DEC 79 - 24 JAN 80	X	X	X	X
BB601240	174	24 JAN 80 - 10 MAR 80	X	***		
BB603100	174	10 MAR 80 - 19 APR 80	X	***		
BB604190	174	19 APR 80 - 26 JUN 80	X	X	X	X
BB605260	174	26 MAY 80 - 8 JUL 80	X	X	X	X
BB607080	174	8 JUL 80 - 19 JUL 80	X	***		
BB609030	174	3 SEP 80 - 2 OCT 80	X	X	X	X
BB610020	174	2 OCT 80 - 3 NOV 80	X	X	X	X
BB611030	174	3 NOV 80 - 12 DEC 80	X	X	X	X
BB612120	174	12 DEC 80 - 14 JAN 81	X	X	X	X
BB601141	171	14 JAN 81 - 20 FEB 81	X	***		
BB602201	174	20 FEB 81 - 20 MAR 81	X	X	X	1/82
BB603201	174	20 MAR 81 - 21 APR 81	X	X	X	1/82
BB604211	174	21 APR 81 - 6 MAY 81	X	X	X	1/82
BB605061	174	6 MAY 81 - 9 JUN 81	X	X	X	1/82
BB606091	174	6 JUN 81 - 29 JUN 81	X	X	X	1/82
BB606291	174	29 JUN 81 - 29 JUL 81	X	X	X	1/82
BB607291	174	29 JUL 81 - 26 AUG 81	X	X	X	1/82

METER SITE DISCONTINUED

Table 6-1. Continued.

DATA SET: ENDECO - BRYAN MOUND DIFFUSER CT

	TYP	PERIOD	COLL	INIT PROC	VAL	TRANS
CT108179	105	17 AUG 79 - 10 SEP 79	X	X	X	X
CT109109	105	10 SEP 79 - 26 SEP 79	X	X	X	X
CT609269	174	26 SEP 79 - 19 OCT 79	X	X	X	X
CT610199	174	19 OCT 79 - 5 NOV 79	X	*		
CT611059	174	5 NOV 79 - 30 NOV 79	X	X	X	X
CT111309	105	30 NOV 79 - 15 DEC 79	X	X	X	X
CT612159	174	15 DEC 79 - 24 JAN 80	X	***		
CT601240	174	24 JAN 80 - 3 MAR 80	X	***		
CT603030	174	3 MAR 80 - 9 APR 80	X	X	X	X
CT604090	174	9 APR 80 - 6 MAY 80	X	X	X	
CT605060	174	6 MAY 80 - 5 JUN 80	X	X	X	R
CT606050	174	5 JUN 80 - 1 JUL 80	X	X	X	R
CT707010	174	1 JUL 80 - 8 JUL 80	X	**	**	R
CT607250	174	25 JUL 80 - 7 AUG 80	X	X	X	R
CT608180	174	18 AUG 80 - 12 SEP 80	X	X	X	R
CT609120	174	12 SEP 80 - 7 OCT 80	X	X	X	R
CT610070	174	7 OCT 80 - 10 NOV 80	X	X	X	X
CT611100	174	10 NOV 80 - 13 DEC 80	X	*	**	X
CT612170	174	17 DEC 80 - 14 JAN 81	X	X	X	X
CT601141	174	14 JAN 81 - 17 FEB 81	X	X	X	X
CT602171	174	17 FEB 81 - 14 MAR 81	X	X	X	X
CT603141	174	14 MAR 81 - 21 APR 81	***			
CT604211	174	21 APR 81 - 6 MAY 81	X	X	X	X
CT605121	174	12 MAY 81 - 1 JUN 81	X	X	X	X
CT706011	174	1 JUN 81 - 26 JUN 81	X	X	X	X
CT806011	174	27 JUN 81 - 8 JUL 81	X	X	X	X
CT607081	174	8 JUN 81 - 29 JUL 81	X	X	X	X
CT607291	174	29 JUL 81 - 25 AUG 81	X	X	X	X
CT608251	174	25 AUG 81 - 23 SEP 81	X	X	X	X
CT609231	174	23 SEP 81 - 20 OCT 81	X	X	X	X
CT610201	174	20 OCT 81 - 16 NOV 81	X	X	X	X
CT611161	174	16 NOV 81 - 16 DEC 81	X	X	X	X
CT612161	174	16 DEC 81 - 27 JAN 82	X	X	X	X
CT601272	174	27 JAN 82 - 17 FEB 82	X	X	X	X
CT602232	174	23 FEB 82 - 24 MAR 82	X	X	***	
CT603242	174	24 MAR 82 - 26 APR 82	X	X	X	X
CT604282	174	28 APR 82 - 24 MAY 82	X	X	X	X
CT605242	174	24 MAY 82 - 14 JUN 82	X	X	X	X
CT606142	174	14 JUN 82 - 12 JUL 82	X	X	X	X
CT607122	174	12 JUL 82 - 20 AUG 82	***			
CT608202	174	20 AUG 82 - 15 SEP 82	X	X	X	X
CT609152	174	15 SEP 82 - 18 OCT 82	X	X	X	X
CT610182	174	18 OCT 82 - 21 NOV 82	X	X	X	X
CT611212	174	21 NOV 82 - 14 DEC 82	X	X	X	X
CT612142	174	14 DEC 82 - 13 JAN 83	X	X	X	X
CT601133	174	13 JAN 83 - 19 FEB 83	X	X	X	X

