DOE/EIS-0029

Final Environmental Impact Statement

(Final Statement to FEA-DES-77-8)

STRATEGIC PETROLEUM RESERVE

Texoma Group Salt Domes

(West Hackberry Expansion, Black Bayou, Vinton, Big Hill)

Cameron and Calcasieu Parishes, Louisiana and Jefferson County, Texas

U.S. DEPARTMENT OF ENERGY

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Responsible Official

Ruth C. Clusen
Assistant Secretary for Environment

U.S. DEPARTMENT OF ENERGY
Washington, D.C. 20545

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APPENDIX U

Environmental Survey of Texoma

Brine Diffuser Sites

EXECUTIVE SUMMARY

Science Applications, Inc. is presently conducting an intensive environmental survey of the proposed Texoma brine diffuser and sites. The physical, chemical, geological, and biological aspects of the environment are being examined. The present document covers the findings of this survey for the time period September-December 1977.

Climatology and Meteorology

The region of the proposed diffuser sites is a maritime subtropical climate marked by normally mild temperatures and humid conditions, but noted for the wintertime effects of storm systems from the north, which produce sudden shifts in temperature and wind in a short period. These shifts persist for several days with normal southeasterly winds becoming reestablished and then once more being displaced by mid-latitude storms from the north and northwest. Summertime patterns are quite humid with subtropical wind systems from the Gulf of Mexico bringing warm moist air into the region. Convective storm activity is common on many summer days. As a result, the normal wind patterns would be onshore with some shifting to offshore winds during the wintertime.

Observations were taken during the Autumn of 1977 by remote stations, and combined with observations taken at land stations. The wintertime pattern of mid-latitude storm passage became established somewhat earlier than normal with a series of cold fronts and strong northwest winds beginning to pass through the area in late November, into December. No evidence was found of land-sea circulation during the observation period.

However, this is as much a result of the methods of instrument operation as of the wind patterns to be found in the region. No extremes in water discharge from rivers occurred during the period with the single exception of a time in mid-December when local precipitation produced a sudden extreme in fresh water discharge.

Physical Oceanography

Between October 20 and December 18, 1977, a physical oceanographic field measurement program was successfully conducted. This effort resulted in:

- Establishing a characteristic current record to be used as input to the MIT Brine Diffuser Model. This record was delivered to CEDDA/NOAA.
- Estimates of local horizontal eddy diffusivity to be used as input into the MIT model. This information has been supplied to CEDDA/NOAA.
- Identification and a general description of significant local physical oceanographic processes occurring in the vicinity of the potential brine diffuser sites.

Measurements taken included speed and direction of currents and wind, water level fluctuations, signficant wave height and period, and the areal and vertical distribution of salinity, temperature, and dissolved oxygen. Additionally, a Lagrangian profile study was conducted to determine estimates of horizontal eddy diffusivity as a function of a spatial scale and to supplement Eulerian measurements.

Initial results from two months of observations suggest that:

- Tides in the area are mixed, with approximately equal amplitudes of the diurnal and semi-diurnal components.
- Tidal currents in the area (away from tidal passes) are of low magnitude and thus provide only a relatively small amount of the total current variability.

- Under certain conditions which are more prevalent during summer, a local sea-breeze system can develop.

- Winds typically had a component directed toward the west and north. For only a small portion of the study period was a component of the wind toward the east.

- The dominant energy bands of winds and currents is at approximately 0.1 cycles/day, with lesser concentrations at about 0.25-0.33 cycles/day.

- For lower frequency variations, a pattern of cross-correlations exist which suggest that near bottom currents are in part drivan by a sloping sea surface which is produced directly or indirectly by wind shear at the surface.

- Alongshore coherence of the alongshore currents is very high, suggesting that the dominant low frequency processes have alongshore spatial scale which exceeds the lateral extent of the study area.

- There is a preliminary evidence of seasonality of winds, currents, and the density field.

- Local vertical density structure responds seasonally and to events which cause the well-mixed layer to extent throughout the vertical column.

- Visual observations and some S, T, D data indicate that at least at the Calcasieu Pass and West Hackberry site, tidal discharge plumes and associated fronts have a direct impact on the local environment.

The continuing field program presently underway will allow for better identification of interrelationships. Two months of data provides only six repetitions of a ten-day cycle. As the total record length increases, confidence intervals in the computed parameters will converge. Additionally expected measurements will allow for characterization of seasonal patterns associated with the end of the oceanic and atmospheric summer season, transition to the winter season, the winter season, and the winter to summer transition.

Brine Plume Modeling

As described in Section 4.3.2.1, Appendix C.3.1.2.1, and Appendix D.25, the MIT Transient Plume Model has been used to estimate the changes in salinity in the Gulf of Mexico in the vicinity of the brine disposal sites for the West Hackberry, Black Bayou, and Big Hill sites. Current and diffusion observations were obtained in the vicinity of these disposal sites. These data have been used by NOAA as inputs into the MIT Model to generate estimates of salinity distributions. Test cases corresponding to stagnation, typical current, and storm passage have been run for each site as data permitted.

Nine test cases have been carried out by NOAA as follows:

Run #	Current Meter	Time Period Covered	Condition
WH-1	West Hackberry Control	1200,11/2/77 to 2100, 11/2/77	Initial data
WH-2	Calcasieu Pass	1300, 11/2/77 to 2200, 11/2/77	Initial data
WH-3	West Hackberry Replacement	1200, 1/3/78 to 0000, 1/6/78	Typical current
WH-4	West Hackberry Replacement	0000, 1/23/78 to 0000, 1/25/78	Storm passage
BB-1	Black Bayou	0600, 11/5/77 to 0000, 11/8/77	Stagnation
BB-2	Black Bayou	0000, 11/18/77 to 0000, 11/22/77	Typical current
BB-3	Black Bayou	0600, 1/24/78 to 0000, 1/26/78	Storm passage
BH-1	Big Hill Secondary	0000, 1/20/78 to 0600, 1/23/78	Typical current
BH-2	Big Hill Secondary	0000, 1/25/78 to 0600, 1/27/78	Storm passage

For Runs WH-1 and WH-2 approximately two weeks of current data were available and the time period covered by each run was taken near the end of the corresponding two-week period. For Runs WH-3 and WH-4 a time series consisting of approximately 62 days of current data was available. The time period covered by Run WH-3 commenced on the 34th day of this series and corresponds to a typical current condition. The time period covered by Run WH-4 commenced on the 54th day of the same series and corresponds to the passage of a storm through the region.

A time series consisting of approximately 103 days of current meter data was available for Runs #BB-1, #BB-2 and #BB-3. The time period covered by Run #BB-1 commenced on the 16th day of the series and corresponds to a stagnation condition. For Run #BB-2 the time period commenced on the 29th day and represents a typical current condition. Run #BB-3 commenced on the 96th day and corresponds to the passage of a storm front.

A time series consisting of approximately 63 days of current meter data was available for Runs BH-1 and BH-2. The time period covered by Run BH-1 commenced on the 52nd day of the series and corresponds to a typical current condition. For Run BH-2 the time period commenced on the 57th day and corresponds to the passage of a storm front.

The results presented for Runs WH-1 through WH-4 are based on actual measured currents in the vicinity of the site for the West Hackberry brine diffuser. The measured currents for Runs WH-1 and WH-2 were somewhat smaller than those for Runs WH-3 and WH-4 but in general the measured currents for the four runs were of the same order of magnitude as the earlier meters corresponding to the first two runs were further removed from the diffuser site than was the location of the current meter used in the last two runs. The total time intervals for the current data, upon which the first two runs were based, were also relatively short (approximately 13 days) compared to the time interval upon which the last two runs were based (approximately 62 days).

The plumes produced in Runs WH-1 and WH-2 were generally oriented along the onshore-offshore axis while those produced in Runs WH-3 and WH-4 tended to be oriented along the longshore axis. In both types of orientation reversal in the plume direction was observed. For predicted salinities of less than 1 ppt the bottom areas covered by the WH-1 and WH-2 plumes were less than the corresponding areas for the earlier Base Case based on estimated currents. For predicted salinities greater than 1 ppt the bottom areas of the WH-1 and WH-2 plumes generally equalled or exceeded the corresponding areas of the Base Case. With the exception of the 1 ppt above ambient contour for Run #WH-4 all salinities predicted in the far field for the WH-3 and WH-4 plumes covered areas greater than the corresponding areas for the Base Case.

In general the plumes of Runs WH-3 and WH-4 appear most representative of the West Hackberry diffuser site. Such plumes tend to be oriented along the longshore axis, most likely drifting to the west. For excess salinities greater than 1 ppt the exposed bottom area amounts to about 8.1×10^7 ft^2 or 1860 acres. The exposed bottom area for excess salinities above 3 ppt amounts to about 9.0×10^6 ft^2 or 207 acres. In order to determine the bottom area exposed to higher salinities, a near-field model must be used which takes into account the initial diffuser jet momentum and the effects of buoyancy.

The results presented for Runs BB-1, BB-2, and BB-3 are based on actual measured currents in the vicinity of the site for the Black Bayou brine diffuser. The total time interval for the current data, upon which the three runs are based, extended for 103 days.

The plumes produced in Runs BB-1, BB-2, and BB-3 tended to be oriented along the longshore axis with both westward and eastward drifting plumes being observed. Reversal in the direction of the plume drift was observed under conditions corresponding to the passage of a storm front.

Comparing the Black Bayou runs (#'s BB-1, BB-2 and BB-3) with the West Hackberry base case (Run #7) some differences in areal extent of the plume were noted. Run #BB-1 (stagnation) most closely approximated the West Hackberry base case, with a smaller areal coverage for the 1 ppt above ambient plume. A similar situation was seen for #BB-3 (storm passage) but here, the 3 ppt coverage was greater than for WH Run #7. For #BB-2, (typical) both the 3 and 1 ppt above ambient contours encompassed larger areas than the West Hackberry base case. These Black Bayou plumes were approximately the same size as those predicted for West Hackberry based on the measured currents for Runs WH-3 and WH-4. For excess salinities greater than 1 ppt the exposed bottom area amounted to about 1960 acres. The bottom exposed to excess salinities greater than 3 ppt amounted to less than 104 acres.

In general the plumes of Run BB-1, BB-2 and BB-3 appear representative of the Black Bayou diffuser site. The plume pattern most frequently observed was oriented along the longshore axis.

The results presented for Runs BH-1 and BH-2 are based on actual measured currents in the vicinity of the site for the Big Hill brine diffuser. The total time interval for the current data, upon which the two runs were based, extended for 63 days.

The plumes produced in Runs BH-1 and BH-2 tended to be oriented along the longshore axis. Reversal in the direction of plume drift was observed in both runs, with both eastward and westward drifting plumes being present. In addition to their primary longshore orientation the plumes to a lesser degree showed a tendency to drift along the onshore-offshore axis.

For all predicted excess salinities the BH-1 and BH-2 plumes covered less bottom area than covered by the plumes generated in the earlier Big Hill Analysis (1). The bottom area exposed to excess salinities greater than 1 ppt amounted to about 724 acres. The bottom area exposed to excess salinities greater than 3 ppt amounted to about 52 acres.

In general the plumes of Runs BH-1 and BH-2 appear representative of the Big Hill diffuser site. These plumes are smaller than those at West Hackberry due primarily to the lower brine discharge rate.

Chemical Oceanography

As a part of the initial environmental baseline survey of the brine disposal sites located offshore of the Texas-Louisiana border, a geochemical sampling and analysis program was carried out in an effort to characterize the ambient, pre-operational conditions at specific candidate locations. The parameters chosen for assessment include (1) trace heavy metals in sediments, sediment pore water, selected macrobiota, as dissolved in the water column and associated with suspended particulate matter; (2) high molecular weight (petroleum-related) hydrocarbons in sediment, selected macrobiota and dissolved in the water column; (3) peripheral geochemical parameters such as total organic carbon, calcium carbonate and grain size distribution in sediments, and dissolved/particulate organic carbon, total suspended load, nutrients and major ionic species in the water column.

Specifically the sampling focused on two candidate disposal sites: West Hackberry, located ∿13 km southwest of Calcasieu Pass, and Big Hill, located ∿30 km southwest of the Sabine River. Also included in significant sampling was a control site for West Hackberry, located ∿16 km southeast of Calcasieu Pass. Both West Hackberry and Big Hill are under the influence of material fluxes from the run-off sources (Calcasieu and Sabine) nearest them as evidenced by essentially all of the geochemical data obtained. The design of this program was made in an effort to describe spatial variations in water column and sediment chemical quality, and to begin a survey of chemical distributions and limits of variation in biological members of the ecosystems under observation. An important aspect is the revealing of temporal variations as well and this can begin to be done after one or more additional samplings are performed during the course of at least one year.

