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**WEST HACKBERRY STRATEGIC PETROLEUM RESERVE
SITE BRINE DISPOSAL MONITORING, YEAR I REPORT**

Final Report. Volume I, Executive Summary

February 1983

Work Performed Under Contract No. AC96-80PO10288

**McNeese State University
Lake Charles, Louisiana**

and

**Texas A & M University
College Station, Texas**

U. S. DEPARTMENT OF ENERGY

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WEST HACKBERRY STRATEGIC PETROLEUM RESERVE SITE BRINE DISPOSAL MONITORING

YEAR I REPORT
FINAL REPORT

VOLUME I
EXECUTIVE SUMMARY

EDITORS

L. R. DeRouen, Project Leader
R. W. Hann, Project Manager
D. M. Casserly, Technical Director
C. Giammona, Deputy Project Manager
V. J. Lascara, Field Coordinator

PRINCIPAL INVESTIGATORS

J. Beck, Special Pollutants
G. Gaston, Benthos
R. Ilg, Nekton
W. P. James, Hydrology and Hydrography
L. Jeffrey, Sediment and Water Quality
F. Kelly, Physical Oceanography
R. Maples, Phytoplankton
R. Randall, Hydrology and Hydrography
F. Slowey, Sediment Quality
S. Swetharanyam, Data Management
M. Vecchione, Zooplankton
D. Weston, Benthos
G. Wolff, Data Management

Prepared for the

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By

McNeese State University
Lake Charles, Louisiana

Texas A & M University
College Station, Texas
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The brine plume measurement requires long hours offshore and a great deal of tedious data recording and analysis. Drs. Robert E. Randall and Wesley P. James acknowledge the fine work of research associate, David Howell; research assistant, Neil McLellan; and student technicians, Jim Bolleter, Randy Grobe, Sylvia Hall, Phil Price, Charles Remkes, Robert Smith, James Tallent, and Brenda Wolf, in these tasks. Through their work the impact of the brine discharge on water resources in the area is estimated.

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Thanks are given also to the personnel at McNeese State University for the inter-university cooperation that has been achieved as a result of this project.

Finally, as in all large programs, there have been spin-off accomplishments and benefits that have accrued as ancillary to the main program mission. These can be measured in terms of new hardware development and scientific technique refinements. Several of the new hardware developments have directly aided industry. For example, Buoy Tech, Inc. has been aided in the redesign of a more effective, elastically tethered buoy system; the Hydrolab CTD system has undergone a significant evolution as a result of performance input from this project that was supplied to the manufacturer; both hardware and software developed to interface a Grundy CTD system with an HP 85 to

provide real time data and graphics while at sea; and Endeco current meters have had hardware modifications to make them the instrument of choice for this type of project.

The plume tracking sled and current meter calibration table are new hardware that have been developed and designed because of this project. New computer graphics, and hydrographic and plume prediction models are new software that are also spin-off benefits from this project that will transfer to government, industry, and the scientific community.

Other accomplishments are mentioned here to briefly document techniques that were new to this program. Underwater color video and 16 mm camera systems have been used to verify the accuracy of sampling methods as well as inspect the actual dispersion of the brine from the diffuser pipeline. An in situ biological sampling device was deployed whereby one could adequately and cost effectively carry out a monitoring study using the recruitment rates of selected zooplankters within and around areas of potentially stressful natural or anthropogenic activity. This method provides standardized sampling that eliminates the input of certain variables which need not be considered in cause-effect relationships and also reduces the amount of noise in the data sets. The sampling system results in less variable monthly and seasonal replicate samples and thus provides a continuous recording of the biological recruitment in the area allowing the

detection of not only the chronic effects of exposure to brine (or other stresses), but also catastrophic impacts that may have occurred between sampling efforts, even though recolonization may have also occurred.

In summary, the accomplishments of this project go beyond simply meeting the requirements of an EPA permit. Its technological and scientific advancements will be shared by the industrial and academic communities as well as by government. This is particularly significant as this report follows on the heels of the high-technology Oceans '82 Conference in Washington, D.C. In keeping with the conference's theme, "Industry, Government, Education--Partners in Progress," this research effort has provided a forum for the exchange of information and ideas to improve understanding and the transfer of technology among the partners.

ABSTRACT

The physical, chemical and biological attributes are described for: 1) a coastal marine environment centered about a Department of Energy Strategic Petroleum Reserve (SPR) brine disposal site located 11.4 km off the southwest coast of Louisiana; and 2) the lower Calcasieu and Sabine estuarine systems that provide leach waters for the SPR project. During the study period, the daily discharge averaged 529,000 barrels of 216 ‰ brine, representing a loading of 18,000 metric tons of salt per day.

Currents in the study area were westward in all months except July and were spatially coherent over long distances. Hydrographic surveys and in situ instrumentation detected a salinity difference between the diffuser site and the control sites which was attributed to the brine plume; typical differences were about 2 ‰, but ranged up to 4.6 ‰. No effect on the natural ambient water temperature was measured. Vertical profiles at the diffuser site showed plume effects as high as 3 m above the bottom. No thermal anomalies were introduced by the plume.

The brine is diluted by the diffuser to 4 or 5% above the ambient salinity, and is further diluted to 1% above the ambient salinity within 6km of the diffuser. An empirical procedure based upon measured plume data was developed to estimate the above ambient contours if the average bottom current, brine salinity, and brine discharge rate were known. The results of this procedure show reasonable agreement with the measured plume tracks.

Water and sediment quality results indicate that brine discharge had no definite impact on the area surrounding the diffuser. Nutrient levels of offshore and inshore waters were similar when considered for each sampling period. Water temperature, dissolved oxygen, pH, turbidity, and oil and grease at or near the diffuser compared to controls showed no adverse change resulting from the discharge of brine. Analyses for special pollutants indicated possible transport of low levels of some priority pollutants from the Intracoastal Waterway to the offshore diffuser area.

A grid of stations centered at the brine diffuser was monitored monthly for biological attributes during the first twelve months of brine discharge. Temporal and spatial distributions of species abundance and diversity were measured for the following: 1) macrobenthic invertebrates, 2) fishes and epibenthic megafauna, and 3) phytoplankton. These assemblages were studied relative to physical and chemical variations occurring in the study area. Emphasis is placed on dominant taxa and those species which support commercial and recreational fisheries.

The marine fauna and flora of the diffuser area were characteristic of coastal assemblages of the northwestern Gulf coast. Dramatic seasonal population fluctuations were documented, but communities were relatively homogeneous within sampling cruises. The macrobenthic community was numerically dominated by polychaetes; the

nekters were typical of the white shrimp community; and the phytoplankton community was dominated by estuarine and neritic diatom species.

One of the primary objectives of this monitoring program was the assessment of brine-related impacts on biotic communities. During the course of the year-long investigation changes in biological communities were observed. Seasonal variability in species abundances was a predominate feature as dramatic population fluctuations occurred in all groups studied. Differences among stations of relatively small magnitude were observed for many species and biomass estimates studied. Some of these differences were consistent when specific comparisons were made between control and diffuser area stations. They include: statistically significant differences in population densities of certain numerically dominant macrobenthic species, and significantly lower values for coefficient of condition (weight at length) of certain nekton target species collected in the vicinity of the brine diffuser, ($.05 < \kappa < .10$ for brown shrimp, sand seatrout, spot and southern kingfish; $.20 < \kappa < .25$ for banded drum). None of the observed changes in biotic communities were catastrophic in nature and all other measured parameters were either within expected ranges of or could not be attributed to diffuser activities.