Table 6-1. Continued.

CT602193	174 19 FEB 83 - 22 MAR 83	X	X	X	X
CT603223	174 22 MAR 83 - 25 APR 83	X	X	X	X
CT604253	174 25 APR 83 - 24 MAY 82	X	X	X	X
CT605243	174 24 MAY 83 - 15 JUN 83	X	X	X	X
CT606153	174 15 JUN 83 - 19 JUL 83	X	X	X	X
CT607193	174 19 JUL 83 - 10 AUG 83	X	X	X	X

DATA SET: ENDECO - BRYAN MOUND DIFFUSER CM

	TYP	PERIOD	COLL	INIT PROC	VAL	TRANS
CM609109	174	10 SEP 79 - 26 SEP 79	X	X	X	X
CM609269	174	26 SEP 79 - 19 OCT 79	X	X	X	X
CM610199	174	19 OCT 79 - 5 NOV 79	X	X	X	X
CM611059	174	5 NOV 79 - 30 NOV 79	X	X	X	X
CM611309	174	30 NOV 79 - 15 DEC 79	X	X	X	X
CM612159	174	15 DEC 79 - 24 JAN 80	X	X	X	X
CM601240	174	24 JAN 80 - 3 MAR 80	X	***		
CM603030	174	3 MAR 80 - 9 APR 80	X	X	X	R
CM604090	174	9 APR 80 - 6 MAY 80	X	X	X	R
CM605060	174	6 MAY 80 - 5 JUN 80	X	X	X	R
CM606050	174	5 JUN 80 - 1 JUL 80	X	X	X	R
CM607010	174	1 JUL 80 - 25 JUL 80	X	X	X	R
CM607250	174	25 JUL 80 - 7 AUG 80	X	X	X	R
CM608180	174	18 AUG 80 - 12 SEP 80	X	X	X	R
CM609120	174	12 SEP 80 - 7 OCT 80	X	X	X	R
CM610070	174	7 OCT 80 - 10 NOV 80	X	X	X	X
CM611100	174	10 NOV 80 - 13 DEC 80	X	X	X	X
CM612130	174	13 DEC 80 - 14 JAN 81	X	X	X	X
CM601141	174	14 JAN 81 - 17 FEB 81	X	X	**	X
CM602171	174	17 FEB 81 - 14 MAR 81	X	X	X	X
CM603141	174	14 MAR 81 - 21 APR 81	X	***		
CM604211	174	21 APR 81 - 6 MAY 81	X	**	X	X
CM605121	174	12 MAY 81 - 1 JUN 81	X	X	X	X
CM706011	174	1 JUN 81 - 26 JUN 81	X	X	X	X
CM806011	174	27 JUN 81 - 8 JUL 81	X	X	X	X
CM607081	174	8 JUN 81 - 29 JUL 81	X	X	X	X
CM607291	174	29 JUL 81 - 25 AUG 81	X	X	X	X
CM608251	174	25 AUG 81 - 23 SEP 81	X	X	X	X
CM609231	174	23 SEP 81 - 20 OCT 81	X	X	X	X
CM610201	174	20 OCT 81 - 16 NOV 81	X	X	X	X
CM611161	174	16 NOV 81 - 16 DEC 81	X	X	X	X
CM612161	174	16 DEC 81 - 27 JAN 82	X	X	X	X
CM601272	174	27 JAN 82 - 18 FEB 82	X	X	X	X
CM602232	174	23 FEB 82 - 24 MAR 82	X	X	X	X
CM603242	174	24 MAR 82 - 26 APR 82	X	X	***	
CM604282	174	28 APR 82 - 24 MAY 82	X	X	X	X

