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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—August 1983

March 1984

Work Performed Under Contract No. AC96-83PO10850

Texas A&M University
College Station, Texas

Technical Information Center
Office of Scientific and Technical Information
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Annual Report for the Bryan Mound Site

from September 1982 through August 1983

VOLUME III
Executive Summary

March 1984

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EXECUTIVE SUMMARY

Introductory Comments

Scientists and engineers at Texas A&M University have been conducting environmental studies of the coastal waters offshore of Freeport, Texas since September 1977. A 30-month study for the period September 1977 through February 1980 was completed before the initiation of brine discharge, and the results were presented in a predisposal report to the Department of Energy in December 1980. 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 at Bryan Mound which is located near Freeport, Texas. When the leaching is completed, the cavern is used for the storage of oil. During March and April 1980, an intensive postdisposal study was conducted to evaluate the immediate effect of brine disposal, and a final report was submitted to the Department of Energy in January 1981.

Brine discharge has continued on a near continuous basis to the present time, and three reports have been published which describe the findings. The first report 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 was published which described the results obtained during the first 18 months of study after initiation of brine discharge. The third report describes the results for the period September 1982 through August 1983, and it was published in June 1983.

The purpose of this report is to describe the findings for 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 is 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 and empirical prediction 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 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 multiport hydraulic 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