Estuarine hydrography studies found that Calcasieu Lake was more saline than Sabine Lake and the Intracoastal Waterway by an average of 8 ‰. The measurements at the raw water intake for leaching

operations showed the water was more saline than that in Sabine Lake by an average of 2.3 ‰. Except during the fall of the year, both Calcasieu and Sabine Lakes were more saline in the southern portion of each lake which is nearest the Gulf of Mexico. No data collected during this study suggest that the brine discharged from the diffuser entered either of the lakes although an early concern was that the brine plume would enter Calcasieu Lake through Calcasieu Pass which is 15.9 km northeast of the diffuser. The longest measured and predicted distances of the +1 contour were 5.7 km and 7.25 km respectively. Water and sediment quality results indicate that brine discharge had no definite impact on the area surrounding the diffuser. Nutrient levels of offshore and inshore waters were similar when considered for each sampling period. Water temperature, dissolved oxygen, pH, turbidity, and oil and grease at or near the diffuser compared to controls showed no adverse change resulting from the discharge of brine.

The fauna and flora of the estuarine stations were typical of coastal plains estuaries. The data varied greatly among stations primarily based on sediment type, salinity, or depth regimes.

EXECUTIVE SUMMARY

This report describes the methodology and significant results of the first year's monitoring effort of the West Hackberry brine disposal site. The investigative tasks, presented as separate sections, are: Physical Oceanography, Estuarine Hydrology and Hydrography, Analysis of Discharge Plume, Water and Sediment Quality, Special Pollutant Surveys, Benthos, Nekton, Phytoplankton, Zooplankton and Data Management. Detailed information on the Strategic Petroleum Reserve Program can be found in the environmental impact statement and its supplements (DOE, 1981). Chemical and biological baseline survey results are available in a synopsis document (NOAA, 1981) of a nine volume baseline characterization produced by the National Marine Fisheries Service under an inter-agency agreement with the Department of Energy, and in a report by McNeese State University and Texas A & M University under Department of Energy contract (DeRouen et al, 1982).

Overview

The Department of Energy Strategic Petroleum Reserve Program plans to store 241 million barrels (bbl) of crude oil in the West Hackberry salt dome in southwest Louisiana. The salt caverns are created by solution mining in which low salinity intracoastal waters are injected into the salt dome and the resultant saturated brine removed for ultimate disposal. The large volumes of brine produced are disposed offshore through a pipeline and diffuser system. The diffuser is a

987.5 long (3240 ft), 91.4 cm (36 in) diameter pipeline with fifty-five 7.62 cm (3 in) ports spaced at 18.2 m (60 ft) centers. It was designed to disperse approximately 1.1 million barrels of brine per day at an exit velocity of 76.2 cm sec^{-1} (2.5 ft sec^{-1}). The seaward end of the diffuser is located 11.2 km (6.2 nm) southwest of Cameron, Louisiana at latitude $29^{\circ}39'52''\text{N}$, longitude $93^{\circ}28'35''\text{W}$.

The National Pollutant Discharge Elimination System (NPDES) permit for the discharge of brine from this facility requires that monitoring be done in accordance with an EPA approved monitoring plan which is part of the permit.

The study plan included a pre-discharge characterization and this post-discharge impact assessment. The objectives were to:

1. characterize the environment in terms of physical, chemical and biological attributes;
2. determine if significant adverse changes in ecosystem productivity and stability of the biological community are occurring as a result of brine discharge; and
3. determine the magnitude of any change observed.

An interdisciplinary team of scientists from McNeese State University has responsibility for the biological tasks (benthos, nekton, phytoplankton, and zooplankton) and the special pollutant task. Scientists from Texas A & M University have responsibility for the offshore physical and chemical oceanography of the study area and the estuarine hydrology and hydrography studies. A total of 34 stations was studied: 24 stations in the vicinity of the diffuser and 10

stations in the Calcasieu and Sabine estuarine systems (Figure 1, Table 1). Emphasis was placed on comparisons of control and diffuser stations along the 10 meter isobath. The data and results described herein were generated from a monthly monitoring effort during the first twelve months of brine discharge, May 1981 - April 1982.

Brine Discharge Data

Intermittent brine discharge began during mid-May 1981 at approximately 50,000 barrels (bbl) per day and 30 parts per thousand ($^{\circ}/_{oo}$) salinity with 31 of 55 diffuser ports open. Both discharge rate and salinity increased to 600,000 bbl per day and 220 $^{\circ}/_{oo}$ salinity by mid-July and continued at this level until late August. From late August to mid-September no discharge occurred. Intermittent pumping, resulting in low discharge volumes, occurred during mid-September to mid-October and again during January 1982. Discharge volumes increased to 500,000 bbl per day by February. Study period maximums of 750,000 bbl per day and salinities of 250 $^{\circ}/_{oo}$ were attained by late February and sustained through April 1982. During this time an additional 19 diffuser ports were uncapped bringing the total to 50 open ports. In late April, eight ports were recapped to maintain exit velocities. During the 12-month study period, the daily discharge averaged 529,000 bbl of 216 $^{\circ}/_{oo}$ brine equalling a loading of over 18,000 metric tons of salt per day.

Figure 1. West Hackberry Offshore Sampling Stations.

Station #	Latitude	Longitude	Loran C		Depth (ft.) (m)	
M-1	29°39'51.4"N	93°33'34.6"W	26522.4	46966.9	31	9.4
M-3	29°39'52.4"N	93°30'34.6"W	26550.6	46966.7	31	9.4
M-6	29°39'52.4"N	93°29'34.6"W	26560.0	46966.7	32	9.8
M-8	29°41'52.2"N	93°28'34.8"W	26580.0	46971.2	26	7.9
M-9	29°40'52.2"N	93°28'35.2"W	26574.8	46968.9	30	9.1
M-10	29°39'52.4"N	93°28'34.6"W	26568.8	46966.7	32	9.8
M-11	29°38'52.2"N	93°28'34.2"W	26564.6	46964.3	34	10.4
M-12	29°37'52.2"N	93°28'34.8"W	26559.6	46962.0	36	11.0
M-13	29°34'52.2"N	93°28'34.8"W	26544.0	46954.9	38	11.6
M-15	29°39'52.2"N	93°27'34.2"W	26579.4	46966.6	32	9.8
M-18	29°39'52.2"N	93°26'34.8"W	26588.4	46966.6	32	9.8
M-20	29°39'52.2"N	93°23'34.8"W	26617.0	46966.4	32	9.8
M-21	29°43'54.6"N	93°28'34.8"W	26598.8	46975.8	18	5.5
M-22	29°31'50.9"N	93°28'34.6"W	26528.9	46947.8	37	11.3
M-23	29°29'48.0"N	93°28'34.6"W	26513.2	46940.6	34	10.4
M10-A	29°40'09.0"N	93°28'12.6"W	26574.3	46967.2	31	9.4
DN	29°40'39.6"N	93°28'12.6"W	26577.4	46968.4	30	9.1
DS	29°39'35.0"N	93°28'12.6"W	26572.3	46966.0	33	10.1
DE	29°40'09.0"N	93°27'36.0"W	26580.3	46967.1	31	9.4
DW	29°40'09.0"N	93°28'43.0"W	26569.5	46967.2	32	9.8
NW	29°40'39.6"N	93°28'48.0"W	26571.5	46968.4	30	9.1
SW	29°39'37.2"N	93°28'48.0"W	26566.5	46966.1	33	10.1
NE	29°40'39.6"N	93°27'40.8"W	26582.5	46968.4	30	9.1
SE	29°39'37.2"N	93°27'36.0"W	26577.6	46966.1	32	9.8
Buoy P (E5)	29°46'11"N	93°20'38"W	in pass		20	6.0
D	29°39'54"N	93°28'44"W	46966.7	26568.8	32	9.8
S	29°27'07"N	93°26'00"W	46936.5	26530.2	41	12.5
N	29°42'50"N	93°28'24"W	46973.4	26585.8	21	6.4
W	29°38'30"N	93°40'00"W	46963.7	26454.8	31	9.4
E-1	30°03'32"N	93°26'09"W				
E-2	30°03'05"N	93°18'41"W				
E-3	29°51'33"N	93°22'00"W				
E-4	29°51'20"N	93°18'47"W				
E-5	29°46'11"N	93°20'38"W				
E-6	30°03'47"N	93°20'55"W				
E-7	30°03'35"N	93°41'55"W				
E-8	29°57'32"N	93°42'40"W				
E-9	29°54'07"N	93°48'13"W				
E-10	29°51'45"N	93°55'06"W				