Table 6-1. Continued.

CM605242	174 24 MAY 82 - 14 JUN 82	X	X	X	X
CM606142	174 14 JUN 82 - 12 JUL 82	X	X	X	X
CM707122	174 12 JUL 82 - 20 AUG 82	X	X	X	X
CM608202	174 20 AUG 82 - 15 SEP 82	X	X	X	X
CM609152	174 15 SEP 82 - 18 OCT 82	X	X	X	X
CM610182	174 18 OCT 82 - 21 NOV 82	X	X	X	X
CM611212	174 21 NOV 82 - 14 DEC 82	X	X	X	X
CM612142	174 14 DEC 82 - 13 JAN 83	X	X	X	X
CM601133	174 13 JAN 83 - 19 FEB 83	X	X	X	X
CM602193	174 19 FEB 83 - 22 MAR 83	X	X	X	X
CM603223	174 22 MAR 83 - 25 APR 83	X	X	X	X
CM604253	174 25 APR 83 - 24 MAY 82	X	X	X	X
CM605243	174 24 MAY 83 - 15 JUN 83	X	X	X	X
CM606153	174 15 JUN 83 - 19 JUL 83	X	X	X	X
CM607193	174 19 JUL 83 - 10 AUG 83	X	X	X	X

DATA SET: ENDECO - BRYAN MOUND DIFFUSER CB

	TYP	PERIOD	COLL	INIT PROC	VAL	TRANS
CB608179	174	17 AUG 79 - 10 SEP 79	X	X	X	X
CB609109	174	10 SEP 79 - 26 SEP 79	X	X	X	X
CB609269	174	26 SEP 79 - 19 OCT 79	X	X	X	X
CB610199	174	19 OCT 79 - 5 NOV 79	X	***		
CB611059	174	5 NOV 79 - 30 NOV 79	X	X	X	X
CB611309	174	30 NOV 79 - 15 DEC 79	X	***		
CB612159	174	15 DEC 79 - 24 JAN 80	X	X	X	X
CB601240	174	24 JAN 80 - 3 MAR 80	X	***		
CB603030	174	3 MAR 80 - 9 APR 80	X	X	X	X
CB604090	174	9 APR 80 - 6 MAY 80	X	X	X	
CB605060	174	6 MAY 80 - 5 JUN 80	X	X	X	R
CB606050	174	6 JUN 80 - 1 JUL 80	X	X	X	R
CB607010	174	1 JUL 80 - 25 JUL 80	X	X	X	R
CB607250	174	25 JUL 80 - 7 AUG 80	X	X	X	R
CB608180	174	18 AUG 80 - 12 SEP 80	X	X	X	R
CB609120	174	12 SEP 80 - 7 OCT 80	X	X	**	X
CB610070	174	7 OCT 80 - 10 NOV 80	X	X	X	X
CB611100	174	10 NOV 80 - 13 DEC 80	X	***		
CB612130	174	13 DEC 80 - 14 JAN 81	X	X	X	X
CB601141	174	14 JAN 81 - 17 FEB 81	X	X	X	X
CB602171	174	17 FEB 81 - 14 MAR 81	X	X	X	X
CB603141	174	14 MAR 81 - 21 APR 81	X	X	X	X
CB604211	174	21 APR 81 - 6 MAY 81	X	X	X	X
CB605121	174	12 MAY 81 - 1 JUN 81	X	X	X	X
CB706011	174	1 JUN 81 - 26 JUN 81	X	X	X	X
CB806011	174	27 JUN 81 - 8 JUL 81	X	X	X	X
CB607081	174	8 JUL 81 - 29 JUL 81	X	X	X	X
CB607291	174	29 JUL 81 - 25 AUG 81	X	X	X	X