West Hackberry and Big Hill sites are distinctively different in sedimentary geochemistry. The Big Hill site, off the Sabine, is characterized by a significantly finer-grained material having correspondingly higher total organic carbon, heavy metal and heavy hydrocarbon contents. Interestingly, however, plots of metal (Cu, Cr, Cd, Pb, Ni, Zn, Mn, Al) vs. Fe for both sites reveals that the Big Hill sediments are actually depleted somewhat in metal burden relative to West Hackberry. The difference is small enough that the probable mechanism is sedimentological difference rather than an indication of enrichment at West Hackberry (i.e., possible pollution effect from Calcasieu). From this data metal-to-Fe prediction intervals were constructed as useful tools in comparing post-operational monitoring data so that any perturbation might be revealed.

In contrast to the West Hackberry site, the site chosen for its control (to the east of Calcasieu) contains signficantly coarser sediments and lower metal and hydrocarbon levels. However, on a metal-to-iron plot the control samples fall well into the same population as the West Hackberry sediments. The difference in sedimentary regime is controlled by proximity to major run-off and by localized current regimes.

The water column suspended loads also reflect the sediment patterns just described. The coarsest West Hackberry control site has by far the lowest suspended load, with West Hackberry intermediary and Big Hill having the highest. Suspended load is a highly variable (both spatially and temporally), parameter, however, its general distributions reflect at least part of the material transport conditions (this close to shore, bed load movement cannot be ignored, although it is very difficult to assess).

Given the inherent short-term temporal and spatial variability in the water-column chemistry in such near-shore settings, the heavy metal burdens of the dissolved and particulate phases of all three locations were found to be remarkably similar. The major fluctuations in particulate metal burdens are correlated with variable amounts of organic carbon present.

Biological tissues examined were from white shrimp, croaker, zooplankton, and squid. The metal burdens of these organisms were again remarkably similar among the three sampling locations and also corresponded quite well for all metals to historic data gathered for the same species from other parts of the Northern Gulf of Mexico. An important aspect to remember in efforts to characterize the food chain with respect to chemical burdens is that natural populational variability will be significant and has to be delineated if an adequate baseline is to be established.

Based on the initial analyses of sediments, the dominant contributing hydrocarbon source is weathered petroleum, followed by terrestrial higher plants and marine infauna. (Total average concentrations for Big Hill, West Hackberry intensive and control are 35 µg/gm, 14 µg/gm, and 6 µg/gm, respectively.) The petroleum component is largely reflected in the prominent occurrence of the unresolved complex mixture (UCM) in both the hexane and benzene fractions where it comprises 80 to 90 percent of the total hydrocarbons detected. The concentrations of the unresolved complex mixtures of plant wax paraffins increase with the mud (silt plus clay) and organic carbon content of the sediments. However, the levels at the Big Hill site are higher than would be expected by the increase in TOC content. The marine component consists of a complex series (10-15 compounds) of C_{25} and C_{21} polyolefins eluting between nC_{20} and nC_{22}. The relative magnitude of the marine component increases with coarser texture. The complexity and variability of these marine component is greatest at the West Hackberry intensive site with the least variability occurring at Big Hill. The water analyses show concentration trends which are similar to those of the sediments. Several distinctive patterns of apparent biogenic (primary productivity) sources have been identified in addition to petrogenic sources. These biogenic "populations" appear primarily at the West Hackberry intensive and control sites. Selected constituents (primarily olefins) are collected in the fish but do not appear to be preserved in the sediments. The hydrocarbon content of the biota samples were predominantly biogenic with only trace anthropogenic (pesticides) and petrogenic (UCM) detected in the white shrimp sample. Alkyl-benzenes and thiophene were notable low level constituents in the anchovy sample.

Biological Oceanography

The present report presents data on the phytoplankton, zooplankton, macrobenthos and demersal nekton, for the Texoma region collected from September through December 1977. In general the community composition of these groups of organisms is characteristic of the coastal waters and in particular of the white shrimp grounds, of the northern Gulf of Mexico. In terms of standing crop the phytoplankton, zooplankton and demersal nekton are comparable to or somewhat higher than reported elsewhere in the northern Gulf. The benthos, however, shows markedly lower standing crops than reported elsewhere. The zooplankton show little in the way of site specific trends. The benthos is also relatively constant except that the Big Hill site seems to be severely depressed. This appears to be associated with the finer sediments in this area. Phytoplankton and demersal nekton show some evidence for a westwardly increasing standing crop. No obvious explanation for this is presently apparent.

All four communities showed marked changes in standing crop from month to month. The phytoplankton standing crop generally increased from October to December. Zooplankton fell from September to November with some recovery in December. The benthos fell from September to October, and then rose from October to December. The demersal nekton increased through November and then fell off slightly. These trends seem to be related. The phytoplankton, zooplankton and benthos show a consistent pattern of minimum standing crops in October with restoration or maximum standing crops in December. This may be related to seasonal and/or climatic phenomenon marking the onset of autumnal environmental conditions. The demersal pattern is explicable in this context as an expression of the autumnal migration cycle. At any event overall changes in standing crop seem to support a general deterioration in the environment during the September-October time frame. Changes in species composition for the benthos, phytoplankton and zooplankton also support this view. Whether the source of this deterioration is climatic or anthropogenic is at this point uncertain.

Conclusions

During the time frame September - December 1977 currents in the Texoma region were predominantly longshore of slight velocity. Resultant brine plumes predicted by the MIT Model for selected sets of current observations were correspondingly oriented in the longshore direction. Reversal of plume direction was noted at all sites, but the tendency was for westward flow. For representative cases the bottom area exposed to salinities in excess of 3 ppt ranged from about 207 acres at West Hackberry, and Black Bayou, to 52 acres at Big Hill, the difference being due to lower discharge rate at Big Hill.

Geochemically the West Hackberry and Big Hill sites were distinctively different entities. Big Hill was characterized by a significantly finer grain material with correspondingly higher total organic carbon, heavy metal and heavy hydrocarbon contents. The dominant hydrocarbon source at all sites was weathered petroleum followed by terrestrial higher plants and marine fauna.

Water column suspended loads reflect the sediment patterns. Sediment load at West Hackberry was markedly lower than Big Hill. Heavy metal burdens of the dissolved and particulate phase were also remarkably similar for all sites.

Biological tissues from selected organisms showed metal burdens remarkably similar for all sites. They also corresponded well for historic data for the same species from other parts of the Gulf of Mexico.

In terms of standing crop the phytoplankton, zooplankton and demersal nekton are comparable to somewhat higher than reported elsewhere in the norther Gulf. The benthos shows markedly lower standing crops than elsewhere reported. The benthos standing crop at Big Hill is significantly lower than observed at the other sites. This appears to be due to the finer grain size distribution at Big Hill.

The phytoplankton and demersal nekton show evidence of westwardly increasing standing crop. Apart from the depressed benthic standing crop at Big Hill, the benthos or zooplankton show little in the way of site specific trends.

All four communities showed marked changes in standing crop from month to month. The demersal nekton show maximum standing crops in November. This may be an expression of the autumnal migration cycle. Phytoplankton, zooplankton and benthos show minimum standing crops in October or November. This suggests a general deterioration in the environment during the September-October time frame. Changes in species composition for the benthos, phytoplankton and zooplankton support this view.

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1.0 INTRODUCTION

Upon implementation of the SPR program, large scale disposal of brine can be expected to impact the coastal waters of the northern Gulf of Mexico. Science Applications, Inc. (SAI) is currently carrying out an intensive environmental baseline study of each of the three disposal sites associated with the Texoma salt domes. In addition, two other control sites are being evaluated: Big Hill Control and West Hackberry Control. All five sites are situated at the 30-foot depth contour at distances of three to five nautical miles from shore. A set of integrated studies of the benthos, demersal organisms, plankton, water column and sediment chemistry, meteorological conditions, and current and wave-tide regimes are being conducted. The present report details the finding of those studies during the first trimester period (September 1977 to December 1977) of the study.

The primary goal of this study is the delineation of the basic structure and functioning of the near offshore Gulf of Mexico ecosystem at each brine disposal site, including the biological, chemical, and physical realms, stressing the relationships between these ecosystem components. In addition to the goal of providing adequate baseline environmental data, the results of the study should serve as the foundation upon which a discharge-phase study could be structured.

The focus of any environmental perturbation is the biota. This is especially true in the Gulf Coast area where certain biotic elements are of direct economic concern. Basic delineation of the faunal and flora components of an ecosystem is the essential first step, and has accordingly received strong emphasis. Biological data has been collected monthly since September 1977 at each of the five brine disposal sites. The biotic components which are expected to receive the major impact are those non-motile forms found in the immediate area of the brine diffuser. For this reason, particular emphasis has been placed on characterizing the benthos (both megafaunal and meiofaunal components) for each site.

The free moving demersal nekton of the northern Gulf includes a variety of regionally-important commercial and recreational species. These species include the white and brown shrimp and numerous species of fish. While the nekton will probably be able to avoid the area of brine discharge, thereby escaping direct injury, such avoidance would eliminate a substantial portion of their breeding and feeding grounds. For this reason, extensive trawl data has been collected from each site on a monthly basis.

Extensive plankton sampling has also been performed monthly during the course of the study. The implementation of offshore brine disposal is most likely to impact the planktonic groups (phytoplankton, zooplankton, and meroplankton) whose distributions are dependent on current regime and would drift through the area of discharge. Many important commercial speices of fishes and crustaceans of the Gulf Coast have meroplanktonic larval stages which must pass through the near shore area on their way to the estuarine nurseries from offshore spawning grounds. This migratory pattern may utilize salinity gradients as an orientation cue. The existence of a down-stream brine plume during the discharge phase may influence such migratory patterns.

While focus of the study has been on the biotic characterization of the area, SAI recognizes that a satisfactory understanding of an ecosystem can only come with an understanding of the physical/chemical/geological environment. For this reason, an intensive effort has been made to describe the non-biotic elements of the system. Basic water column characterizations (vertical salinity, temperature, dissolved oxygen and pH profiles, surface and near-bottom nutrient, chlorophyll, or phaeophytin determinations) were done concurrently with biological sampling. All benthic samples were processed for grain size distribution, carbonate content and total organic matter. Since a large part of the foodbase in the benthic habitat is detritus (especially in the near-shore Gulf where high turbidity prevails), ATP analyses were performed on selected samples as a tool in evaluating microfloral activity in the sediment system.

Spatial variations in water column and sediment chemical quality are necessary in delineating the overall composition of the system. In order to assess the potential impact of various osmotic effects, ionic imbalances, and toxic element distribution during discharge, the important chemical elements in the dissolved and particulate phases of both the water column and sediments have been determined. The background levels of chemical elements can the be compared with concentrations in various biota (plankton and nekton) as determined from tissue assays. The chemical parameters which were monitored include trace elements, hydrocarbons, bulk anions and cations, nutrients, TIC, TOC, POC, DOC, and ATP.

Much of the spatial variability of biota and water quality parameters depend directly on the physical oceanography. This necessitated a detailed analysis of this component. Such data was also necessary as input into the MIT transient plume model utilized to delineate the area of impact. For these reasons, data on current regime, wave-tide conditions, and regional meteorology was collected.

Section 2.0

The Physical Environment

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2.1 CLIMATOLOGY AND METEOROLOGY

2.1.1 General Climatology

The subtropical climate of the diffuser sites is influenced by the relatively warm waters of the Gulf of Mexico and by the continental land mass to the north and west of the study area. Rainfall and humidity are typically highest in the summer on a monthly average basis, with late summer and fall periods of intense rainfall due to convective storms and tropical hurricanes.

Spring and summer in the proposed diffuser sites areas are dominated by the Bermuda High, an extensive semi-permanent high pressure system centered in the Atlantic Ocean off the southeastern United States which causes a southeasterly flow in the general circulation in the diffuser area. There is generally little variation in these seasons, with high humidities, small diurnal temperature variations, and convective activity occurring, especially in the summertime. Seabreeze circulations are sometimes present during periods of light winds. However, analysis of station data from the field station located onsite has revealed no signigicant energy at the diurnal or semidiurnal period, indicating that large-scale synoptic circulations dominate the winds in the area and mask any small-scale land-sea breeze circulations.

Tropical cyclones and attendant strong winds occur in this region, normally in late summer and early fall. Most approach from the southeast and the equatorial Atlantic ocean. More than one half of the tropical cyclones become hurricanes, that is, storms with sustained wind speeds exceeding 74 mph (64 knots).

Winters are generally short and mild with persistent low stratus ceilings and rain. It is common for cold fronts representing the edge of Continental mid-latitude circulations to penetrate the coastal region on a periodic basis, especially in the period of November through February or early March. This passage of cold fronts is marked by a sudden drop in air temperature and the shift of prevailing winds from the eastern quadrant, that is, northeast through south, to the northwestern quadrant, that is, west through north. Such wind shifts will persist for one to three days bringing in colder, drier air. The prevailing southeast subtropical circulation will then be re-established until the next front passes. Analysis of station data from the Beaumont/Port Arthur weather station indicates a drop of 50°F in 18 hours, during the period of January 6-8, 1978. This is one indication of the severity and suddenness which the protruding polar air masses and cold fronts can change the wintertime circulation. Such occasional intrusions of polar air brought air temperatures below freezing and down as low as the 20's during the period of observation. Advective-radiative fogs can also result from this intrusion of air masses during the wintertime period.