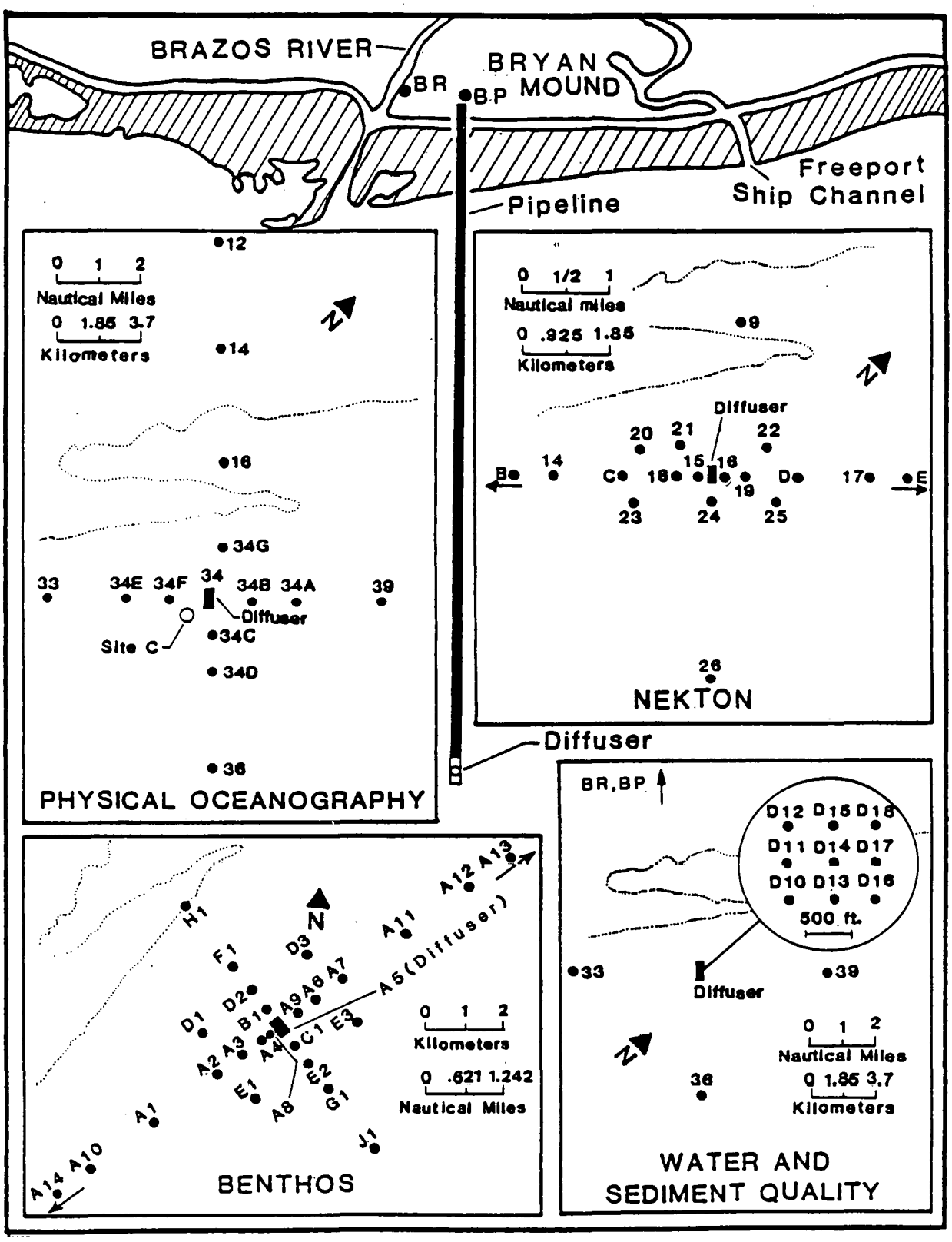

Figure 1. Composite of project sampling station locations.

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 began on March 10, 1980 through the 15 furthest offshore ports. During the first four months of operation, the brine was discharged for approximately 10 to 16 hours per day at a nominal flowrate of 230,000 barrels/day and a brine salinity of 240 o/oo. 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 1980. Since this time, the discharge has been almost always 24 hrs/day.

In November 1980, the brine discharge rate was consistently near 680,000 barrels/day, and by December the brine 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 three additional ports were opened for a total of 34 open diffuser ports, and the brine discharge subsequently was increased to near 750,000 barrels/day on August 23, 1981. In January 1982, it was increased to a daily average rate near 1,000,000 barrels/day which has been maintained to the present time with a brine salinity near 250 o/oo.

For the period of this report from September 1982 through August 1983, the average daily brine discharge rate, hours of operation, average