Table 6-1. Continued.

CB608251	174 25 AUG 81 - 23 SEP 81	X	X	X	X
CB609231	174 23 SEP 81 - 20 OCT 81	X	X	X	X
CB610201	174 20 OCT 81 - 16 NOV 81	X	X	X	X
CB611161	174 16 NOV 81 - 16 DEC 81	X	X	X	X
CB612161	174 16 DEC 81 - 27 JAN 82	X	X	X	X
CB601272	174 27 JAN 82 - METER LOST	***			
CB602232	174 23 FEB 82 - 24 MAR 82	**	X	X	X
CB603242	174 24 MAR 82 - 26 APR 82	X	X	X	X
CB604272	174 28 APR 82 - 24 MAY 82	X	X	X	X
CB605242	174 24 MAY 82 - 14 JUN 82	X	X	X	X
CB606142	174 14 JUN 82 - 12 JUL 82	X	X	X	X
CB607122	174 12 JUL 82 - 20 AUG 82	***			
CB608202	174 20 AUG 82 - 15 SEP 82	X	X	X	X
CB609152	174 15 SEP 82 - 18 OCT 82	**	X	X	X
CB610182	174 18 OCT 82 - 21 NOV 82	X	X	X	X
CB611212	174 21 NOV 82 - 14 DEC 82	X	X	X	X
CB612142	174 14 DEC 82 - 13 JAN 83	X	X	X	X
CB601133	174 13 JAN 83 - 19 FEB 83	***			
CB602193	174 19 FEB 83 - 22 MAR 83	X	X	X	X
CB603223	174 22 MAR 83 - 25 APR 83	X	X	X	X
CB604253	174 25 APR 83 - 24 MAY 82	X	X	X	X

DATA SET: ENDECO - BRYAN MOUND DIFFUSER CX

	TYP	PERIOD	COLL	INIT PROC	VAL	TRANS
CX607141	174	14 JUL 81 - 29 JUL 81	X	X	X	X
CX608071	174	7 AUG 81 - 25 AUG 81	X	X	X	X
CX608251	174	25 AUG 81 - 23 SEP 81	X	X	X	X
CX609231	174	23 SEP 81 - 20 OCT 81	X	X	X	X
CX610201	174	20 OCT 81 - METER LOST	***			
CX611161	174	16 NOV 81 - 26 NOV 81	**	X	X	X
CX602182	174	18 FEB 82 - 24 MAR 82	X	X	X	X
CX603242	174	24 MAR 82 - 28 APR 82	X	X	X	X
CX604282	174	28 APR 82 - 24 MAY 82	X	X	X	X

METER SITE DISCONTINUED

Table 6-1. Continued.