2.1.1.1 Meteorology: General Observations

Over 100 years of meteorological data have been recorded at Galveston, Texas (directly west of the sites), and nearly 70 years are recorded at Port Arthur, Texas (north of the sites); a shorter period of record is available at Lake Charles, Louisiana (northeast of the sites). All of these station locations are maritime subtropical climates, with little man-made impact on the observed meteorology and climatology, and hence are somewhat applicable to the description of the general meteorology of the diffuser sites.

2.1.1.2 Air Temperatures

Moderate temperature variations prevail in the region due to the dominance of southeasterly subtropical circulations and the moderating influence of the Gulf of Mexico waters. The result is warm humid summers, mild winters, with few days below freezing, and a number of days in the upper 80's and lower 90's. Summer temperatures around the sites average in the mid 80's. Climatologically-observed winter temperatures are in the 50's and 60's, although these wintertime averages are not replicative of daily conditions because of the periodic intrusions of cold fronts. Table 2.1-1 illustrates monthly values of mean temperature for two land stations, Galveston, Texas and Lake Charles, Louisiana.

2.1.1.3 Precipitation

Table 2.1-2 summarizes long term mean monthly precipitation amounts at Galveston and Lake Charles. Although total rainfall is not highly variable from month to month, the type and frequency of occurrence, and the extreme values are largely functions of the season or month of the year. The largest total amount of rainfall occurs during the summer, usually associated with either local thunderstorms, tropical storms, or hurricanes. Local convective activity often causes severe thunderstorms and precipitation. In winter, precipitation frequency is increased because of midlatitude frontal passage and the attendant frontal activity, including strong intermittent precipitation. This

Table 2.1-1 Long-term, Monthly Average and Extreme Air Temperatures for Galveston, Texas/Lake Charles, Louisiana

(Observations and periods of records for the two stations are separated by a slash; hence, "65/59" means Galveston: 65, Lake Charles: 59)

TEMPERATURE (to nearest degree)

Month	Normal[a]			Extremes[b]			
	Average Daily Maximum (°F)	Average Daily Minimum (°F)	Average Monthly (°F)	Record Highest	Year	Record Lowest	Year
J	59/62	48/43	53.9/52.3	77/79	1969/1972	11/20	1886/1970
F	62/65	51/46	56.2/55.1	83/83	1932/1972	8/26	1899/1970
M	66/70	56/51	61.0/60.3	85/86	1879/1974	27/29	1943/1968
A	73/78	65/59	69.2/68.9	92/92	1953/1965	38/34	1938/1971
M	80/84	72/66	75.9/75.2	93/93	1911/1972	52/50	1954/1971
J	85/90	77/72	81.3/80.7	99/98	1918/1969	57/58	1903/1974
J	87/91	79/74	83.2/82.4	101/99	1932/1970	66/61	1910/1967
A	88/91	79/73	83.3/82.2	100/97	1924/1976	67/61	1966/1967
S	85/88	75/69	80.0/78.4	96/96	1927/1964	52/47	1942/1967
O	78/82	68/58	73.1/70.0	94/91	1952/1971	41/36	1925/1964
N	69/71	58/49	63.5/60.2	85/86	1886/1971	26/23	1911/1976
D	63/64	52/44	57.1/54.3	80/82	1918/1966	18/24	1880/1973
YR	74.5/78.0	65.0/58.6	69.8/68.3	101/99	Jul./Jul. 1932/1970	8/20	Feb/Jan 1899/1970

Source: U.S. Department of Commerce, 1976
[a]1931 - 1960/1964 - 1976
[b]Periods of records: Galveston: 106 years (1870 - 1976)/Lake Charles: 12 years (1964 - 1976)

Table 2.1-2 Long-term, Mean Monthly Precipitation Amounts Measured at Galveston, Texas/Lake Charles, Louisiana

(Observations and periods of records for the two stations are separated by a slash; hence, "15.49/8.90" means Galveston: 15.49/Lake Charles 8.90)

Precipitation

Month	Normal Total[a]	Maximum Monthly[b]	Year	Minimum Monthly	Year
	(inches)	(inches)		(inches)	
J	3.02/4.04	10.39/12.69	1899/1974	0.02/0.78	1909/1971
F	2.67/4.47	8.29/6.75	1881/1969	0.09/0.80	1954/1962
M	2.60/3.84	9.49/7.40	1973/1973	0.06/0.27	1953/1971
A	2.63/4.33	11.04/10.95	1904/1973	0.01/0.64	1887/1963
M	3.16/5.06	10.50/11.01	1929/1974	T[c]/0.57	1889/1963
J	4.05/5.04	15.49/8.90	1919/1968	T[c]/0.84	1907/1969
J	4.41/6.55	18.74/10.06	1900/1969	T[c]/0.48	1962/1962
A	4.40/4.75	19.08/17.36	1915/1962	0.00/0.77	1902/1976
S	5.60/4.13	26.01/19.96	1885/1973	0.04/1.01	1924/1962
O	2.83/3.48	17.78/17.28	1871/1970	T[c]/T[c]	1952/1963
N	3.16/4.08	16.18/7.30	1940/1974	0.03/0.11	1903/1967
D	3.67/5.70	10.28/13.27	1887/1967	0.23/2.07	1889/1975
YR	42.20/55.47	26.01/19.96	1885/1973	0.00/T[c]	1902/1963

Source: U.S. Department of Commerce, 1976

[a]1931 - 1960/1964 - 1976

[b]Periods of records: Galveston: 106 years (1870 - 1976)/
Lake Charles: 15 years (1961 - 1976)

[c]T = Trace, an amount less than 0.01 inches

precipitation may occur any time of day since it is not caused by convective activity, and continue intermittently for several days. Yearly mean precipitation levels for Galveston, Houston and Port Arthur are: 44.7 inches, 47.3 inches, and 52.8 inches respectively. Snowfall is, as expected, quite light in this region. For the three or four mentioned stations the average yearly snowfall from 1970-1977 winter seasons was approximately 0.4 of an inch total for the entire year.

2.1.1.4 Windspeed and Direction

Surface Winds*

Surface winds along the Gulf Coast are dominated throughout most of the year by the Bermuda High. Thus, prevailing winds are from the south, southeast, and east quadrants in the January through June period. Wind shifts through a more easterly direction during July and August as the Bermuda High migrates north, and then becomes more southerly again as the high then moves further south during the fall period. During the November to February period, as mentioned above, this prevailing wind direction is greatly modified by the passage of midlatitude fronts passing through the area.

Table 2.1-3 summarizes the percent of frequencies of wind direction and speed for Galveston, on a yearly basis, over a ten year period of observation. Note the occurrence of strongest (class 6) winds from the northwest through northeast which is the result of wintertime frontal passage.

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*NB-Meteorology convention for wind direction is used throughout i.e., wind direction is stated as bearing from which wind is blowing. This is universal convention.

Table 2.1-3 Percentage Frequencies of Wind Direction and Speed, Galveston, Texas - Annual Observations, 1951-1960 (87,672 obs.)

Speed Class	1	2	3	4	5	6	Total
Knots	0-3	4-6	7-10	11-16	17-21	>21	
Direction							
N	.2	.8	1.7	2.0	1.3	.6	6.7
NNE	.1	.6	1.7	1.8	1.0	.4	5.6
NE	.2	.8	2.2	1.9	.6	.2	5.9
ENE	.1	.6	1.4	1.3	.5	.1	4.0
E	.2	.9	2.2	1.9	.6	.1	5.9
ESE	.1	1.1	3.7	3.3	.6	.1	8.9
SE	.2	1.7	6.0	4.0	.6	.1	12.3
SSE	.1	1.4	6.1	4.9	.6	0	13.2
S	.3	1.6	6.1	5.1	.9	.1	14.0
SSW	.1	.7	2.4	2.5	.7	.1	6.4
SW	.2	.7	1.5	1.1	.4	.1	4.1
WSW	.1	.5	.8	.3	.1	0	1.8
W	.1	.5	.7	.3	.1	0	1.8
WNW	.1	.4	.8	.5	.2	.1	2.1
NW	.1	.5	.9	.8	.5	.2	3.1
NNW	.1	.3	.7	.8	.7	.5	3.0
	1.1						1.1
Total	3.5	12.8	39.0	32.5	9.5	2.9	

Extreme Winds

Table 2.1-4 summarizes the mean speed and prevailing direction, and fastest recorded speed and direction and year of occurrence for extreme winds at Port Arthur, Texas, a station more inland than Galveston but in the same climatic zone. The recorded speeds are in fact winds runs, that is averaged winds normalized to the 10 meter meteorological datum. Comparing wintertime means and extremes again shows the dominance of winter fronts.

2.1.1.5 Hurricanes and Tropical Storms

Hurricanes and tropical storms are commonly formed in the tropical Atlantic or on the edge of the Carribbean. These often enter the Gulf of Mexico, and make landfall in the central Gulf area. Landfalls in the region of either High Island or Cameron are less common than further east. Hurricane season is typically from June through October, however, late summer and early fall are more common periods for hurricane occurrence. The average number of years between occurrences of hurricanes is 3.2 years at Galveston.

During the period of observation, this is, September through December 1977, none of the cyclones or named hurricanes which formed penetrated as far west as the study site. In recent history, Hurricane Camille, in 1969, was the most severe incidence of tropical storm passage through the area. The very shallow shelf region in this part of the Gulf of Mexico, low lying land areas, high water table, and frequent inundation of low lying areas by normal precipitation events mean that storm surge and wave run-up are a common cause of extreme damage and

Table 2.1-4 Monthly Mean Wind Speeds (mph) and Fastest Recorded Wind Speeds, Port Arthur, Texas (period of record 1944-1976)

Month	Mean Speed	Prevailing Direction	Fastest Speed	Direction	Year of Occurrence
Jan.	11.3	N	50	S	1957
Feb.	11.8	S	62	SE	1969
March	12.2	S	66	SW	1964
April	12.3	S	60	NW	1966
May	10.6	S	74	SW	1971
June	9.1	S	72	NW	1957
July	7.9	S	66	SW	1963
Aug.	7.5	S	73	E	1964
Sept.	8.7	NE	56	SW	1968
Oct.	9.0	N	65	NW	1956
Nov.	10.5	N	60	NE	1963
Dec.	10.8	N	69	S	1953
Yearly average	10.2	S			

casualties onshore. During the cyclone of 1900, more than 6000 people died on Galveston Island during one of these storm surges. Extreme drops in surface pressure and extreme winds are common occurrences during such events.

2.1.2 Local Meteorology: Field Observations

2.1.2.1 Instrumentation Location and Operation

A field station recording wind speed, wind direction, and (sporadically) air temperature was emplaced at the High Island site and put into operation in November 1977. The data under discussion extends continuously through December 31, 1977. This station is located on an offshore drilling structure some eight miles off High Island, Texas. Data was also obtained from another station, located off Cameron, Louisiana. The West Cameron station will be referred to an AGA and the High Island station will be referred to an ARCO.

2.1.2.2 September 1977

The primary synoptic scale feature in the region during the month of September, 1977 was the passage of Hurricane Babe which intensified upon entering the Gulf of Mexico from the South Atlantic where it formed. Its landfall was the Louisiana coast, somewhat east of the site on September 5.

Afterwards it moved slowly northeast with associated heavy rains and storm patterns along the coast. Babe's passage was followed by the normal seasonal patterns of the region, that is, prevailing south and southeast winds sometimes bringing convective precipitation from the Gulf of Mexico. Blocking highs to the north prevented later storm tracks from mid-latitude storms passing through the region. Generally high temperatures prevailed. Analysis of temperature data for the Port Arthur weather service station (U. S. Dept. of Commerce, 1978) for the period (Figure 2.1-1) indicated fairly small diurnal and semidiurnal temperature variations and little in the way of extreme temperatures on a daily basis. Figure 2.1-2, the wind rose for the AGA station (located somewhat south of the sites) indicates that the winds were dominantly from the south with some stronger gusts from the east, these primarily being the result of Babe's passage to the east. In general, these patterns are typical of the region for the late summer and early fall period.

2.1.2.3 October 1977

October was marked by passage of a mild cold front and associated frontal precipitation in the early part of the month, followed by generally west and northwest winds later on. A deepening trough in mid-October brought heavy rains to the region. This trough moved slowly east, followed by cold air passing through and temperatures dropping into the 30's and 40's, rather unusual for the sites that early in the winter. Temperature records for Port Arthur indicate passage of these fronts brought more extreme diurnal variations in temperature as fall patterns became established and mid-latitude storm tracks began to penetrate into the region. Figure 2.1-3, also from AGA, indicates the sudden emergency of fall/winter patterns as north and northeast winds, and to some extent northwest winds, begin to be established. Note that the strongest winds are from the north, north-northeast and northeast and from the south.