Table 1. West Hackberry Offshore Sampling Stations.

Physical Oceanography

The monthly hydrographic cruises and in situ recorded time series of temperature and salinity together provide a coherent picture of the spatial distribution of the hydrographic variables and their temporal variation in the West Hackberry study area. Temperature has a large annual cycle with small short period variability. The lowest bottom temperature at the diffuser site was 9.4°C in January and the highest was 31.0°C in July. Cross shelf temperature differences are 2°C or less when the water column is warming and 3 - 4°C when it is cooling. Vertical temperature differences are less than 1°C most of the time, but in July and August top to bottom differences increase to about 3°C. No effect on the natural ambient water temperature due to brine discharge was measured.

Cross shelf salinity differences persisted throughout most of the study period, but exceeded 15‰ at times in June 1981 and March-April 1982. Vertical salinity stratification at the diffuser site was very strong in July 1981 reaching a maximum of 14 ‰. Temporal variations in ambient bottom salinity were up 10 ‰ over a few days and up to 8 ‰ in less than one day. The annual spring decrease in salinity began in June 1981, apparently later than normal because of a late maximum in Mississippi/Atchafalaya river discharge. In 1982, a decreasing trend in salinity began in March. The lowest ambient bottom salinity recorded at the diffuser site was 19.7 ‰; the highest was 32.7 ‰.

Salinity effects from brine discharge were clearly detected by both the hydrographic surveys and the in situ near bottom meter at the diffuser site. Salinity differences between the diffuser site and the control sites, at 1.0 m to 1.8 m above the bottom, indicate a maximum above ambient salinity increase of 4.6 ‰, and a typical increase of about 3 ‰. Vertical profiles indicate that salinity effects from brine discharge can reach a height of 3 m above the bottom near the diffuser.

Because of the low magnitude of short term temperature variability, density fluctuations and gradients are primarily determined by salinity.

Variation in dissolved oxygen near the bottom followed showed an annual cycle with a maximum of 9.2 mg L⁻¹ in February 1982 and a minimum of almost zero in July and August 1981. The hypoxic/anoxic conditions near the bottom covered the entire study area from the shore to 30 km offshore and 8 km east and west of the diffuser. Very close to the diffuser, there was an increase in dissolved oxygen during the anoxic period, apparently as a result of mixing induced by the discharge jets. The anoxia is apparently related to the strong salinity stratification and may be an annual event.

Currents were studied by a variety of methods. Most of the energy in the currents is contained in the lower frequencies of the along-shelf component. The cross shelf component has much less energy than the alongshelf component. Currents were found to be very coherent in

an alongshelf direction throughout the study area, and indeed, even as far as Bryan Mound site. Periods near 10 days and 3 days were the most strongly coherent. (The coherence squared function which is computed as part of cross spectral analysis is the counter part of the correlation coefficient of linear regression. Coherence is a measure of the similarity between fluctuations in two time series).

The alongshelf component of wind stress was found to be coherent with the alongshelf top and bottom currents, but only near a period of 3 days. At periods near 10 days, there was no significant coherence.

The monthly mean alongshelf current was downcast in all months except July 1981 at the surface. The upcoast current in July 1981 was in opposition to the mean alongshore wind which was downcoast in all months including July 1981.

A comparison of the West Hackberry and Bryan Mound diffuser sites shows that the residual component of bottom currents is much stronger at Bryan Mound. (The residual current is the current remaining after the mean and periodic components are removed). The tidal constituents at both sites are similar and have amplitudes of $2 - 3 \text{ cm s}^{-1}$. The long term mean bottom currents are slightly stronger at West Hackberry. The average current in the upper layers is weaker at West Hackberry (about one half). Average upwelling intensity is less at West Hackberry and strong stratification persists from spring to fall. These conditions suggest that the West Hackberry region may be more vulnerable than the Bryan Mound region, particularly during the summer

months to the effects of strong stratification such as low dissolved oxygen in the bottom layers, weaker residual bottom currents and weaker mixing.

Estuarine Hydrology and Hydrography

The twelve-month postdisposal study of the estuarine hydrography shows that Calcasieu and Sabine Lakes were found to be well mixed estuaries with occasional stratification, and the Intracoastal Waterway connecting the two lakes was also found to be well mixed with occasional stratification, and the Intracoastal Waterway connecting the two lakes was also found to be well mixed with occasional stratification. Calcasieu Pass was likewise found to be well mixed with occasional stratification.

The salinity data show the salinity in Calcasieu Lake increased from north to south except in October and November 1981 when the salinity on the east side of the south end of the lake was slightly fresher than that at the north end. The south end of Calcasieu Lake is divided into an east and west side, and the salinity in the sides was essentially the same except for these months when the west side was more saline than the east and just the opposite in one other month. In the Intracoastal Waterway, the salinity data show the salinity at the Calcasieu end of the waterway was always more saline except during July 1981 when large freshwater input to the waterway caused the Calcasieu end of the waterway to be less saline than near Sabine Lake. In Sabine Lake, the salinity increased from north to south during May through

August 1981 and reversed the trend from September through December. The north to south salinity increase returned during the remainder of the year.

The maximum salinity in the Calcasieu Lake, Intracoastal Waterway, and Sabine Lake was 26.8 ‰, 20.5 ‰, and 19.2 ‰ respectively. The Calcasieu Lake, Intracoastal Waterway, and Sabine Lake had minimum salinities of 2.2 ‰, 0.2 ‰, and 0.3 ‰ respectively. The average salinity data for Calcasieu Lake, Intracoastal Waterway, and Sabine Lake show Calcasieu Lake was more saline than Sabine Lake by an average of 8.0 ‰. These data also show the water available at the raw water intake for leaching operations was more saline than that in Sabine Lake by an average of 2.3 ‰.