DATA SET: ENDECO - BRYAN MOUND DIFFUSER CY

	TYP	PERIOD	COLL	INIT PROC	VAL	TRANS
CY608261	174	26 AUG 81 - 23 SEP 81	X	X	X	X
CY609231	174	23 SEP 81 - 20 OCT 81	X	X	X	X
CY610201	174	20 OCT 81 - 16 NOV 81	X	X	X	X
CY611161	174	16 NOV 81	***			

METER SITE DISCONTINUED

DATA SET: ENDECO - BRYAN MOUND DIFFUSER CZ

	TYP	PERIOD	COLL	INIT PROC	VAL	TRANS
CZ609241	174	24 SEP 81 - 20 OCT 81	X	X	X	X
CZ610201	174	20 OCT 81 - 16 NOV 81	X	X	X	X
CZ611161	174	16 NOV 81 - 07 DEC 81	**	X	X	X
CZ612071	174	07 DEC 81 - 09 DEC 81	X	X	X	X
CZ601272	174	27 JAN 82 - 12 FEB 82	X	X	X	X
CZ603022	174	02 FEB 82 - 24 MAR 82	X	X	X	X
CZ603242	174	24 MAR 82 - 26 APR 82	**	X	X	X
CZ604272	174	27 APR 82 - 24 MAY 82	X	X	X	X
CZ605242	174	24 MAY 82 - 14 JUN 82	X	X	X	X
CZ606142	174	14 JUL 82 - 12 JUL 82	X	X	X	X
CZ707122	174	12 JUL 82 - 10 AUG 82	X	X	X	X
CZ608202	174	20 AUG 82 - 15 SEP 82	X	X	X	X
CZ609152	174	15 SEP 82 - 18 OCT 82	X	X	X	X
CZ610182	174	18 OCT 82 - 21 NOV 82	X	X	X	X
CZ611212	174	21 NOV 82 - 14 DEC 82	X	X	X	X
CZ612142	174	14 DEC 82 - 13 JAN 83	**	X	X	X
CZ601133	174	13 JAN 83 - 19 FEB 83	**	X	X	X
CZ602193	174	19 FEB 83 - 22 MAR 83	**	X	X	X
CZ603223	174	22 MAR 83 - 25 APR 83	X	X	X	X
CZ604253	174	25 APR 83 - 24 MAY 82	X	X	X	X
CZ605243	174	24 MAY 83 - 15 JUN 83	X	X	X	X
CZ706153	174	15 JUN 83 - 19 JUL 83	X	X	X	X
CZ607193	174	19 JUL 83 - 10 AUG 83	X	X	X	X

Table 6-1. Continued.

DATA SET: ENDECO - BRYAN MOUND DIFFUSER CU

	TYP	PERIOD	COLL	INIT PROC	VAL	TRANS
CU604282	174	28 APR 82 - 24 MAY 82	X	X	X	X
CU605242	174	24 MAY 82 - 14 JUN 82	X	X	X	X
CU606142	174	14 JUN 82 - 12 JUL 82	X	X	X	X
CU707122	174	12 JUL 82 - 01 AUG 82	X	X	X	X
CU608202	174	20 AUG 82 - 15 SEP 82	X	X	X	X
CU609152	174	15 SEP 82 - 18 OCT 82	X	X	X	X
CU610182	174	18 OCT 82 - 21 NOV 82	**	X	X	X
CU611212	174	21 NOV 82 - 14 DEC 82	X	X	X	X
CU612142	174	14 DEC 82 - 13 JAN 83	***			
CU601133	174	13 JAN 83 - 19 FEB 83	X	X	X	X
CU602193	174	19 FEB 83 - 22 MAR 83	X	X	X	X
CU603223	174	22 MAR 83 - 25 APR 83	X	X	X	X
CU604253	174	25 APR 83 - 24 MAY 82	X	X	X	X
CU605243	174	24 MAY 83 - 15 JUN 83	X	X	X	X
CU606153	174	15 JUN 83 - 19 JUL 83	X	X	X	X
CU607193	174	19 JUL 83 - 10 AUG 83	X	X	X	X