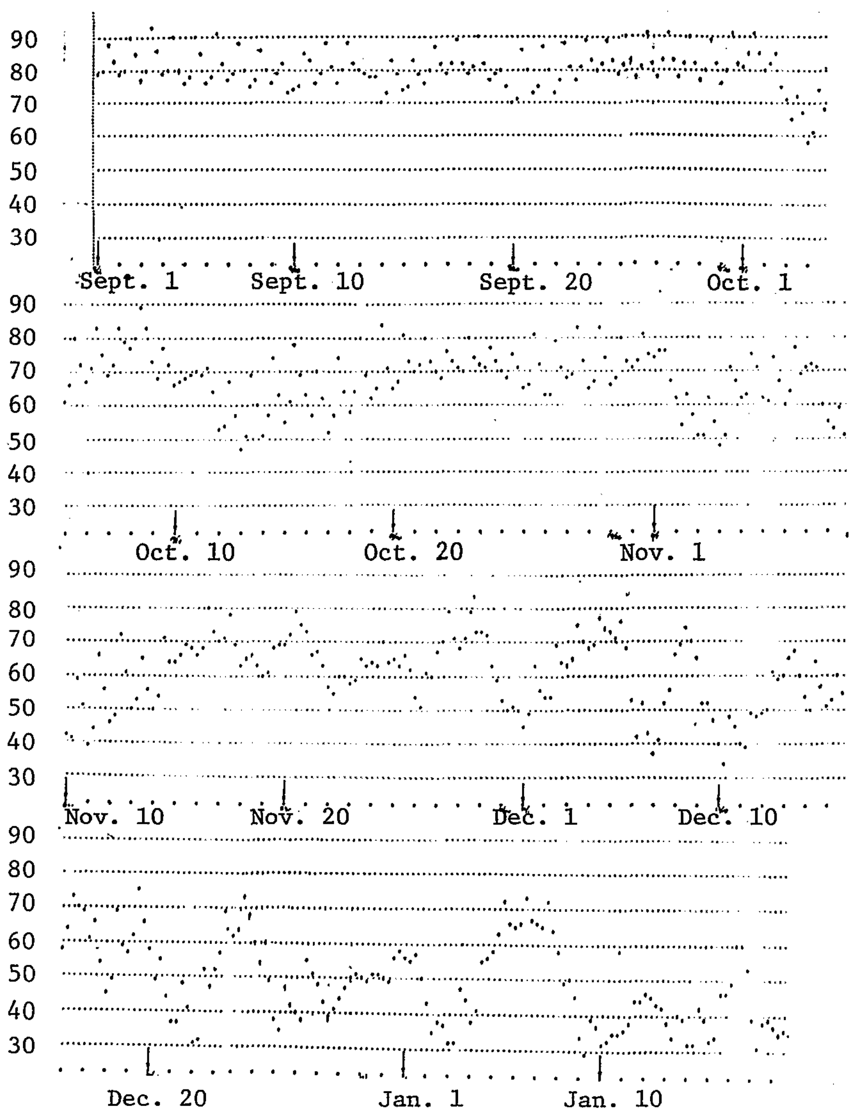


Figure 2.1-1 Temperature Record (six-hour running averages, plotted every six hours), Port Arthur NWS Station, 1 September 1977 - 18 January 1978 (^{0}F)

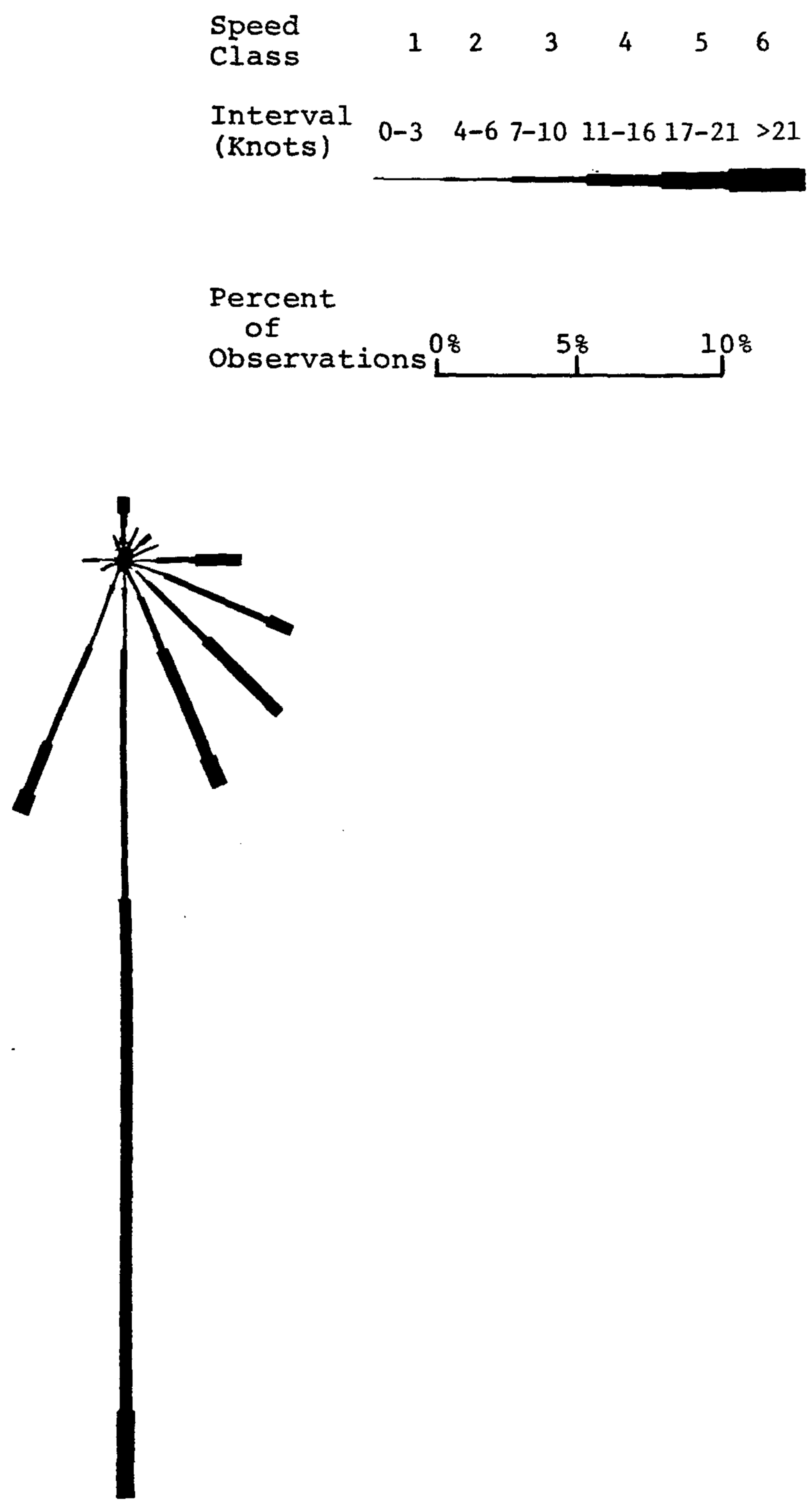


Figure 2.1-2 Wind Rose, AGA Tenneco Platform, Location 27 59N, 93 02W - September 1977.

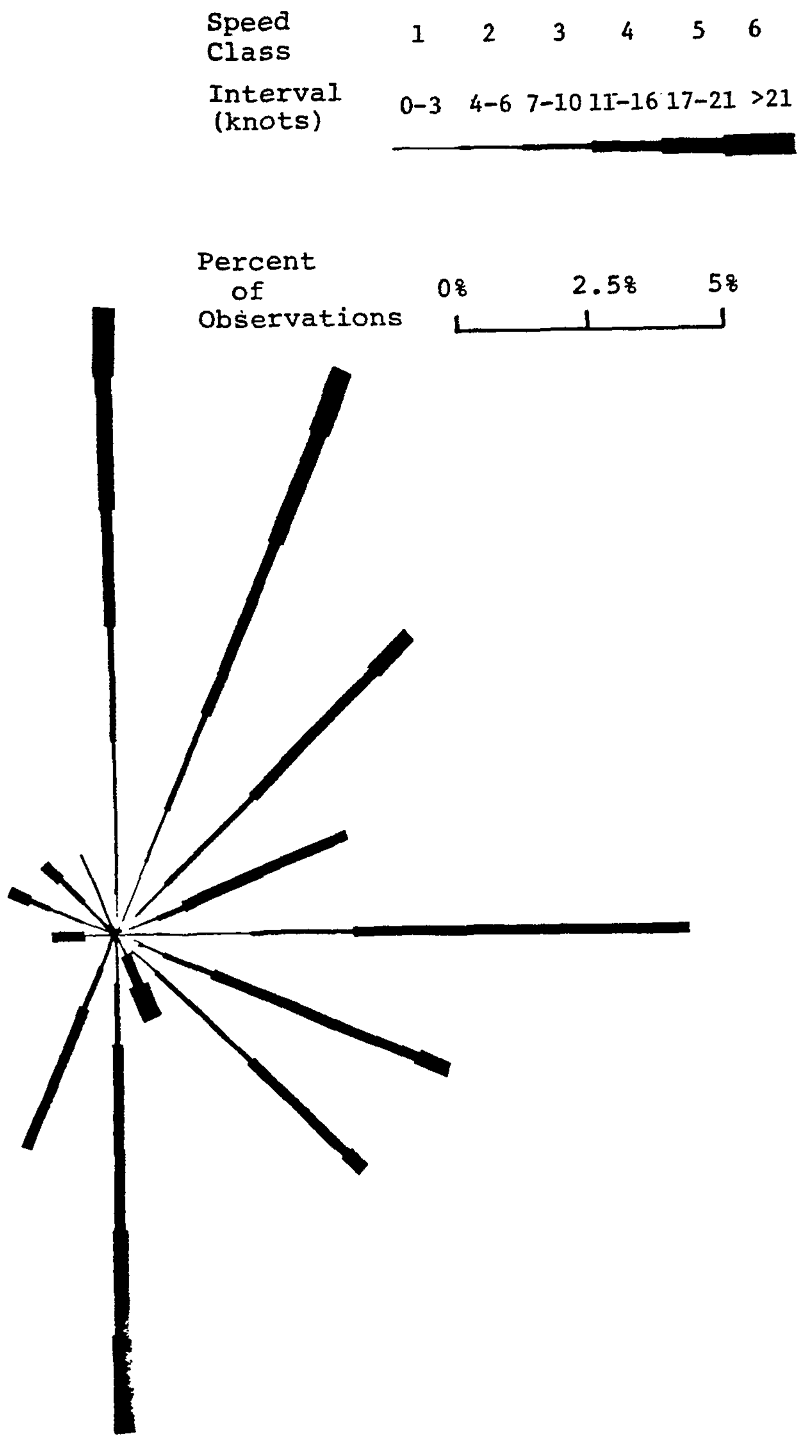


Figure 2.1-3 Wind Rose, AGA Tenneco Platform, Location 27 59N, 93 02W - October 1977.

This indicates the beginning of normal switching pattern from the south and southeast winds to north and northwest winds as mid-latitude storms pass through the region during the late fall and winter seasons.

2.1.2.4 November 1977

The month of November began with a weak trough deepening to a stationary cyclonic pattern over the area by the 5th of the month with attendant showers. The trough then moved east very slowly, allowing generally cold temperatures to remain. Temperatures then rose to normal or slightly below. This was followed in mod-month by an outbreak of Arctic air from western Canada, with temperatures in the 30's and 40's. Lows remained stationary over eastern Canada, and the sites and the region felt cold air for a week or more at a time, especially around mid-month. Winds were generally from the northwest and west once thres patterns became established. As the low weakened, it was followed by high temperatures in the normal 60 to 80 degree range. Near the end of the month another weak front passed through the area and remained stationary with mildly lower temperatures as late fall and early winter patterns were reestablished once more. The temperature records at Port Arthur show the very intense cold air penetration around mid-month. Temperatures became much colder with passages of fronts through the area.