The dissolved oxygen data indicate no persistent anoxic conditions were observed. The annual dissolved oxygen cycle consisted of a minimum occurring usually during the summer months and a maximum being reached in the winter months. The average data during this study show the minimum in Calcasieu Lake, Intracoastal Waterway, and Sabine Lake was 5.5, 4.9, and 6.2 mg L⁻¹ which occurred in August, July and September respectively. The average dissolved oxygen maximum in Calcasieu Lake, Intracoastal Waterway, and Sabine Lake was 10.6, 10.9, and 10.4 mg L⁻¹ respectively with all of them occurring in January 1982. The three water systems had dissolved oxygen values which were normally within 1 mg L⁻¹ of each other indicating very little

dissolved oxygen variation within the Calcasieu-Sabine estuarine system.

The temperature data illustrated the annual cycle for the Calcasieu-Sabine estuarine system. The maximum average temperature for the Calcasieu Lake, Intracoastal Waterway, and Sabine Lake were 30.0°C, 31.1°C, and 30.9°C respectively with all of them occurring in August. The minimum average temperature in the same order was 6.5°C, 8.9°C, and 9.1°C respectively and each of them, again, occurred in January 1982. The salinity data show no indication of the discharge brine entering Calcasieu Pass and subsequently increasing the salinity of Calcasieu Lake. The Sabine Lake data also show no indication of the brine discharge entering that lake. This result is further confirmed by the brine plume measurements (Chapter 4) which show the +1 ‰ above ambient salinity contour never reached the entrance to Calcasieu or Sabine Lake.

The U.S. Geological Survey's daily streamflow records for Calcasieu and Sabine Lakes were obtained for the period October 1967 through October 1981. The streamflow records indicated that the low flow period for Calcasieu Lake extended from July through November. Because of reservoir storage in the drainage area, the low flow period for Sabine Lake included only October and November. It was estimated that the gauged freshwater inflow to Sabine Lake represented 82% of the total freshwater inflow to Sabine and the gauged inflow to Calcasieu Lake represented 70% of the total freshwater inflow to Calcasieu Lake.

Texas Department of Water Resources conducted a study of Sabine Lake and developed equations relating average monthly gauged freshwater inflow to average monthly salinity in upper Sabine Lake. Three years of salinity data were available for Calcasieu Lake and a similar expression was developed for Calcasieu Lake relating average monthly gauged freshwater inflow to salinity in the upper Calcasieu Lake. From these equations, changes in salinity resulting from changes in gauged freshwater inflow were computed for each lake.

The flow characteristics of the ICWW were evaluated to determine (1) how much water flows in the ICWW from Sabine to Calcasieu or from Calcasieu to Sabine, and (2) how much of the water pumped from the ICWW is from Calcasieu and how much is from Sabine. The raw water intake structure is located closer to Calcasieu Lake than Sabine Lake. It was estimated the 65% of the pumped water would represent a diversion from Calcasieu and 35% of the pumped water would represent a diversion from Sabine regardless of the direction of flow in the ICWW. During the period of low freshwater inflow to the Calcasieu/Sabine system, the salinity of the diverted water increases and much of the pumped water is from the Gulf of Mexico rather than freshwater inflow.

Changes in salinity caused by pumping 1.98 cms (70 cfs) and 1.42 cms (50 cfs) from the ICWW were estimated for upper Calcasieu Lake and upper Sabine Lake. These computations indicated that a diversion of 1.98 cms (70 cfs) from the ICWW would cause a maximum increase in salinity of 0.45 ‰ in the Calcasieu system and 0.09 ‰ in the

Sabine system. A diversion of 1.42 cms (50 cfs) from the ICWW would cause a maximum increase in salinity of 0.32 ‰ in Calcasieu and 0.07 ‰ in Sabine. The maximum increases in salinity would occur in the ICWW and the Calcasieu ship channel with smaller salinity increases in upper Calcasieu Lake.

The following conclusions were reached in this part of the study concerning pumping water from the ICWW.

1. The project should not increase salt water intrusion into the groundwater aquifers of the area. Salt water intrusion is caused by over pumping the aquifers and not the salinity level in Calcasieu Lake.
2. The project should not increase the salt water intrusion into the freshwater marsh areas. Salt water intrusion occurs when the water table is lowered by evapotranspiration during low rainfall periods and/or the recharge has been reduced. The construction of the ICWW has modified the overland flow recharge of the wetlands south of the ICWW and is probably responsible for much of the salt water intrusion into freshwater marsh areas.
3. The project will increase the salinity in upper Calcasieu Lake. Model study indicates the largest change in salinity (0.5 ‰ maximum) will occur in the ship channel and in the ICWW. The increase in salinity in upper Calcasieu Lake will be less (0.2 ‰ maximum).

4. The increase in salinity of the salt water wedge up the Calcasieu River at Lake Charles is expected to be in the order of $0.01 \text{ }^{\circ}/\text{oo}$.

No conclusion was reached as to whether or not the pumping would cause a significant increase in salinity. When these changes are compared to the natural variations that occur in these estuaries, it can be concluded that the project by itself will probably not cause a significant increase in salinity. However, the effects of the diversions are additive and when the effects of all present and future diversions are considered, there will be a significant change in salinity. At some level of diversion, it may be necessary to limit or restrict additional diversions of the system.

It is concluded that Calcasieu and Sabine Lakes are well mixed estuaries and that no data collected during this study suggest that the brine discharged from the West Hackberry diffuser entered either of the lakes.

Brine Plume Measurements

A plume tracking system consisting of a towing sled which housed a conductivity, temperature, and depth (CTD) probe was towed by a research vessel on a predetermined search course through the expected brine plume area. The probe continuously measured the conductivity of the water at a distance of 25.4 cm (10 in) above the sea floor. It was then converted to salinity. These data were recorded and subsequently used to construct isohaline contour plots which indicate the areal

coverage of the plume and the magnitude of the excess salinity concentration. In addition, vertical salinity and dissolved oxygen profiles were measured in the vicinity of the diffuser to evaluate the vertical extent of the plume and the effect of the brine discharge on the vertical distribution of dissolved oxygen.

Brine discharge was scheduled to begin on May 10, 1981, and brine plume measurements were planned for once a week during the first month after discharge began, once every two weeks during the second month, and once a month thereafter. The first two plume measurements were made on May 25 and June 1, 1981, but no contours were closed which was attributed to low brine salinity. The June 9 plume measurement resulted in a closed contour of 30 ‰ which encompassed an area of 9.4 km². The +1 above ambient contour covered a small area of 0.3 km², and the highest salinity was 30.9 ‰ which was 1.2 ‰ above the ambient salinity. On this date, the brine was being discharged at a rate of 23,580 barrels hr⁻¹ and a salinity of 178 ‰.

The June 17 plume measurement resulted in only a +1 ‰ salinity contour encompassing an area of 0.4 km². The first large brine plume was measured on June 30 when the discharge rate was 28,307 barrels hr⁻¹ and the brine salinity was 208 ‰. High salinity stratification and large cross shelf salinity variation were present on this date which made it very difficult to evaluate the ambient salinity. Results showed the closing of a +4, +3, +2, and +1 ‰

contours with inside areas of 0.6, 3.9, 9.4, and 22.8 km². The July 17 plume measurement completed the initial weekly and biweekly plume tracking cruises, and it did not show any closed contours.

On August 12, 1981, brine was being discharged at a rate of 25,643 barrels hr⁻¹ and a salinity of 228 ‰. The highest measured salinity was 32.1 ‰ and the highest above ambient salinity was 4.4 ‰. There were four closed above ambient salinity contours (+1, +2, +3, and +4) and the areal coverage inside these contours was 32.2, 10.8, 4.2, and 1.1 km² respectively. The 32.2 km² area was the largest areal extent measured for the +1 ‰ contour during the first year of discharge, and the longest distance from the diffuser to the +1 contour was 5.7 km in the direction of 199°T (True North).