DATA SET: ENDECO - BRYAN MOUND DIFFUSER CV

	TYP	PERIOD	COLL	INIT PROC	VAL	TRANS
CV607193	174	19 JUL 83 - 10 AUG 83	X	X	X	X

DATA SET: ENDECO - BRYAN MOUND DIFFUSER CW

	TYP	PERIOD	COLL	INIT PROC	VAL	TRANS
CW607193	174	19 JUL 83 - 10 AUG 83	X	X	X	X

DATA SET: ENDECO - BRYAN MOUND CONTROL - KU

	TYP	PERIOD	COLL	INIT PROC	VAL	TRANS
KU606153	174	15 JUN 83 - 19 JUL 83	X	X	X	X
KU607193	174	19 JUL 83 - 10 AUG 83	X	X	X	X

Table 6-1. Continued.

DATA SET: ENDECO - BRYAN MOUND CONTROL - KZ

	TYP	PERIOD	COLL	INIT PROC	VAL	TRANS
KZ606153	174	15 JUN 83 - 19 JUL 83	X	X	X	X
KZ607193	174	19 JUL 83 - 10 AUG 83	X	X	X	X

NOTES: BRYAN MOUND

LOC	LAT	LONG	Depth of Meter	Depth of water
RAT	28 47' 04.4"	95 18' 44.8"	3.6 M (12 FT)	18.8 (62 FT)
RAM	"	"	9.4 (31)	"
RAB	"	"	17.0 (56)	"
RBT	28 41' 57.5"	95 25' 42.4"	3.6 (12)	18.8 (62 FT)
RBM	"	"	9.4 (31)	"
RBB	"	"	17.0 (56)	"
DCT	28 43' 53.9"	95 14' 34.3"	3.6 (12)	21.9 (72 FT)
DCM	"	"	10.9 (36)	"
DCB	"	"	20.1 (66)	"
DCX	28 43' 59.5"	95 14' 25.0"	21.5 M (70.5 FT)	21.9 (72 FT)
DCY	28 43' 27.0"	95 14' 25.8"	21.2 M (69.5 FT)	21.6 (71 FT)
DCZ	28 43' 53.9"	95 14' 34.3"	21.5 M (70.5 FT)	21.6 (72 FT)
DCU	28 43' 53.9"	95 14' 34.3"	20.1 M (66 FT)	21.9 (72 FT)
DCV	"	"	17.0 M (56 FT)	"
DCW	"	"	20.6 M (68 FT)	"
CKU	28 44' 48.0"	95 13' 36.0"	19.2 M (63 FT)	21.0 (69 FT)
CKZ	28 44' 48.0"	95 13' 36.0"	20.6 M (67.5 FT)	21.0 (69 FT)

BUOY COORDINATES:

	LAT	LONG
CX = BUOY B	28 43' 59.48" N	95 14' 25.0 " W
CY = BUOY E	28 44' 26.95" N	95 14' 25.80" W
CZ = BUOY C	28 43' 53.91" N	95 14' 34.30" W
CU = BUOY C	28 43' 53.91" N	95 14' 34.30" W
KZ = BUOY K	28 43' 48.0 " N	95 13' 36.0 " W
KU = BUOY K	28 43' 48.0 " N	95 13' 36.0 " W

TYP: 105 means a Type 105 current meter (speed and direction).
174 means a Type 174 current meter (speed, direction, conductivity, and temperature).

Table 6-1. Continued.

COLLECTED: For 105 meters the film cartridge has been retrieved. For 174 meters the magnetic tape cassette has been retrieved

INITIAL PROCESSING: For 105 meters the film cartridge has been sent to Endeco for processing, returned, and entered into the database. For 174 meters the data on the cassette has been entered into the database directly.

VALIDATED; Data has been checked for anamolous or questionable values an flagged where appropriate, calibration constants have been applied, and instrument has been checked for accuracy and drift.