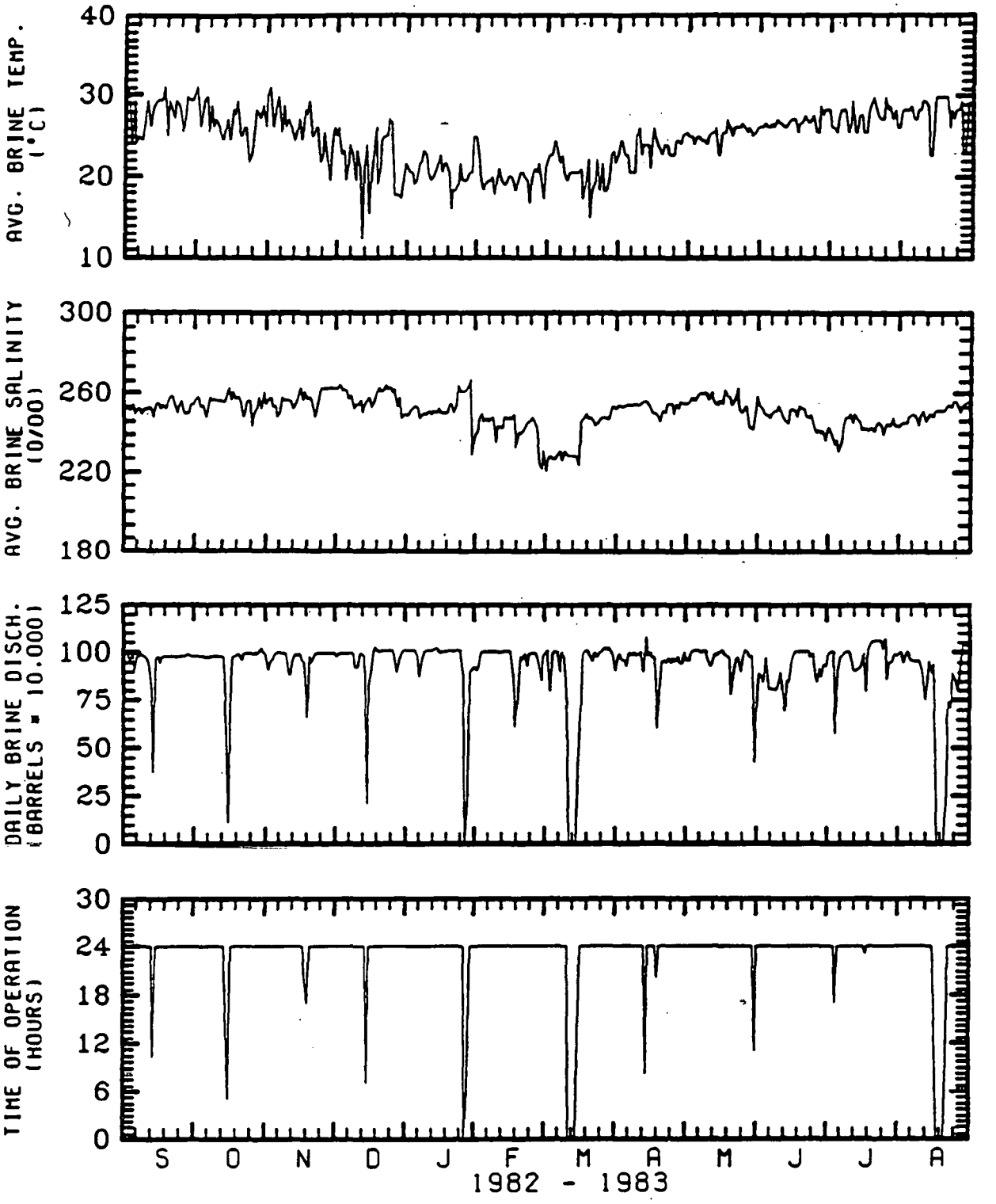

Figure 2. Brine discharge characteristics for the period September 1982 through August 1983.

brine salinity, and average brine temperature are illustrated in Figure 2.

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

Physical Oceanography

The physical oceanography studies utilize data collected primarily by Texas A&M University from in situ instrumentation and synoptic hydrographic cruises, near the Bryan Mound site of the Strategic Petroleum Reserve brine disposal operation offshore of Freeport, Texas. The focus is primarily on the period of September 1982 through August 1983, but results of recent analyses of data from other sources and other periods are also presented.

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 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 present 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 (station 34) 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.

At the diffuser site (station 34), 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 the present 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).

Brine Plume

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 ambient salinity of 34.7 o/oo. It was the second highest measured bottom salinity since brine disposal

began, and 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 +1 o/oo above ambient contour was 14.8 lm^2 on June 8 and 40.0 km^2 on August 11. The August 11 areal extent was the largest measured during the reporting period and the second largest since brine disposal began. The largest areal extent was 50.4 km^2 which was measured on January 24, 1982 during the 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 onshore, 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 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 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. The average maximum vertical extent was 3.3 m. The vertical profile measurements during this period were about 50% of the predicted jet 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.

In conclusion, the highest measured bottom salinity for the plume measurements during the reporting period 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 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 vertical extent during the period was 3.3 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 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 stratification 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.

Water and Sediment Quality

During this reporting period, water and sediment quality monitoring has consisted of collecting water samples quarterly at the fourteen stations shown in Figure 1. Twelve stations were located offshore in the vicinity of the diffuser and the remaining two stations were located onshore at the brine pond (BP) and the Brazos River (BR) raw water intake structure. 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 1981, February 1982, May 1982, 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^{+}, Br^{-}, I^{-}, 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 1982 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.

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 never during this reporting period 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 are small relative to controls 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. Comparison of gas chromatography/mass spectra data for sediment and brine pit hydrocarbons strongly suggests the brine to be this source.

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:

1. 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.

2. 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.

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 therefore 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.