During September, the brine discharge was stopped and no plume measurements were attempted. The next plume measurement was conducted on October 28 when the brine was being pumped at a rate of 24,500 barrels hr⁻¹ and a salinity of 225 ‰. The highest measured salinity was 35.8 ‰ and four above ambient contours were determined with areas of 6.6, 1.5, 0.5, and 0.1 km² inside the +1, +2, +3, and +4 ‰ contours respectively.

The November and December plume measurements were conducted when the brine discharge rate and salinity were near 21,500 barrels hr⁻¹ and 205 ‰, respectively. The November data shows that four above ambient contours were measured and the area inside the +1 ‰ contour was 20.3 km². The December data resulted in three above

ambient contours with the +1 ‰ contour covering an area of 8.4 km². The highest salinity measured on these dates was 34.4 ‰ and 34.3 ‰ in November and December respectively.

During January, the brine discharge was being batched which means brine was being pumped to the Gulf of Mexico for only short periods of time (approximately 8 to 12 hours), and consequently, no measurements were attempted. On February 14, 1982, the brine discharge was back to a continuous operation with a rate of 23,892 barrels hr⁻¹ and salinity of 217 ‰. The highest salinity (36.0 ‰) and highest above ambient salinity (+4.9 ‰) were measured on this date in the immediate vicinity of the diffuser, and four above ambient contours were measured. The areas inside the +1, +2, +3, and +4 contours was 23.2, 12.4, 2.5, and 0.5 km².

In March 1982, the brine discharge was greatly increased to 35,042 barrels hr⁻¹ and the salinity was 180 ‰. The combination of the high discharge rate and low brine salinity resulted in no closed salinity contours. The April 30, 1982 discharge rate was 23,315 barrels hr⁻¹ and the salinity was 224 ‰. This plume had three above ambient contours with inside areas of 19.9, 10.0, and 4.9 km² for the +1, +2, and +3 ‰ contours respectively, and the highest salinity was 31.6 ‰.

Distances were measured from the center of the diffuser to the various above ambient contours. These data indicate the longest distance to the +1 ‰ above ambient contour was 5.7 km (3.1 nm)

from the diffuser in the direction of 199°T, or southsouthwest of the diffuser. The longest distance to the +2, +3, and +4 ‰ contours was 4.4, 3.4, and 1.7 km (2.4, 1.8, and 0.9 nm) respectively. The maximum inshore and offshore distances for the +1 ‰ above ambient contour were 2.9 km (1.6 nm) and 5.3 km (2.9 nm). In the upcoast and downcoast direction, the largest distances to the +1 ‰ above ambient contour were 2.7 km (1.5 nm) and 4.8 km (2.6 nm) respectively.

During the 12 month study, the bottom temperature data collected during the plume measurements show no indication of significant thermal plume. The maximum difference between the brine temperature measured at the brine pit and the ambient bottom temperature in the offshore area was only 8.3°C. The bottom temperatures measured during the plume tracks varied less than 1°C and were considered nearly isothermal.

The vertical extent of the plume was determined by measuring vertical salinity profiles directly over and in the immediate vicinity of the diffuser. These profiles were then compared to the ambient profile. The vertical distance above the bottom at which the salinity profile deviated from the ambient profile was determined to be the vertical extent of the brine plume, and these values were then compared to the values computed from empirical relationships.

The diffuser had 32 open ports for every vertical profile measurement except for April 30, 1982. On June 1, 1981, the measured vertical extent was 2.5 m while the computed vertical extent was 6.7 m. The June 9 and 30 profiles indicated the vertical extent was 0.6 m and

1.5 m while the computed values predicted 4.5 and 4.6 m respectively. These data indicate the measurements were not taken directly over the diffuser ports and thus, the measured data are much lower than the computed values. The August and October vertical profiles were nearly 50 percent of the computed values, and the exit velocities for these dates were 7.8 and 7.4 m s⁻¹. The exit velocity dropped to 6.6 m s⁻¹ on November 25 and December 16, and the measured vertical extent dropped to 1.5 and 2.0 m while the computed values were 3.9 and 4.0 m respectively.

The February 14, 1982 profile shows a 2.2 m vertical extent while the computed value was 4.1 m. The brine discharge rate increased greatly on March 1, 1982 which resulted in an exit velocity of 10.6 m s⁻¹. The computed vertical extent was 6.0 m, but the measured value was only 0.6 m. The low brine salinity made it very difficult to determine any deviation from the ambient salinity profile. The April 30, 1982 vertical salinity profile clearly shows a rapid departure from the ambient profile at 2.1 m while the computed vertical extent was 3.3 m due to the decreased exit velocity of 5.4 m s⁻¹.

In all the vertical profiles, the measured vertical extent was much less than the computed values indicating the measured vertical data was taken from the plume settling around the diffuser area and not from the area directly over the brine jets whose vertical extent is believed to be much higher and closer to the computed values. Using all the vertical profile data, the average exit velocity was 7.6 m

s^{-1} and the average computed vertical extent was 4.5 m. The average measured vertical extent was 1.8 m which is 40% of the computed value. In the Bryan Mound study (Randall, 1981a), the initial period of discharge (March 10 through July 15, 1980) showed the average exit velocity was 6.7 m s^{-1} , and the average measured and computed vertical extent was 3.7 m and 4.0 m respectively. During the second period from July 16, 1980 through August 24, 1981, the average exit velocity was 8.0 m s^{-1} and the average measured and computed vertical extent was 5.2 and 4.5 m respectively. The low measured vertical extent of West Hackberry plume is believed to be caused by the inability to keep the CTD/DO sensor directly over the diffuser, and consequently, the height of the plume settling to the bottom is the value measured. The lower brine salinities for the West Hackberry discharge is also a cause of the low measured vertical extent.

Vertical dissolved oxygen profiles were collected simultaneously with the vertical salinity profiles, and the data collected in the vicinity of the diffuser were compared to that collected at the control stations. A deviation in vertical distribution between the diffuser stations and the control station was interpreted as an effect due to the brine discharge. On June 9, 1981, the vertical profile measured directly over the diffuser showed the dissolved oxygen decreased sharply to 3.9 mg L^{-1} at 8.8 m and then increased slightly to 4.2 mg L^{-1} at the bottom. The slight increase in dissolved oxygen near the bottom in contrast to the continued decline of the dissolved

oxygen at the control station to a value of 2.8 mg L^{-1} . It is believed that the brine discharge entrains the higher oxygenated water in the negatively buoyant plume as it falls to the bottom and spreads over the sea floor.

The July 17 vertical dissolved oxygen profiles were collected during a period of anoxia in the bottom waters which covered an extensive bottom area along the Gulf coast and far exceeded the small area covered by the brine plume. The vertical profile measured directly over the diffuser showed the dissolved oxygen gradient was noticeably less than that at the control station and this was similarly attributed to the brine discharge. The bottom dissolved oxygen value at the control station was 0.2 mg L^{-1} , and at the diffuser site, it was 0.5 mg L^{-1} , so the brine discharge apparently affected the gradient, but it did not remove the anoxic conditions.