Generally the average temperatures over the month remained in the normal range, but with much colder temperatures at the beginning and the end of the month. Figure 2.1-4 shows this extreme pattern becoming established and is a good example of the region's wintertime wind patterns, that is winds dominating in two quadrants, the southeast and

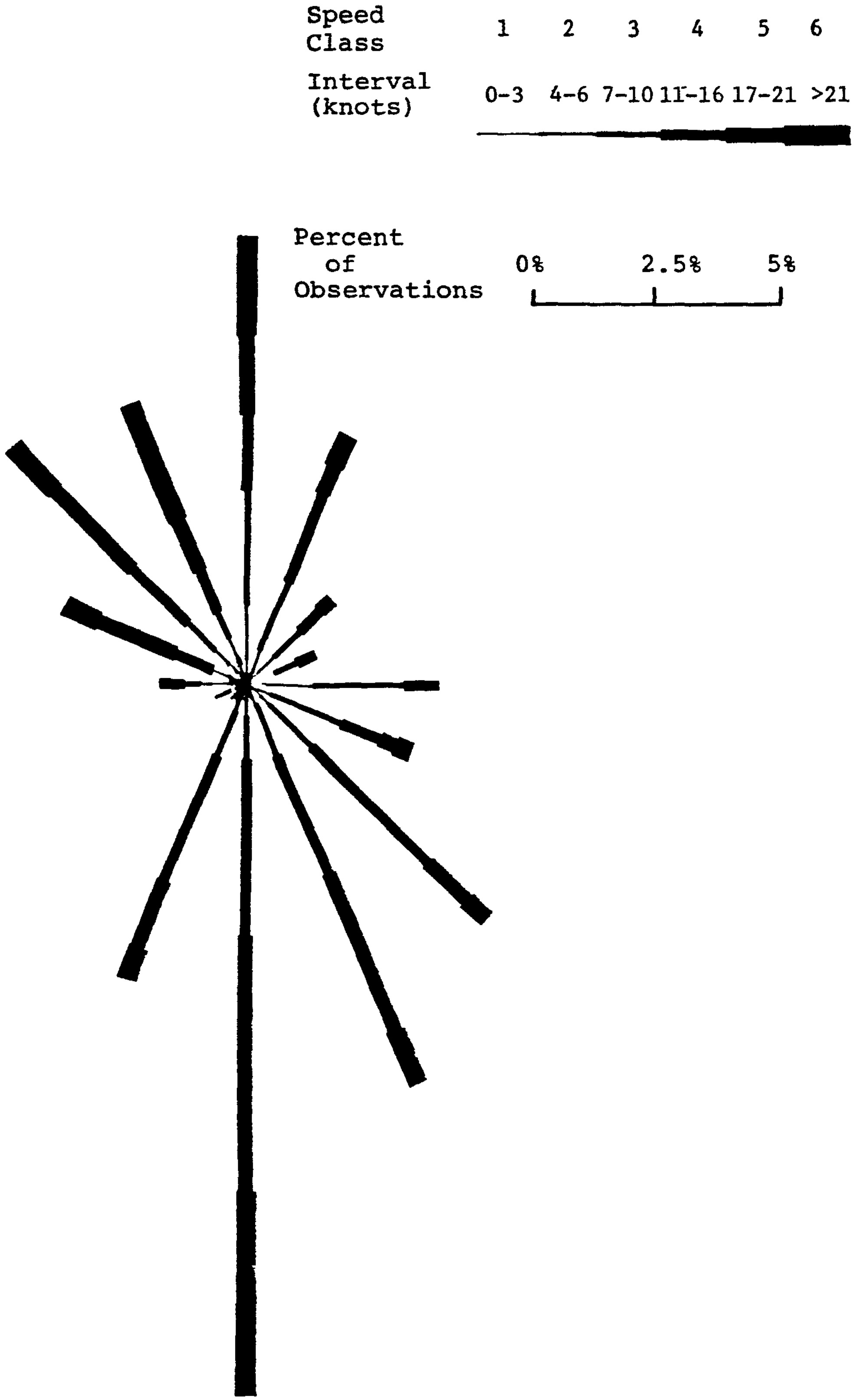


Figure 2.1-4 Wind Rose, AGA Tenneco Platform, Location 27 59N, 93 02W - (part of) November 1977.

the northwest. Note particularly the strong dominance of class 6 winds in the north and northwest. These are the result of the intense low pressure cold front passing through in the early part of the month. Figure 2.1-5, from ARCO, indicates similar patterns. It should be noted that this instrument was not put into operation until November 20, and therefore does not reflect all of the patterns for the remainder of the month. Rather, it shows primarily the period of varying wind conditions because of subsequent passage of cold fronts through the area. Stick diagrams (not shown) show that, generally, wind conditions were fairly mild, and dominant winds were from the south and southeast, with some intense periods of north and northwest winds as the fronts passed through. Generally the region and the sites at this time of year are still south of most of the fronts and, therefore, the established patterns from the south and southeast remain most evident.

2.1.2.5 December 1977

A deepening trough brought an outbreak of Arctic air and lower temperatures into the Gulf region. This was the dominant synoptic pattern for the month of December. The early part of the month, that is around December 5th, was marked by this emerging front. The Arctic air mass attending it brought temperatures into the 20's and 30's, as shown by the Port Arthur temperature records. A series of low further north brought cold air into the south, while warmer air and rising temperatures returned the area to normal again. Temperatures dropped once more as a succeeding front passed through around December 10th. This pattern repeated throughout the month. As wave patterns remained west of the

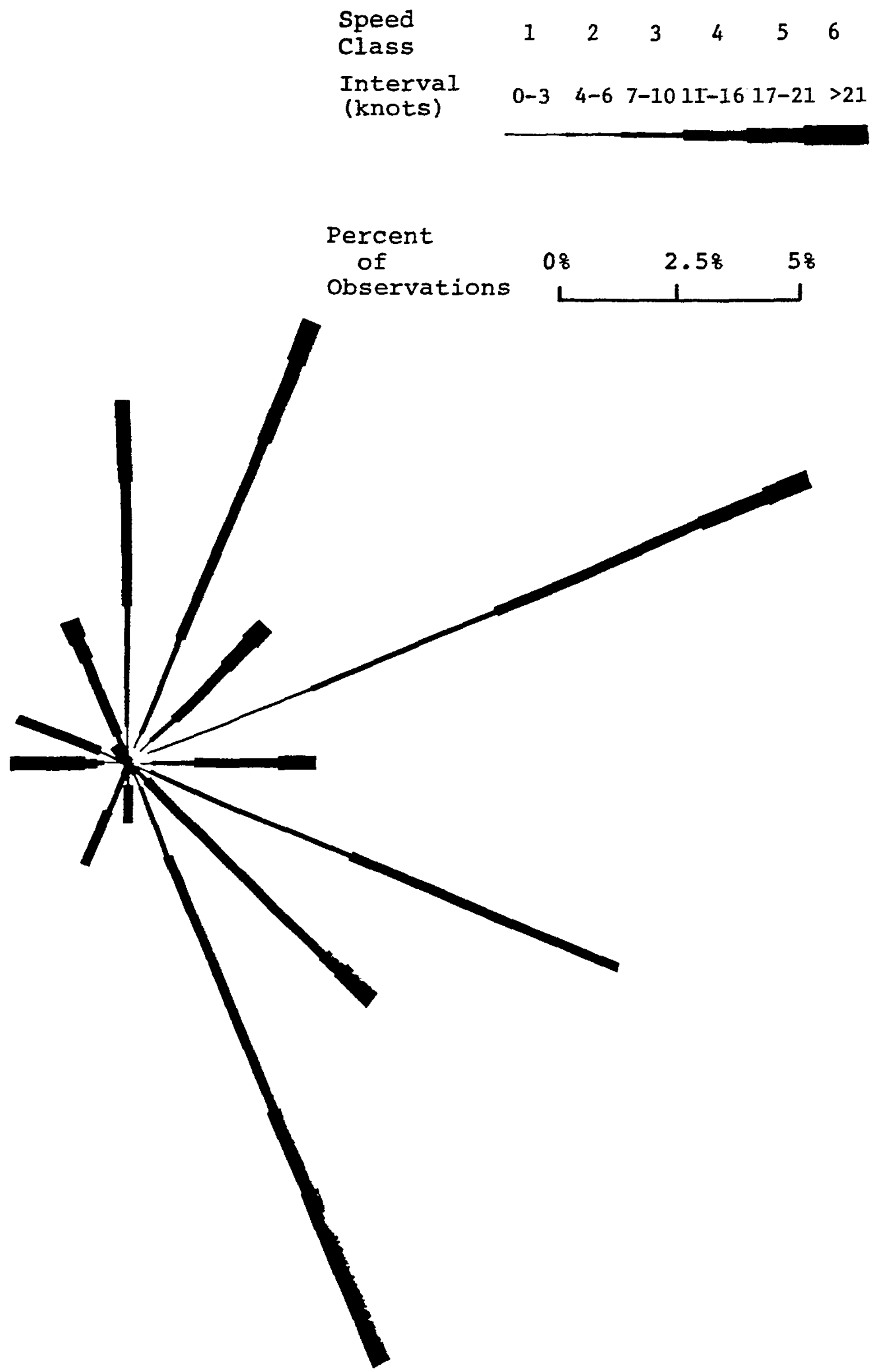


Figure 2.1-5 Wind Rose, High Island Station, Location 29 31N, 94 06.7W - (part of) November 1977.

site blocking the inflow of normally moist warm Gulf air, the temperature stayed somewhat lower than normal. Generally cooler temperatures prevailed through mid-December. Successive fronts brought in cold air and abrupt temperature drops and wind shifts to the north and northwest, followed by a slow rise in temperature as the front passed through. Winds then shifted somewhat to the south again and were succeeded 3 or 4 days later by a reestablishment of colder Arctic conditions north of the sites and into the region. Figure 2.1-6 indicates this pattern.

Generally the wind patterns of the month remain from the eastern and southeastern quadrant, but the strongest winds are dominantly from the northern quadrant, indicating the passage of successive fronts through the region. Wind stick figures and Port Arthur temperature data indicate the same pattern. This is the pattern which is common throughout the region, winds becoming established from the north and northwest for 2 or 3 days at a time, followed by a sudden shift to the south and southeast for another 2 or 3 days until another front passes through. The only significant difference in the period of observation was that it became established somewhat early. This is in keeping with generally colder and more extreme conditions throughout the United States in the winter of 1977 and 1978.

2.1.3 General Observations

The period of observation (September 1, 1977 through December 31, 1977) is typical of the region's meteorology as observed at land stations. The marine stations indicate that winds are generally from the south or southeast through the early fall period, and exhibit the

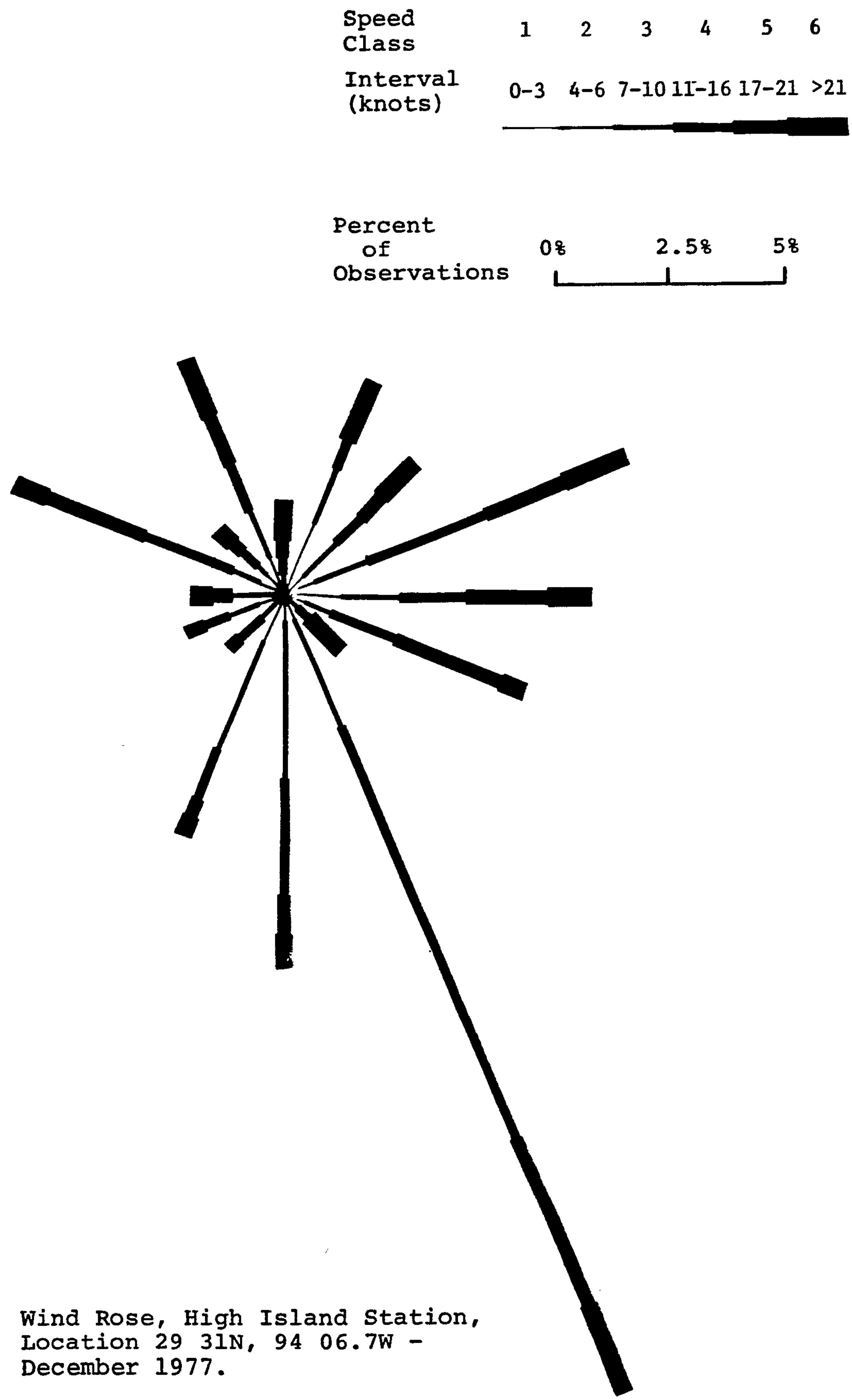


Figure 2.1-6 Wind Rose, High Island Station, Location 29 31N, 94 06.7W - December 1977.

alternating northwest-southeast patterns associated with midlatitude storm systems as winter gets underway. Murray (1974) indicates the dominance of wind-induced current drift in the shallow Gulf of Mexico on-shore drift of surface waters during much of the year. The ensuing shift in wind patterns to the north and northwest would reverse this pattern.