* - meter damaged, data questionable
** - meter damaged, some data loss
*** - meter damaged, total data loss

DATA SET: WATER QUALITY

MONTHLY CRUISES

DATA SET NAME	CRUISE	CODED	VALIDATED	TRANSMITTED
WQ.CRU01	20 Feb 79	X	X	X
WQ.CRU02	27 Feb 79	X	X	X
WQ.CRU03	28 Mar 79	X	X	X
WQ.CRU04	24 Apr 79	X	X	X
WQ.CRU05	24 May 79	X	X	X
WQ.CRU06	29 Jun 79	X	X	X
WQ.CRU07	30 Jul 79	X	X	X
WQ.CRU08	30 Aug 79	X	X	X
WQ.CRU09	22 Sep 79	X	X	X
WQ.CRU10	26 Oct 79	X	X	X
WQ.CRU11	30 Nov 79	X	X	X
WQ.CRU12	20 Dec 79	X	X	X
WQ.CRU13	25 Jan 80	X	X	X
WQ.CRU14	29 FEB 80	X	X	X
WQ.CRU15	25 MAR 80	X	X	X
WQ.CRU16	7 APR 80	X	X	X
WQ.CRU17	28 APR 80	X	X	X
WQ.CRU18	27 MAY 80	X	X	X
WQ.CRU19	30 JUN 80	X	X	X
WQ.CRU20	20 AUG 80	X	X	X
WQ.CRU21	18 SEP 80	X	X	X
WQ.CRU22	14 OCT 80	X	X	X
WQ.CRU23	11 NOV 80	X	X	X
WQ.CRU24	23 DEC 80	X	X	X
WQ.CRU25	15 JAN 81	X	X	X
WQ.CRU26	18 FEB 81	X	X	X
WQ.CRU27	24 MAR 81	X	X	X

Table 6-1. Continued.

WQ.CRU28	12 APR 81	X	X	X
WQ.CRU29	5 MAY 81	X	X	X
WQ.CRU30	17 JUN 81	X	X	X
WQ.CRU31	9 JUL 81	X	X	X
WQ.CRU32	18 AUG 81	X	X	X

DATA SET: QUARTERLY SEDIMENT DATA CRUISES

DATA SET NAME	CRUISE	CODED	VALIDATED	TRANSMITTED
WQ.QSCRU01	30 AUG 79	X	X	X
WQ.QSCRU02	30 NOV 79	X	X	X
WQ.QSCRU03	29 FEB 80	X	X	X
WQ.QSCRU04	25 MAR 80	X	X	X
WQ.QSCRU05	7 APR 80	X	X	X
WQ.QSCRU06	30 JUN 80	X	X	X
WQ.QSCRU07	20 AUG 80	X	X	X
WQ.QSCRU08	14 OCT 80	X	X	X
WQ.QSCRU09	15 JAN 81	X	X	X
WQ.QSCRU10	24 MAR 81	X	X	X
WQ.QSCRU11	09 JUL 81	X	X	X
WQ.QSCRU12	17 NOV 81	X	X	X
WQ.QSCRU13	08 FEB 82	X	X	X
WQ.QSCRU14	12 MAY 82	X	X	X
WQ.QSCRU15	16 AUG 82	X	X	X
WQ.QSCRU16	16 NOV 82	X	X	11/83
WQ.QSCRU17	22 FEB 83	X	X	11/83

DATA SET: QUARTERLY WATER COLUMN DATA CRUISES

DATA SET NAME	CRUISE	CODED	VALIDATED	TRANSMITTED
WQ.QWCRU01	30 AUG 79	X	X	X
WQ.QWCRU02	30 NOV 79	X	X	X
WQ.QWCRU03	29 FEB 80	X	X	X
WQ.QWCRU04	25 MAR 80	X	X	X
WQ.QWCRU05	7 APR 80	X	X	X
WQ.QWCRU06	30 JUN 80	X	X	X
WQ.QWCRU07	20 AUG 80	X	X	X
WQ.QWCRU08	14 OCT 80	X	X	X
WQ.QWCRU09	15 JAN 81	X	X	X
WQ.QWCRU10	24 MAR 81	X	X	X
WQ.QWCRU11	09 JUL 81	X	X	X
WQ.QWCRU12	17 NOV 81	X	X	X
WQ.QWCRU13	08 FEB 82	X	X	X

Table 6-1. Continued.