The August 12, 1981 vertical dissolved oxygen profiles indicated the anoxic conditions had disappeared and there was only a small decrease in dissolved oxygen from surface to bottom. These same results were obtained at both the diffuser site and control stations. Similar results were obtained for the months of October 1981 through March 1982. However, the April 30, 1982 data showed a stronger dissolved oxygen gradient from surface to bottom, and similar results were obtained as those observed on June 9 which again was attributed to the brine discharge.

The experimental data collected during the plume measurements were used to develop an empirical procedure for predicting the areal extent of the plume. For this procedure, the upstream and downstream distance from the center of the diffuser to the above ambient contours and the maximum width of each contour were measured from actual plume measurements. These data were plotted as a function of a parameter consisting of the average bottom current, discharge rate, brine salinity and ambient salinity. Least squares curve fits were made to the data in order to obtain empirical relationships for the upstream length, downstream length, and width. Thus, the lengths and widths of the above ambient contours were estimated and the end points were connected using arcs of an ellipse. The results of the empirical predictions were compared to actual plume measurements and the procedure provided reasonable estimates of the plume contours. The ability to predict the existence of above ambient contours and empirical equations for higher above ambient contours needs to be developed as a more extensive data base becomes available. These procedures were used to provide plume estimates for periods when plume measurements were not available provided the average bottom current, brine salinity, and brine discharge rate were known.

The percent of time a specific area in the vicinity of the diffuser was exposed to +1, +2, and +3 ‰ above ambient salinity was estimated for the 12 month study period. The empirical equations for evaluating the size of the brine plume, the bottom current meter

data in the diffuser area, and the brine discharge data for the entire 12 month postdisposal period were used for this computation. Over the 12 month (approximately 365 days) postdisposal period, of which 56 days could not be analyzed because of lack of data, the percent exposure time to the +1, +2, and +3 ‰ above ambient salinity was predicted in the vicinity of the diffuser. The results indicate that the percent exposure time was fairly evenly distributed in all directions. There was some favoring of the W, WNW, and NW directions, and the least percents of exposure time were usually in the E, ESE and SE directions. The maximum extent of the +1, +2, and +3 contours was 7.25, 4.25, and 2.75 km (3.9, 2.3, and 1.5 nm) from the center of the diffuser.

The highest bottom salinity of 36.0 ‰ was measured on February 14, 1982, and it was 4.9 ‰ above the ambient salinity. The brine was being discharged at a rate of 23,896 barrels hr^{-1} and a salinity of 217 ‰. The highest above ambient salinity contour measured during the year was +4 ‰ which occurred on June 30, August 12, October 28, and November 25 in 1981, and February 14 in 1982. A +3 ‰ contour was measured on June 30, August 12, October 28, November 25 and December 16 in 1981 and on February 14, and April 30 in 1982. The largest areal extent within the +1 ‰ contour was 32.2 km^2 which occurred on August 12, 1981. The maximum measured horizontal extent of the salinity plume based on the +1 ‰ above ambient salinity contour was 5.7 km (3.1 nm) from the diffuser. Thus, it is concluded that the diffuser is diluting the brine to 4 to 5 ‰

above the ambient salinity and it is further diluted by advection and turbulence to 1 ‰ above the ambient salinity within 6 km of the diffuser.

An early concern was that the brine plume would enter the Calcasieu Lake through Calcasieu Pass. The Pass is 15.9 km northeast of the diffuser and the longest measured and predicted distances of the +1 contour were 5.7 km and 7.25 km respectively. Thus, it is concluded that the brine did not enter Calcasieu Pass or Calcasieu Lake.

Water and Sediment Quality

Nutrient levels of offshore and inshore waters were similar when considered for each sampling period. Highest levels were found in inshore and bottom offshore waters. This was true for all nutrients except for the possible exception of nitrate, which was higher in offshore surface water during portions of the year. Water temperature, dissolved oxygen, pH, turbidity, and oil and grease at or near the diffuser compared to controls have shown no adverse change resulting from the discharge of brine. Low dissolved oxygen observed at all stations in early July 1981 appeared to be related to a broader environmental problem rather than to brine discharge. Although some increase in bottom water salinity at the diffuser and near diffuser stations relative to controls was observed, major ions and ion ratios measured in the water column and sediment pore waters indicate that brine discharge had no adverse effect on these parameters during the first year of discharge. Although levels of some major ions (Na^+ ,

Cl⁻) were elevated near the diffuser relative to controls, fluctuations during the period made it difficult to establish a pattern for these major ions. These fluctuations probably resulted from variations in brine salinity and discharge rate during the past year. Similar fluctuations were observed at Bryan Mound during the first year of discharge after which a pattern was established showing an increase in these parameters with time. The trend observed at Bryan Mound would suggest that similar changes might be expected to occur at the West Hackberry site with time.

Most of the estuarine sediments were poorly sorted clayey silts with average mean diameters in the range of 6.49 to 8.23 ϕ units. All the nearshore sediments showed some variability from month to month, but E3 and E5 were highly variable in grain size distribution. This variability with time is probably caused by tidal movement of bottom sediments. Most of the offshore sediments were silty clays with average diameters in the range of 7.08 to 9.86 ϕ units. One exception was M22 with average grain size diameter of 2.91 ϕ (a sandy sediment).

Total organic carbon (TOC) of both nearshore and offshore sediments varied by a factor of two at a given station over the period of May 1981 to April 1982. There is no real evidence that the diffuser has had any impact on the TOC of the sediments around the diffuser. Although the sediments in the nearshore area were somewhat coarser in grain size distribution, the concentration levels of TOC of the estuarine sediments were about the same overall.

At times pore water salinities become elevated at several stations around the diffuser, but they can within a month decrease to a lower value, depending on the overlying water salinity. There does not appear to be a steady accumulation of salt in the upper three inches of sediment at the end of 18 months. It would be of interest to collect cores at stations M10 and M10A and determine the pore water salinity with depth to see how far the diluted brine might extend.

It should be noted also that really excessive pore water salinities have not been found in the impacted stations yet.

The pore water salinity of the sediments at E1, E2, E3, E4, and E5 were lower than the offshore sediments as expected, but also variable with similar pore water salinities. There is no evidence that the operation of the brine diffuser had any impact on the pore water salinity of the estuarine sediments.

Special Pollutants

The special pollutant survey was designed to monitor effects of brine discharge on the redistribution of pollutants from the Intra-coastal Waterway as well as contamination originating from the West Hackberry salt dome. The pollutants measured included the major ions, Sodium (Na), Potassium (K), Magnesium (Mg), Calcium (Ca), Chloride (CL), Sulphate (SO_4); the total metals, Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), Mercury (Hg) and Zinc (Zn); as well as pesticides, herbicides and high molecular weight hydrocarbons. Water samples were collected using a 3 liter Van Dorn bottle in the

Intracoastal Waterway, the brine pond and at the diffuser. Sediment samples were collected in the Intracoastal Waterway (0.05 m² Ekman grab sampler) and at the diffuser (0.1 m² Smith-McIntyre grab sampler). In order to determine whether pollutants were transferred to the biota, tissue samples were also collected. The selected species included white shrimp (Penaeus setiferus), moon snail (Polinices duplicatus) and spider crab (Libinia dubia).

The average major ion concentrations in the brine were: Cl (128 ‰); Na (78 ‰); SO₄ (2.66 ‰); Ca (0.77 ‰); Mg (0.20 ‰) and K (0.19 ‰). Compared to diffuser area seawater, the brine contained approximately ten times more Na and Cl ions and two times the Ca concentration.