Spectral analysis of the data from both stations fails to exhibit any significant energy at the semidiurnal period that would be associated with land-sea breezes. Wind roses indicate quite strong and persistent winds throughout the period, as do stick diagrams. Since the land-sea breeze pattern is generally quite weak and easily masked by larger scale circulations, it is not possible with the given data to observe such patterns. There are no National Weather Service land-sea breeze stations in the area to give independent observations. In addition, the way in which data is taken at each station, that is, Port Arthur, Galveston, and Lake Charles, NWS Stations, AGA remote station and ARCO station, possibly preclude detailed spectral analysis in a way that would show existence or nonexistence of land-sea breezes.

Hydrologic data for the period (U. S. Geological Survey, 1978, private communication) for the Neches River Basin indicate no extremes in discharge except for the time period around December 15, marked by a passage of a front through the area and associated precipitation behind the front. Generally the winter-time pattern of precipitation for extended periods had not been established by the period of observation.

2.2 PHYSICAL OCEANOGRAPHY

2.2.1 Background

Since early September 1977, a physical oceanographic study has been conducted in the Gulf of Mexico region extending from approximately 20 km east of Calcasieu Pass (Louisiana) to 30 km west of Sabine Pass (Texas). This effort is part of the Texoma brine diffuser environmental impact study, designed to assess the impact on the local ecology of the discharge of brine resulting from leaching of salt domes for storage of petroleum reserves. The purpose of the Physical Oceanographic Study is not only to describe the physical environment in the region, but also to provide inputs to a computer model developed by Massachusetts Institute of Technology (MIT) which is being used for predicting characteristics of the discharged brine plume.

Beginning October 20, 1977, near bottom currents have been monitored at six sites using ENDECO current meters mounted on shallow moorings and positioned 2 meters above the bottom. In addition, wave, tide, and wind records were obtained in the vicinity of the West Hackberry and Big Hill sites, and conductivity, temperature, depth and dissolved oxygen (C,T,D-DO) casts were made on a series of grids centered on the six instrument sites. Additionally, the motion of clusters of drogues was monitored by aerial photography for a duration of four days to characterize near bottom and mid-depth horizontal diffusivities and to supplement Eulerian current measurements with Lagrangian observations.

This report presents data collected from October 20, 1977 to December 15, 1977, as well as a preliminary assessment of mechanisms which would appear to govern current dynamics for this part of the year.

2.2.2 Methodology

2.2.2.1 Experimental Site

The study area, instrumentation sites, and potential diffuser locations are shown in Figure 2.1. This region extends over the inner continental shelf from approximately 30 km west of Sabine Pass, TX (Big Hill Station) to approximately 20 km east of Calcasieu Pass, LA (West Hackberry Control Station). Since it was expected that diffusers would be constructed at a depth of approximately 9 m, measurements were concentrated on or about this isobath, which is 8-10 km offshore, and runs generally parallel to the slightly arcuate coast. Over this shelf area, local bathymetry shows little relative relief and a gentle offshore slope.

2.2.2.2 Experimental Design

The number, location, and spacing of instrument stations required for monitoring currents, winds, water level, and waves were selected to provide sufficient data to describe the physical processes which occur in the study area. In addition, the design was developed to provide needed input to the MIT Brine Diffuser Model run by the Center for Experimental Design and Analysis/NOAA.

In the original design, measurements were concentrated on the primary sites of Big Hill and West Hackberry, which were instrumented with two current meters placed 2 and 5 meters above the bottom, a wave-tide gage, and a meteorological package. Currents were further documented at Big Hill Control, Black Bayou, and West Hackberry Control by a current meter placed 2 meters above the bottom. A sixth current meter was deployed near Calcasieu

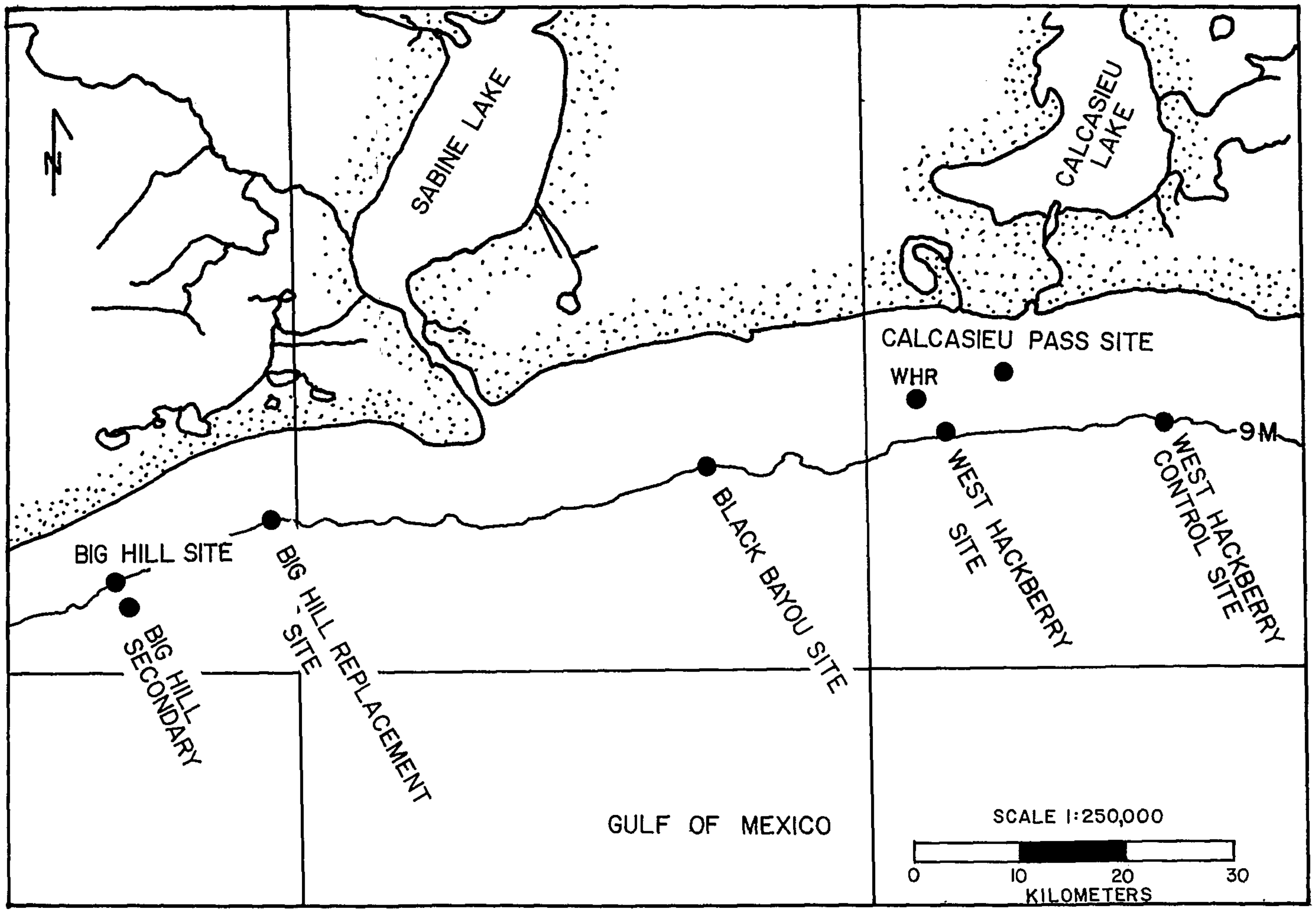


Figure 2.2-1 Study area and instrument site locations.

Pass to assess possible effects on regional dynamics of tidal and run-off discharge from the Calcasieu estuary. Current meter depths were selected on the basis of preliminary results of the MIT discharge model, which indicated that the brine was unlikely to rise above mid-depth, but rather would settle back toward the bottom following an initial rise.

Monthly CTD-DO casts were made on grids centered on the six current meter sites described above. These grids coincided with biological sampling stations.

Following initiation of the field program, it was decided that most instruments would be moved slightly away from their original locations because of intense shrimp trawling in the region. Soon after initial deployment, it was clear that regardless of notice given and surface markers used, any instrument not placed in close proximity to a fixed structure had a very low probability of surviving the entire measurement period. Consequently, most stations were moved, so all but the Calcasieu Pass station were within 150 m of an oil rig or stand pipe, where they were better protected.

2.2.2.3 Instrumentation

In order to understand and describe the currents' temporal and spatial variations, as well as the forcing mechanisms which govern their dynamics, it is required to continuously monitor current speed and direction, wind speed and direction, wave height and period, water level fluctuations, and the salinity-temperature distribution in the vicinity of the primary sites. The following sections describe the instrumentation used in the course of the present program.

Current Measurements

Currents were measured with ENDECO Model 105 tethered current meters. This instrument is a battery-powered, neutrally buoyant, shrouded impeller type meter designed to measure: 1) water current speed by integrating rotor revolutions over a selectable time interval set by the manufacturer, and 2) direction by defining the meter's orientation with respect to magnetic north. Data were recorded internally on 16 mm film at a sampling rate controlled by a crystal oscillator. The ENDECO 105's were present to sample currents over half-hour intervals. At this sampling rate, the suggested rotation period is 45 days.

It was felt that the ENDECO current meter was most suitable for use within the wave zone, because this instrument is normally attached at the end of a 1.5m nylon tether, secured to a taut mooring line by means of a Cook clamp. As a result, the current meter is effectively uncoupled from mooring motion induced by wave action and moves in an orientation determined by hydrodynamic forces generated on the impeller shroud by the mean flow.

A detailed program for ensuring data quality, as well as instrument reliability, was maintained throughout the study. Prior to leaving ENDECO facilities, each current meter impeller was balanced in water and calibrated in a flow tank. Additionaly, each compass was calibrated after being mounted in the instrument. These compass checks consisted of turning the instrument in known 15° arcs. By comparing recorded orientation with the known orientation, a deviation curve can be generated for each instrument. These individual speed calibration and compass deviation curves are used by ENDECO during preliminary data reduction.

Moorings for the ENDECO meters were designed for a two-month study. Their configuration is shown in Figure 2.2.2. Buoyancy is provided by three vinyl buoys. The Cook clamps securing the current meter mylon tether are attached to a stainless steel rope, 1 mm in diameter, connected by a chain to a 360 kg railroad wheel. Contacts between dissimilar metals occurred at two points, (A) and (B). However, as anticipated, corrosion was not a factor in the two-month study.

In order to facilitate relocating instruments, all moorings were equipped with an ENDECO Model 883 Continental Shelf pinger. Each of these pingers transmitted a periodic omnidirection acoustical signal at one of three known frequencies. Although they are designed to provide a nominal range of 3.2 km, it was assumed that the operational distance between a mooring and the acoustic receiver would be limited to 1.6 km (1 mile), because of likely attenuations due to plankton concentrations or other suspended particulate matter.

Pingers were located with the aid of a Burnett's acoustical directional receiver. This instrument can be used both as a diver-held and over-the-side receiver, each with a 5^o sensitivity arc. Generally, only the diver-held unit was used, since the research vessel could relocate stations to within 75 meters using Loran A and radar. Using the diver held unit, a diver could swim directly to the mooring by simply moving the receiver through an arc and determining the direction of maximum signal.