Nekton

Nekton trawling was conducted aboard the R/V EXCELLENCE II at an array of eighteen stations centered around the diffuser site in 21.6 m of water as shown in Figure 1. The data were collected quarterly (November, February, May and August) during the day. The data collection and processing procedures were the same as those in previous studies. Collections were made with a 10.4 m Hollis-Special commerical trawl equipped with tickler chains and 4.4 cm stretched-mesh netting in the cod-end. All tows were made in a straight line, and duplicate tows were made at all stations at a speed of about three knots for ten minutes bottom time duration. These data were processed and analyzed in order to evaluate the impact of the brine disposal on the local nekton community.

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 (brown shrimp) has been the principal species, except during September 1981 through August 1982 study period when P. setiferus (white shrimp) 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 (longspined porgy) was the most numerous species, comprising a much greater percentage of catches than it had to date. Cynoscion nothus (silver sea trout) and Chloroscombrus chrysurus (Atlantic bumper), dominants on day-cruises in prior studies, were less abundant, though still a principal species. Other fishes that have been consistently abundant and usually principal species in inter-report comparisons included Syacium gunteri (shoal

flounder), Anchoa hepsetus (striped anchovy) and Peprilus burti (Gulf butterfish). 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 versus no brine contrast was significant. Furthermore, among-stations and brine related effects accounted for a relatively small portion of overall model variation.

Any impact which the 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 versus 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 versus 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.

In conclusion, it appears that brine disposal at Bryan Mound has had negligible 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 areas over which the stocks may range, 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 the age of 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 5 to 6 o/oo in the very near field and lower salinities within a very restricted

area. To date, the 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; Randall, preliminary data for September 1982 through August 1983). The maximum limits of higher observed brine elevations (3 to 6 o/oo) are much smaller (0.04 to 9.3 km^2). Therefore, areas impacted by the defined brine plume are negligible 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 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 mortalitics 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 (brown shrimp), P. setiferus (white shrimp), Anchoa mitchilli (bay anchovy), Cynoscion arenarius (sand seatrout), C. nothus (silver seatrout), Diplectrum bivittatum (dwarf sand perch), Leiostomus xanthurus (spot), Menticirrhus americanus (southern kingfish), Micropogonias undulatus (croaker), Paralichthys lethostigma (southern flounder), Stenotomus caprinus (longspined porgy) and Urophycis floridanus (southern hake) 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, before there might be any more than minor impacts on local nekton stocks/populations.

Benthos

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. Brine was considered to be included in the latter category, because it contains no organic material.

The brine diffuser area was first sampled on December 2, 1977. The original benthos sampling pattern consisted of 15 stations located on transects parallel with the shoreline, and also arranged in concentric circles centered around the brine diffuser location. In October 1977, four additional stations were added. These 19 stations were sampled monthly through February 24, 1982. In November 1981 a new sampling scheme was implemented which added seven new stations to the periphery of the study area, bringing the total number of stations to 26 as shown in Figure 1. This sampling 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 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.

Each station was sampled in triplicate by divers using Ekman grabs (232 cm^2 x 15 cm deep). On the bottom each grab was carefully moved to an undisturbed location by the diver and pushed into the bottom and triggered. Water and sediment samples were also collected immediately above the bottom.

The 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), principal components analysis (PCA) using the same species as in cluster analysis and pooled data from each station at each site 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. 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.

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. Pore water salinities have consistently been reported higher than bottom water, which is 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. A tendency for the average brine flow to be toward the southwest and/or offshore as indicated by the +0.5 o/oo isohaline was also detected.

3. Both the total numbers of species and individuals collected have returned to more "normal" levels. 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. Quarterly abundances over the entire project varied greatly at both control and brine stations. May and November showed the least variance.

6. Statistical analysis indicated that mean abundances were significantly higher at control stations in the first half of the year (November to February). No differences were noted in May or August. Species diversity around the diffuser remained significantly lower than at control stations throughout the year (November excepted).

7. 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.

8. Hypoxia was noted in the study area and it severely impacted the Crustacea.

9. Redox values and population levels were highly correlated: positive redox equals increased abundances, negative redox equals lower abundances.

10. Lead and cadmium have had no detectable impact as yet. The effects of increased concentrations or chronic exposure has not been determined.

11. 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.