The major ion concentrations and ionic ratios in mid-depth diffuser waters and diffuser area sediments were not appreciably altered due to brine discharge. Those concentrations were higher in the marine sediments as compared to the intracoastal sediments. Heavy rainfall prior to the March 1982 sampling period resulted in lower ion concentrations when compared to previous surveys.

Heavy metal concentrations are considered low with As, Cd, Cr and Zn values at or near detection limits for most samples. Diffuser area sediments typically contained higher heavy metal concentrations for Cr, Cu and Zn than Intracoastal Waterway sediments at Station E1.

Heavy metal concentrations in March 1982 brine water samples differed from previous surveys. Higher concentrations of Cu (4.0

$\mu\text{g L}^{-1}$), Cr ($70 \mu\text{g L}^{-1}$), Hg ($6.0 \mu\text{g L}^{-1}$) and Zn ($180 \mu\text{g L}^{-1}$) were observed during this month. Hg ($0.6 \mu\text{g L}^{-1}$) and Zn ($50 \mu\text{g L}^{-1}$) were also higher at the diffuser station than during previous surveys.

Arsenic, Cd and Cr concentrations in biota were near or below detection limits. No clear trend of changing metal concentrations was apparent in the biota; however, concentrations of Cr, Cd and Hg were slightly elevated in the March 1982 survey.

Repetitive GC/MS scans detected only high molecular weight hydrocarbons of biogenic origin and in the March 1982 survey high concentrations of bis-(2-ethyl-hexyl) phthalate and di-n-butyl phthalate. Pollutants quantified by electron capture detectors included: PCB-1242, hexachlorobenzene (HCB), silvex, parathion, and delta-BHC. In March 1982 PCB-1242 and HCB were found in all samples collected and appear to be accumulating in the biota. Bis-(2-ethyl-hexyl) phthalate was found in extremely high concentrations in sediments and biota. The other compounds were generally found in sediment samples only.

These data suggest that some target pollutants are widespread in the area while others may be transported from Intracoastal Waterway to the diffuser area. Future surveys will reveal the consistency and significance of these observations.

Marine Biology

Monthly biological sampling occurred at a minimum of nine marine stations centered about the diffuser (Figure 1). The stations are aligned in an east-west transect approximately along the 10 meter isobath and in a north-south or across-shelf transect. Emphasis was placed on comparisons of control versus impacted sites with determination of cross-shelf and temporal variations as secondary objectives. Species abundances and diversity were measured for: 1) macrobenthic invertebrates; 2) fishes and epibenthic megafauna; 3) phytoplankton; and 4) zooplankton. These assemblages were studied relative to physical and chemical variations occurring in the study area.

Upon arrival at each station and prior to biological sampling, general oceanographic and meteorological observations and a water quality profile were recorded. Data include the field LORAN C reading, time (GMT), date (GMT), depth (m), wind direction (tens of degrees), wind speed (nmi h^{-1}), weather, cloud cover and sea state. The weather and sea state conditions were obtained on site from the NOAA weather service, visually verified and recorded using the NOAA codes.

Conductivity ($\mu \text{ mho cm}^{-1}$), temperature ($^{\circ}\text{C}$), depth (m), dissolved oxygen (mg l^{-1}), and pH profiles were taken with a Hydrolab Series 8000 meter. The measurements were taken within one meter of the bottom, within one meter of the surface and every three meters in between. If stratification was evident, the profile measurements were performed at one meter intervals. Water samples were

also collected at the surface, mid-depth, and near the bottom with a Van Dorn bottle for nephelometric turbidity analysis.

Benthos

Benthic samples were collected monthly using a 0.1m² Smith-McIntyre grab sampler. Samples were rinsed on board ship; organisms retained on a 0.5 mm sieve were preserved in a buffered solution of 10% formaldehyde in seawater and returned to the laboratory for further analyses. All invertebrate organisms collected were identified to the lowest possible taxon, usually species, and enumerated. Concurrent sediment samples were collected for analyses to assist in the interpretation of benthic data.

Surficial sediments of the offshore study area were generally silty clays with approximately 10% sand, 35% silt and 55% clay. With only a few exceptions (most notably M3) there was a general homogeneity in sediment type among the stations. Of particular importance was the similarity in substrate composition among selected control (M18 and M20) and near-diffuser (M10A and DW) sites. This close similarity in sediment type, and the consequent similarity in faunal composition, enhanced the potential for detection of brine discharge impact in matched site comparisons.

Inter-replicate substrate variability at a given station was generally consistent month after month supporting the contention that this variability was a reflection of habitat patchiness. Temporal

variability was evidenced by an increase in median particle diameter (decreased ϕ) during the summer of 1981.

The marine macrobenthic fauna of the study area was characterized by strong numerical dominance of relatively few species. These dominant species exhibited dramatic population fluctuations both spatially and temporally. Following the onset of brine discharge in May 1981, several species of macrobenthos irrupted in large numbers in the immediate area of the brine diffuser. These species included the polychaete, Mediomastus californiensis, and Phoronis sp. A. Both are opportunistic species whose population irruptions may be in response to environmental perturbation.

During July-September 1981, the bottom waters of the study area were hypoxic and periodically anoxic. This condition was less severe near the diffuser (station M10A) due to increased dissolved oxygen concentrations in the brine plume. The effects of hypoxia were reflected by decreases in both total macrobenthic species and total individuals at control (stations M18 and M20), diffuser and near-field sites (stations M10A, DW, M10, DE). Stations M10A and M10, however, temporarily maintained higher species numbers during hypoxic conditions.

Of the top five numerically dominant species, three showed no consistent statistically significant differences in density between impact and control stations. Two species, Magelona cf. phyllisae and Cirratulus cf. filiformis, did show such differences. M. cf. phyllisae

showed significantly higher densities at impact sites in 6 of the 12 months. C. cf. filiformis was the dominant species from November 1981 to May 1982, attaining densities exceeding 5000 individuals m^{-2} . Population levels at control sites were significantly higher than those at the diffuser and near-field sites. Interstitial salinity values at sites M10A and DW were consistently 2-3 ‰ above those of control stations during much of the sampling period, confirming the potential for impact.

No consistent statistically significant differences in total macrofaunal density was observed between impact and control stations. Significantly greater numbers of species were observed at impact sites compared to control sites. This is evident in Shannon diversity index values, most notably in the species richness component of the index. This variation existed in both pre- and post-discharge investigations.

Nekton

Fishes and epibenthic macrofauna were sampled using a 15.2 m semi-balloon otter trawl with 19 mm square mesh. Duplicate samples were collected monthly during the day at 11 stations. Total numbers and total weights were recorded for all species whereas individual lengths and weights were measured and recorded for sciaenid fishes and penaeid shrimps.

In general, nektonic organisms collected in the West Hackberry study area were typical of the white shrimp community assemblage described by Chittenden et al. (1980). The important commercial and

recreational species captured included Penaeus setiferus (white shrimp), Penaeus aztecus (brown shrimp), Callinectes sapidus (blue crab), Micropogonias undulatus (Atlantic croaker), Cynoscion arenarius (sand sea trout), Cynoscion nothus (silver sea trout) and Menticirrhus americanus (southern kingfish).