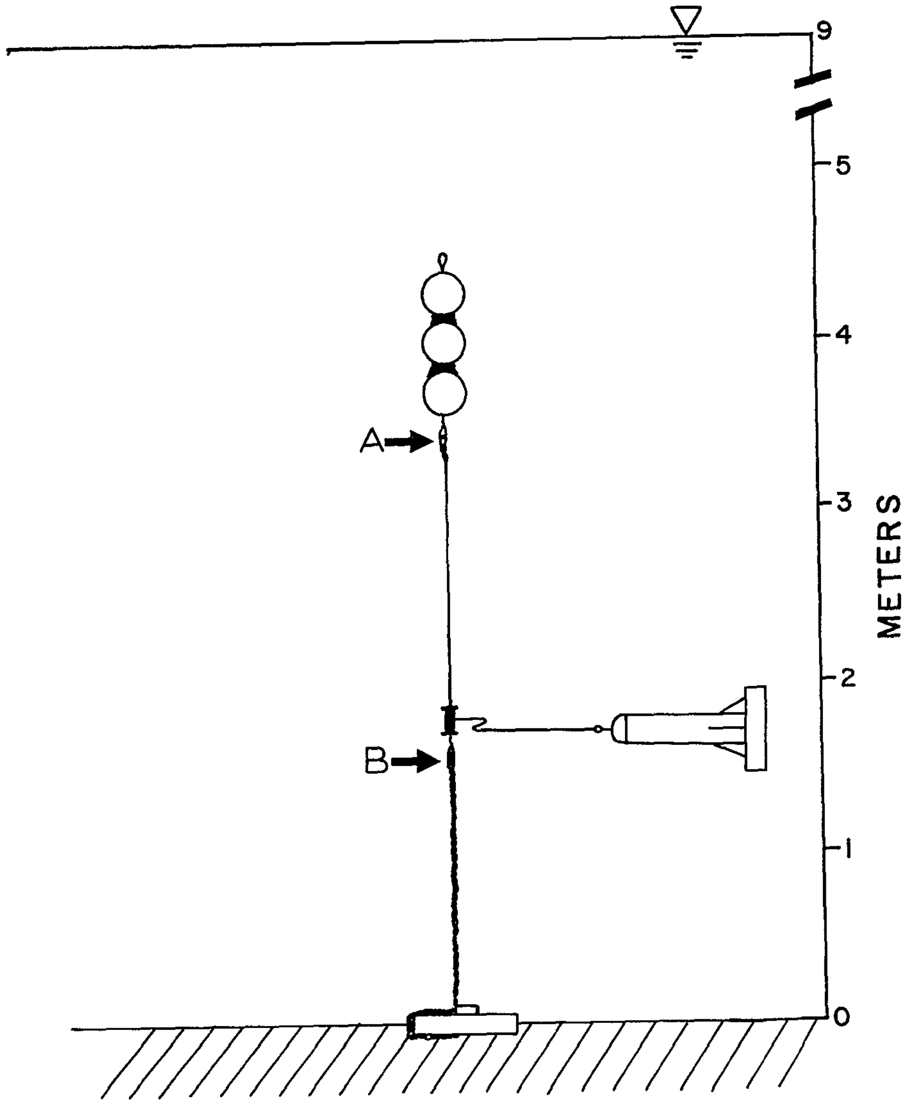


Figure 2.2-2 Schematic mooring used for current meter. Contacts between dissimilar metals occurred at points A and B.

Wave and Tide Measurements

A Hydro Products Model 525 in-situ wave-tide gage was used for measuring water level fluctuations and surface wave characteristics at the two primary sites. This instrument uses a pressure transducer activated by variations in the magnitude of the overlying water column. Changes in water level are transformed into proportional variations in an electrical signal, which is analyzed, averaged, and recorded every half hour on an analog chart.

Wave height is represented by significant wave height, ($H_{1/3}$). which is obtained by averaging over 20 minutes the height of the highest 1/3 of the recorded waves. Individual wave periods are determined, using the zero upcrossing definition of period. Period is averaged over 20 minutes and plotted as a frequency (Hertz). Tide level is determined by low-pass filtering the transducer output over 7.8 minutes, thus eliminating the influence of high frequency fluctuations associated with waves. Such a pressure-sensing wave-tide gage is known to record wave heights lower than true values (Ippen, 1966). All wave-tide gages were thoroughly dry-lab tested according to the Hydro Products Quality Assurance Program, prior to shipment from the factory. Moreover, many of the instruments were previously field tested and resulting data quality evaluated.

Wave-tide gages were attached to a short mooring, with the sensor at a depth of approximately 8 meters; i.e., one meter above the bottom. This mooring consisted of a length of 1/4" (0.6cm) stainless steel wire, approximately 2 to 3 m long, supported by a Norwegian bumper buoy providing 68 kg of buoyancy, and connected to a 360 kg railroad wheel by a length of

3/8" (1 cm) chain. In place, the bottom of the wave-tide gage was attached to the wire immediately above the wheel. An ENDECO Model 883 Continental Shelf pinger was attached for easy relocation on subsequent rotation cruises.

Meteorological Measurements

Meteorological data was taken using a MRI Model 1071 automatic weather station. Wind speed is sensed using a three cup anemometer geared to a spring reset marker element internal to the machine. The element has a helical ridge which, when combined with the constant chart speed, produces a straight line wind run as the recorded data. Each such separate run represents a .1 mile traverse. Knowing the constant chart speed and the angle of the wind run line, an average speed of the traverse can be calculated. Wind direction is sensed by a vane and recorded in analog form. Orientation to north is determined during instrument deployment using sighting markers and a compass to orient the instrument.

The Big Hill instrument was placed at a height of approximately 18 m on a platform approximately 2.5 miles south of the Big Hill station ($29^{o}31'$N, $94^{o}06'$W). The second instrument was placed at an elevation of about 10 m on a platform approximately 4 miles east of the West Hackberry site ($29^{o}39'$N, $93^{o}23'$W). Results of a rather complicated analysis of the analog records produced hourly estimates of wind speed and direction. Wind data for the experimental period prior to deployment of the above instruments was obtained from the National Weather Service. This record was taken at AMOS Station P-00 in West Cameron Block 643 (29°18'N,93°00'W) by a completely automatic station which identifies one minute averages of speed and direction. The station is interrogated three times per hour. The data transmitted on interrogation are the most recent values of average speed and direction.

Hydrological Measurements

Hydrographic measurements were conducted with a Hydrolab Surveyor Model 6D *in-situ* water quality analyzer. This fully integrated system consists: (1) a sealed deck unit containing the power unit, a panel meter, and necessary adjustment and calibration screws; (2) the instrument cable for supporting the sonde and for transmitting the signal from the sensors to the deck unit; (3) a sonde; and (4) the probes. Dissolved oxygen, conductivity, pH, chlorinity, temperature, eH, depth, were measured. A probe which supplied a standard reference signal also was on the sonde. Continuous flow over the various sensors is assured with the aid of an external motor driven fan.

This instrument was calibrated according to manufacturer procedures making use of an internal standard reference and/or sensing standard solutions. During cruises, sensors were always kept in an oxygenated saline solution. Vertically sequential measurements were made with all available probes on a systematic grid. At each station, the sonde was lowered by hand and all the above parameters recorded at 1 meter intervals. Although this instrument has a rated accuracy better than 1/100 of a standard unit, it has been conservatively assumed that the precision of the measurements is only 1/20 of a standard unit; i.e., 0.05°C or 0.05ml/L for DO.

Surface Buoys

As mentioned in Section 2.2.2.2, the original design called for deployment of surface buoys at all instruments not in close proximity of a permanent structure. These buoys, which had daymarks of three horizontal orange reflective strips on a white background, were floating 1.2 meters above water level, thus offering good day time visibility. They could also be easily located at night, as they were equipped with a light flashing with a sequence of 0.5 sec. on, 2.5 sec. off.

These buoys proved to be of little use as protection for instruments since most disappeared shortly after deployment and the moorings beneath them were disturbed. In view of this situation, those instruments deployed away from a permanent structure were moved close to an oil rig or standpipe.

2.2.2.4 Field Operations

Marine operations related to the deployment/rotation of current meters, anemometers, and wave-tide gages, and associated with monitoring by aerial photography the motion of clusters of drogues in order to determine horizontal diffusivities at the primary site, are described in the following two sections.

Deployment/Rotation of Field Instrumentation

The initial deployment cruise took place from October 19-21, 1977. A total of eight current meters, two wave-tide gages, and five surface markers were deployed at locations shown in Figure 2.2-1. The current meter and wave-tide gage moorings were launched according to a free fall procedure. Once the wheels were resting on their side, the instruments were attached to the taut line by divers. None of the anchors sank deeply into the bottom, as a layer of shell fragments was often found below a surface layer of silts and clays.

The first rotation cruise was conducted from November 2-4, 1977. It had been anticipated, during the design phase of the program, that as a precautionary measure, all instrumentation would be retrieved and redeployed after a two-week period, in view of the potential risk of biofouling in an area where biological activity was suspected to be high. The mooring sites were reoccupied, using the ship's Loran-A and radar capability, and the pinger attached to the instrumentation located by means of the diver-held acoustic receiver described in a previous section. It was determined that for current meters treated with Woolsey 171 anti-fouling paint, racing finish, biofouling would not influence the data return, and that a nominal rotation period of 30 days could be established without jeopardizing the quality of the data. This schedule coincided with the sampling intervals for the biological/chemical oceanography study and the required rotation period of the wave-tide gages. A summary of cruise activities is presented in Table 2.2-1.

It is anticipated that a similar rotation will be maintained until program completion.

Drogue Study

In addition to Eulerian measurements described in previous sections, motion of clusters of drogues, providing Lagrangian velocities at various

Cruise 1 10/19-10/21/77	o Deploy current meters at West Hackberry Control, Calcasieu Pass, West Hackberry, Black Bayou, Big Hill Control, and Big Hill. o Deploy wave-tide gage at W. Hackberry and Big Hill. o Deploy surface markers at each station except Black Bayou.
Cruise 2 11/2-11/4/77	o Retrieve and redeploy current meters at West Hackberry Control, Calcasieu Pass. o Deploy Big Hill replacement.
Cruise 3 11/19-11/21/77	o Retrieve and redeploy West Hackberry wave-tide gage. o Retrieve and redeploy current meters at Calcasieu Pass, Black Bayou and Big Hill replacement.
Cruise 3a 11/30-12/1/77	o Deploy wave-tide gage at Big Hill replacement. o Deploy current meters at Big Hill secondary and West Hackberry replacement.
Cruise 4 12/17-12/18/77	o Retrieve and redeploy wave-tide gage at Big Hill replacement. o Retrieve and redeploy current meters at Calcasieu Pass, West Hackberry replacement, Black Bayou, Big Hill replacement, and Big Hill secondary.

Table 2.2-1. Summary of physical oceanographic cruise activity.

depths, was monitored by aerial photography for a duration of four days, in order to characterize the horizontal diffusivity prevailing at the site. These values were to be used in the MIT Brine Diffuser model. A total of 20 drogues were constructed which consisted of a surface float and a submerged drag element. The surface unit, shown in Figure 2.2-3, is composed of a vertical PVC tube containing dye, surrounded by six cylindrical floats tied together by metal straps. Additional flotation is provided by a surface collar, below which four horizontal, uniquely color-coded arms are attached. When the drogue was deployed in the field, these arms floated just below the surface, which permitted easy identification in aerial photographs. In addition, dye contained in the central cylinder would slowly leak out through holes drilled in the PVC tube, just below the collar flotation and hence close to the surface water level, and would generate easily discernable streaks of dye on the sea surface.

The drogue drag element consisted of a thin, 1.2 m X 1.2 m metal blind, weighted on the lower edge with a piece of bar iron, and suspended below the surface floats at a predetermined depth.

The drogues were deployed in the vicinity of the West Hackberry site, from October 26-29, 1977, according to patterns designed to provide information on horizontal diffusivities at various depths, as well as Lagrangian velocity profiles. The following table summarizes the purpose of the field investigations during these four days.