WQ.QWCRU14	12 MAY 82	X	X	X
WQ.QWCRU15	16 AUG 82	X	X	X
WQ.QWCRU16	16 NOV 82	X	X	11/83
WQ.QWCRU17	22 FEB 83	X	X	11/83

DATA SET: ADDITIONAL QUARTERLY WATER COLUMN DATA CRUISES

DATA SET NAME	CRUISE	CODED	VALIDATED	TRANSMITTED
WQ.QWADD12	17 NOV 81	X	X	X
WQ.QWADD13	08 FEB 82	X	X	X
WQ.QWADD14	12 MAY 82	X	X	X
WQ.QWADD15	16 AUG 82	X	X	X
WQ.QWADD16	16 NOV 82	X	X	11/83
WQ.QWADD17	22 FEB 83	X	X	11/83

management section has developed a data file management and inventory system which substantially reduces the storage space requirements, and consequently the expense, of direct access data storage.

Used in conjunction with the data file management and inventory system is a software package acquired by the DPC. The Tape Management System (TMS) catalogs direct access files onto tape and maintains a record of its location and characteristics. Direct access files written to a TMS tape can be incorporated into the series of programming commands by a user with no prior knowledge of various utility programs previously required to accomplish these tasks. As the project's data files continue to expand, direct access storage costs can be controlled with this system.

The data management section has developed programs that convert raw data into suitable format for use in commercial statistical packages such as SAS (Statistical Analysis System). Data management has also acquired and developed programs and statistical packages that can significantly enhance a principal investigator's capabilities for data reduction and analysis (e.g., EAP, Ecological Analysis Package). This software provides graphic as well as table generation.

6.5 Data Documentation and Transmittal

One of the primary responsibilities of the data management section is the monthly transmittal of validated data to NESDIS. The following section describes the process, forms and documentation involved.

Newly validated on-line data is copied to magnetic tape and forwarded to the data manager at NESDIS. Included with the tapes are the

1. Letter of Transmittal - a form which briefly states the contents of the tapes which is signed by NESDIS staff personnel and returned to the data management section as verification that the

tapes have been received.

2. Cover letter and copy of Letter of Transmittal - this is sent separately and simply informs NESDIS that a tape is en route.
3. Tape dump - a hard copy of the actual contents of the data contained on the tape.
4. Data Documentation/Data Format - a form which gives specific information on the sampling parameters (location, type of vessel, etc.) and describes the data's format and variables.
5. File List - identifies the sequential location of a specific file contained on the tape.

Copies of these forms are kept by the data management section as well as the project manager for every data transmittal. The tapes are sent by certified mail in clearly marked mailing cartons which describe the contents. The certified mail receipt serves as verification that tapes were sent to NESDIS and the returned certified postcard, as well as the letter of transmittal, verifies that NESDIS received the tapes. A continuous monitoring of the data from validated data copied onto magnetic tapes to their arrival at NESDIS is thus established.

Two additional documentation forms are used in the summary of project data collection and analysis. A Report of Observations/Samples Collected by Oceanographic Programs (ROSCOP), which describes the data variables and collection parameters in an encodable form for the data base at NESDIS, is sent at the conclusion of each sampling cruise. The data management section also generates and updates monthly an inventory listing of the status of each project investigator's data files (see Table 6-1). This file contains information on the current status of each section's data and is used as a cross-reference between the data management section and

NESDIS to insure the project's data is completely transmitted and accurately identified. All of the project's validated data from the Bryan Mound site has been transmitted to NESDIS for the current report period.

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