Dominant trends in the data did not appear to be related to operation of the brine diffuser. Analyses have indicated that bottom depth, season, and dissolved oxygen content of the bottom waters varied more consistently with the biological data than did within-cruise changes in temperature, salinity, pH or turbidity. Samples from the near shore station (M21 at 4m depth) usually contained the largest total numbers of specimens. Samples with the smallest total numbers usually were collected at the deepest station (M22 at 11 m depth). Intermediate numbers of individuals were generally collected at the stations along the 10 m isobath. An overall seasonal trend of total numbers (large in the summer and small in the winter) was interrupted in late June and early July. During these months, catches were limited by low dissolved oxygen concentrations in the bottom waters of all stations except M21, the 4m station.

Cluster analysis of the monthly data sets indicated that the diffuser station (M10A) and the down-current near-field station were consistently similar to each other. This station pair was usually distinct from the remaining stations along the east-west transect. In contrast, during three months of sampling before brine discharge began,

all stations along the east-west transect were very similar. Multivariate analyses indicated that variations in salinity and sediment type may account for observed differences in species abundances between diffuser and control stations.

The coefficient of condition (weight at length) of the brown shrimp (P. aztecus) and 4 species of sciaenid fishes was significantly lower at the diffuser site than at control sites ($.05 < \alpha < .10$ for brown shrimp, sand seatrout, spot and southern kingfish; $.20 < \alpha < .25$ for banded drum). This would indicate that these species had undergone stress in the vicinity of the diffuser.

Phytoplankton

During this study nine stations were sampled for phytoplankton at discrete depths each month. Water samples collected by Van Dorn bottles were analyzed for taxonomic composition, cell numbers, chlorophyll a, phaeopigment, species diversity, and temporal distribution of species.

There were 146 taxa of phytoplankton identified during this study. Forty-four genera, 100 species and two varieties of diatoms were identified. Diatoms dominated the phytoplankton for most of the year with substantial populations of dinoflagellates and microflagellates present in the late spring and summer months. The major diatoms were Skeletonema costatum, Cerataulina pelagica, Asterionella glacialis, Leptocylindrus danicus, Hemaulis sinensis and Rhizosolenia fragilissima. Species of Nitzschia, Chaetoceros and Rhizosolenia formed important

secondary associations. The dinoflagellate community was dominated by species of Prorocentrum, notably P. compressum, Ceratium and Dinophysis. Five species of red tide organisms were found: Prorocentrum minimum, Glenodinium splendens, Noctiluca milaris, Oscillatoria erythraea and Gonyaulax monilata. A bloom of G. monilata occurred in the late summer and early fall of 1981. In general, the phytoplankton of the study area were similar in both composition and numbers to those of other reports for the Gulf of Mexico.

Based on the statistical analyses conducted on species composition, seasonal distribution, species diversity values, cell numbers and chlorophyll a it appeared that the discharge of brine had little effect on either phytoplankton community structure or standing crop.

Zooplankton

Results will be published in Volume III Addendum when they are accepted as a deliverable by the Department of Energy.

Biological Oceanography Impact Summary

During the course of the year-long investigation changes in biological communities were observed. Seasonal variability in species abundances was a predominant feature as dramatic population fluctuations occurred in all groups studied. Among station differences, of relatively small magnitude, were observed for many species and biomass estimates. Some of these differences were consistent when specific comparisons were made between control and

diffuser area stations. They include: statistically significant differences in population densities of certain numerically dominant macrobenthic species, and significantly lower values for coefficient of condition (weight at length) of certain nekton target species collected in the vicinity of the brine diffuser. None of the observed changes in biotic communities were catastrophic in nature and the causal agents are not fully understood.

These findings do not fit the accepted definition of irreversible or irreparable harm but they are indicative of the early stages of environmental stress. If increased discharge is anticipated or if salinities and/or plume areas are likely to exceed those observed or predicted during this twelve month investigation then the significance of these findings should be evaluated. The area is highly productive in fisheries harvests; is subjected to intense fishing pressure; is important for various life history stages of many marine and estuarine organisms, and periodically undergoes stratification and hypoxic events.

Estuarine Biology

Five estuarine stations, E1 through E5 (Figure 1), were sampled monthly from May 1981 - April 1982. The station locations were determined by dead reckoning. At each site, observations of weather conditions and water quality were recorded as at the marine stations.

Five replicate benthic samples from each site were collected using a 0.05 m² Ekman grab at stations E1 through E4 and a 0.1 m² Smith-

McIntyre grab at Station E5. Field processing and laboratory workup of estuarine samples were identical to those of the marine samples.

The benthic macrofauna of Calcasieu Lake were generally similar to other northern Gulf of Mexico estuaries. Habitats were numerically dominated by polychaetes and molluscs: Mediomastus californiensis; Paraprionospio pinnata; Streblospio benedicti; Parandalia fauveli; Mulinia lateralis and Macoma mitchelli. Station E5, at the mouth of the estuary, include Phoronis sp. A, a species more abundant on the inner shelf than other estuarine habitats. Most of these species are considered tolerant of wide salinity and temperature fluctuations.

Separation of stations and species groups by multivariate analyses were interpreted largely on the basis of salinity differences between sites sampled. Each cluster generally contained only collections from a particular site, indicating that the species and populations of that site were characteristic of only a single habitat. Each habitat was unique in its relative abundance of species and unique presence of rare species. Station E5 in Calcasieu Pass was the only estuarine station affected by low dissolved oxygen concentrations resulting in decreased abundances of macrobenthic species.

Nekton were collected monthly at four estuarine stations (E1-E4). Replicate tows were made using a 4.9 m commercial otter trawl equipped with a tickler chain.

The estuarine nekton community was dominated both numerically and in terms of biomass by relatively few species. Among the dominants

were species of commercial and recreational importance including: the Atlantic croaker, Micropogonias undulatus, the blue crab, Callinectes sapidus, the white shrimp Penaeus setiferus, the brown shrimp, P. aztecus and the Atlantic menhaden, Brevoortia patronus.

Monthly estuarine phytoplankton samples were collected and processed as the marine phytoplankton samples. Near surface and near bottom samples were taken at stations E1 and E5 while only near surface samples were taken at the shallow stations: E2, E3 and E4.

The lower salinities at stations E1 and E2 reflected the influence of drainage from the Calcasieu and Sabine basins. A freshwater assemblage composed primarily of Navicula, Melosira and Cyclotella spp. of phytoplankton occurred at these two Northmost stations. Stations E3, E4 and E5 possessed higher salinities and common estuarine phytoplankton species, e.g. species of Cerataulina, Nitzschia, Asterionella, Rhizosolenia, Skeletomena and Chaetoceros. Station E5, in Calcasieu Pass, had higher salinities and frequently possessed phytoplankton species from the adjacent neritic community, e.g. species of Prorocentrum, Ditylum, Thalassiosira, Coscinodiscus, Navicula, Chaetoceros and Guinardia. Both the species composition and temporal distribution of species in the estuary and adjacent stations were not unusual considering the diversity of environments represented. One noteworthy event of the study period was a bloom of the toxic red tide organism, Gonyaulax monilata, in the southern end of Calcasieu Lake during late summer and early fall of 1981. For these disciplines no

changes were observed which could be attributed to SPR activities in the area.

In the following chapters, the specific hypotheses, sampling designs, statistical analyses, results, and interpretations of the post discharge phase (May 1981 - April 1982) are detailed for each task.