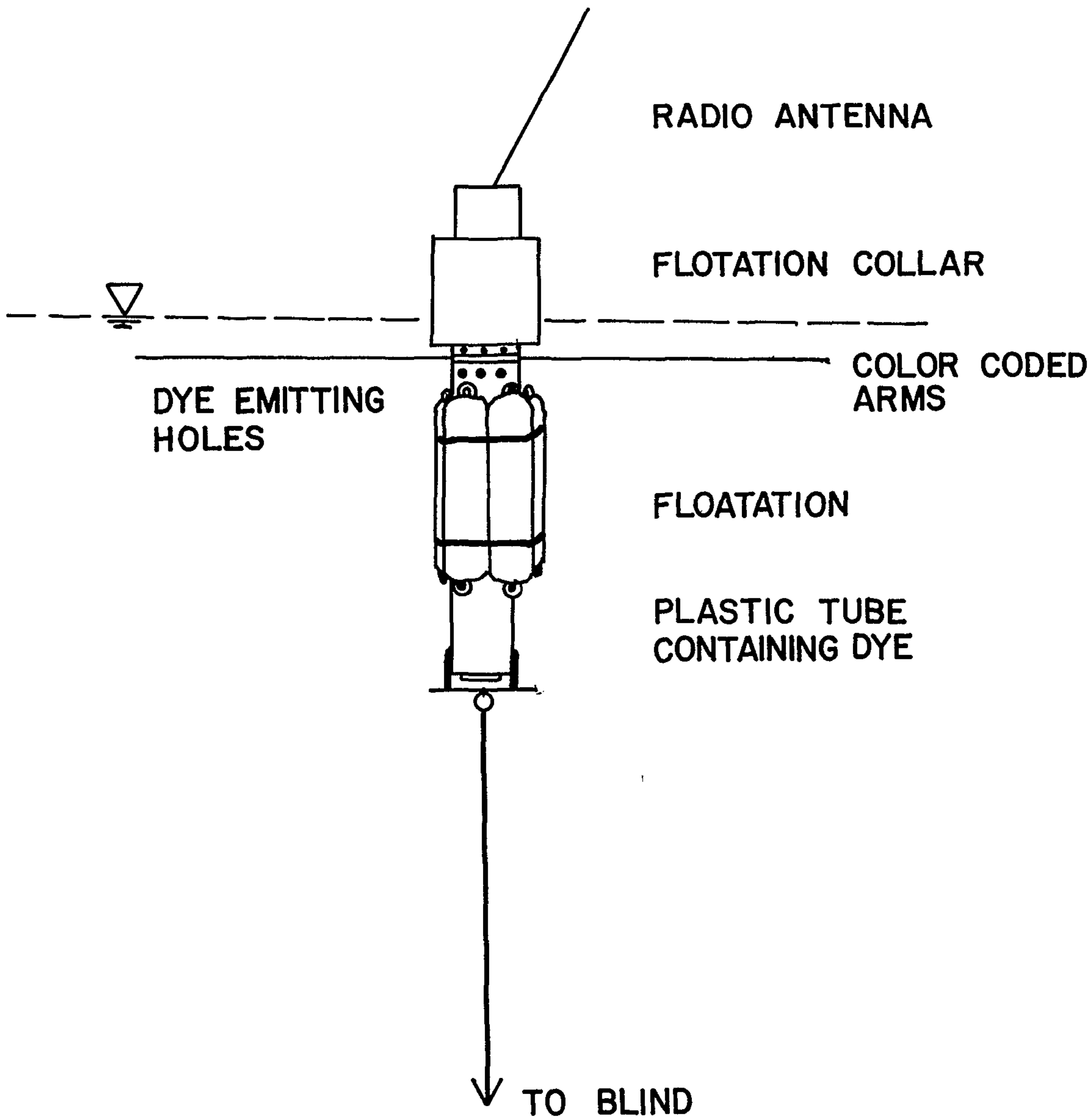


Figure 2.2-3. Surface float used with drogues. Radios were only included in 5 floats during the last 24 hours of the study.

Date	Purpose of Drogue Motion Monitoring
October 26	Determination of horizontal diffusivities near bottom and at mid-depth
October 27	Determination of horizontal diffisivities near bottom and at mid-depth
October 28	Determination of near bottom horizontal diffusivities and measurements of Lagrangian velocity profiles (short-term)
October 29	Measurement of Lagrangian velocity profiles (long-term).

Table 2.2-2. Drogue Project Activities

During the first two days, two clusters of 10 drogues, separated from one another, were released with their drag element at depths of 4.6 and 7.6 m, respectively, according to a straight line pattern either parallel or perpendicualr to the local isobath. Initial drogue spacing was 50 m or less. Monitoring of their relative displacement was accomplished by aerial photography, using two 87^{0}lens, 70 mm Hasselblad MK-10 cameras which provided simultaneous positive and negative color transparencies of the same field of view. Flight parameters of the camera bearing Cessna-337 (altitude, attitude, heading, latitude, and longitude) were displayed on a data panel and photographed when a vertical picture of the drogue field was taken. This information, in turn, could be used in the data reduction to correct for variations in plane orientation. Photographic runs were made every 10 to 15 minutes for approximately 5 hours. Results of this study are presented in Section 2.2.4.1.

Vertical Current Velocity Profile Measurements

During the last two days of the drogue study, vertical profiles of horizontal current velocity were obtained using an over-the-side current meter. The ship was moored fore and aft with a slight bias to the wind, so that the ships motion would be minimal. In addition, a tripod supporting a current meter sensor which could be set at depths of 1 to 7 feet (.3 to 2.1 m) from the bottom was deployed to document the vertical profile prevailing in the near bottom layer. Care was taken in construction of the tripod to minimize effects of the frame on the current field. Data collected by both methods are provided in Section 2.2.4.1.

2.2.3 Data Analysis

Methodology followed to reduce and analyze current meter, meteorological, wave/water level, and hydrographic data is described in the following sections.

2.2.3.1. Currents and Wind Data

Half-hour estimates of current speed and direction were made with ENDECO 105 current meters and were recorded on photographic film. These films were processed by ENDECO and data transferred to a computer-compatible magnetic tape. Upon receipt of these tapes at SAI, current vectors were corrected for magnetic variation and then resolved into orthogonal velocity components. In the coordinate system used, currents are positive alongshore towards the east -- and positive offshore and perpendicular to local isobaths. Rotation of the alongshore component from true north is given in Table 2.2-5. As they became available, records at a given station for successive monitoring periods were joined to create a single continuous time series. Wind date (speed and direction) were treated in the same manner and used the same direction convention as for current meter data. For this discussion, wind direction is the direction toward which the wind was blowing (i.e., the oceanographic direction convention). Time series were filtered using a low pass symmetrical cosine filter developed originally by Oregon State University. Filtering of time series results in removing variations in a particular frequency range without affecting the mean value or fluctuations outside the desired range. The filter used in this analysis has a cut-off

Figures generated during analysis of the two-month records collected in the course of this study are presented in Section 2.2.4. It should be noted that two records (Calcasieu Pass and Big Hill Replacement) seemed to have short intervals during which the current meter impellor was obstructed, probably due to debris. These incidents usually did not last for more than six hours and occurred during periods of relatively high currents; thus they are easily distinguishable. Reasonable corrections can usually be made to minimize effects of these interruptions. Other than these minor breaks, data collected during the first two months are of high quality and essentially continuous from the time of deployment.

2.2.3.2 Water Level and Waves

Water level and wave data were transcribed from analog records. Water level variations were analyzed for tidal components, primarily diurnal and semidiurnal. Tide induced fluctuations were stored and removed from the water level record, and the remaining residual water level variations graphed and used in identification of dynamic processes which are producing the observed currents.

2.2.3.3 Conductivity, Temperature, and Dissolved Oxygen

An estimate of salinity can be obtained from conductivity and temperature measurements, using standard Naval Oceanographic Office conversion tables. Salinity and temperature, in turn, can be combined to describe the vertical density field. Contouring of each density component and dissolved oxygen often provide indications of local dynamic processes.

2.2.4 Results and Discussion

Results of the one-time drogue study of diffusion and Lagrangian velocities, and the general physical oceanographic program will be presented separately since these two studies generally examine processes of distinctly different time scales.

2.2.4.1 Diffusion Coefficient Determination

Failure of the Fickian equation to predict oceanic diffusion has been evident since the early part of this century. The classical paper by Stommel (1949) discusses fundamental aspects of horizontal diffusion and shows that the semi-empirical "4/3" power law dependence of the eddy diffusion coefficient on length can be deduced from turbulence theories. Since that time, many experimental results have been made available in the literature. Ozmidov (1960) has made more precise the "dissipation" constant in the relationship

$$K_H = C_1 \epsilon^{1/3} L^{4/3} \qquad (1)$$

where $C_1 = (4 \times 10^{-2})$, a universal constant, ϵ is the rate of dissipation of kinetic energy, L the length scale, and K_H the horizontal eddy diffusion coefficient.

As developed by Stommel, the neighbor diffusivity method for estimating the coefficient of eddy diffusion involves monitoring the relative displacement of a cluster of drogues. If a pair of drogues is separated by a distance L at time $t=t_0$ and by $L+\Delta L$ at $t=t_0+\Delta t$, then the relative displacement, ΔL, can be used as a measure of the intensity of diffusion at a length scale of L.

The one dimensional diffusion equation is

$$\frac{DS}{Dt} = K_h (1) \frac{\partial^2 S}{\partial X^2} \qquad (2)$$

where S= represents local concentration. A solution to Eq. 2 for the neighbor diffusivity calculations is given by

$$S = \frac{\text{Constant}}{(\Delta t)^{1/2}} \exp - \left(\frac{(\Delta L)^2}{4\Delta t K_h(L)} \right) \qquad (3)$$

i.e., a Gaussian distribution with a variance, σ^2, expressed by

$$\sigma^2 = 2\Delta t K_h(L) \qquad (4)$$

Eq. 4 can be written as

$$K_h(L) = \frac{(\Delta L)^2}{2\Delta t} \text{ where } (\Delta L)^2 = \sigma^2 \qquad (5)$$

Thus, spreading of the drogues is similar to horizontal spreading of a dye patch. As seen above, for a collection of drogues at a given depth, every ΔL and Δt for each pair of drogues defines an estimate of $K_h(L)$. Values of K(L) are partitioned on the basis of separation, L, and all diffusivity estimates within a range of values of L are ensemble averaged. For this experiment, values of K(L) were averaged for 120 m increments of L; i.e., 60m - 180m, 180 m - 300 m, etc. Ensemble averaged diffusivities, K were next plotted against L to produce an empirical functional relationship between K_h and L. These plots of ensemble averages of horizontal eddy diffusivity, K_h, as a function of a length scale, L, are given in Figures 2.2-4, and 2.2-5. Also given are two power laws of the form

$$K_h = AL^B \qquad (6).$$

Use of this functional relationship of K and L is suggested by Equation (1) where A includes the effects of ϵ and C.

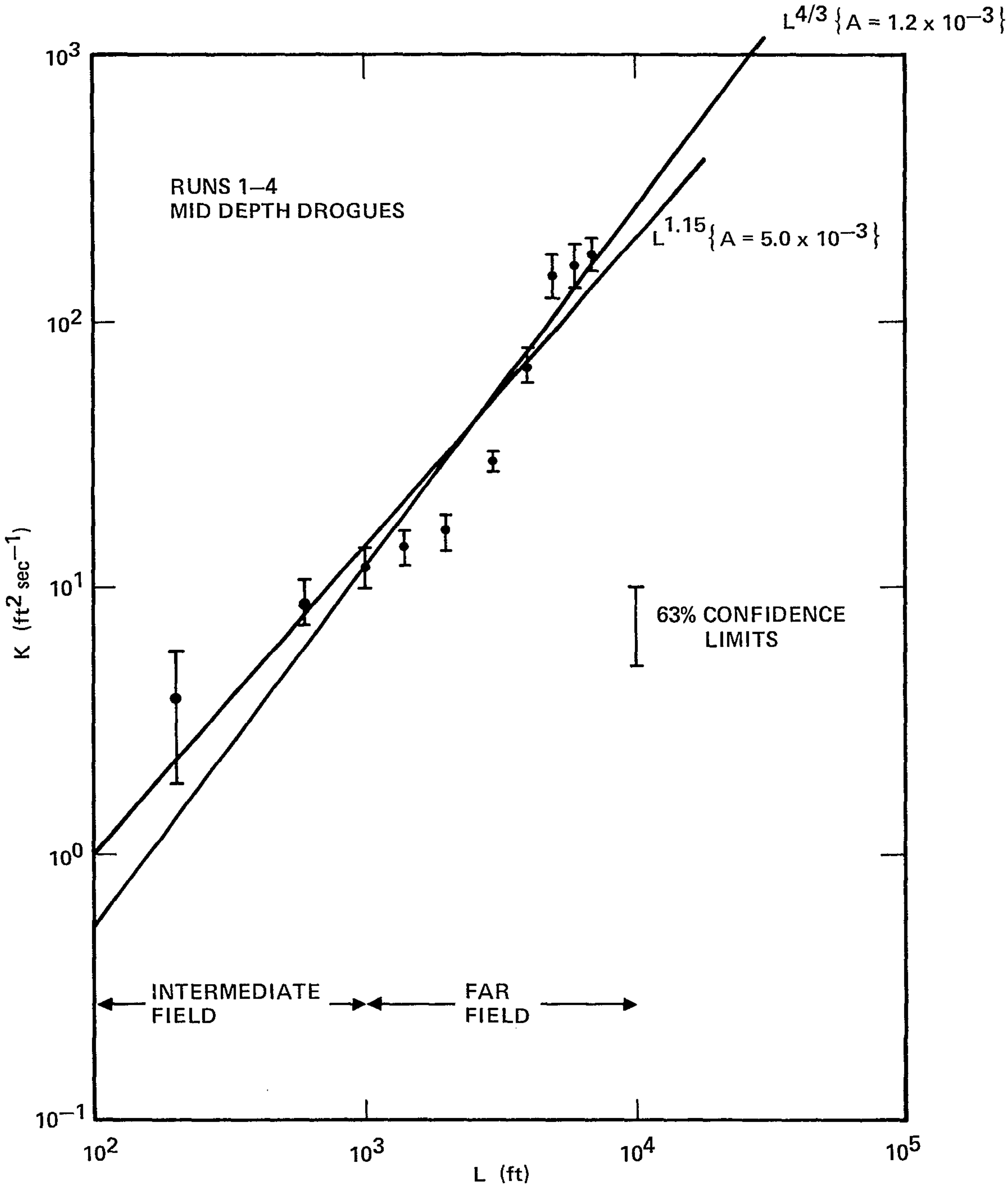


Figure 2.2-4. Horizontal Diffusion Coefficient VS Drogue Separation Mid-Depth Drogues.

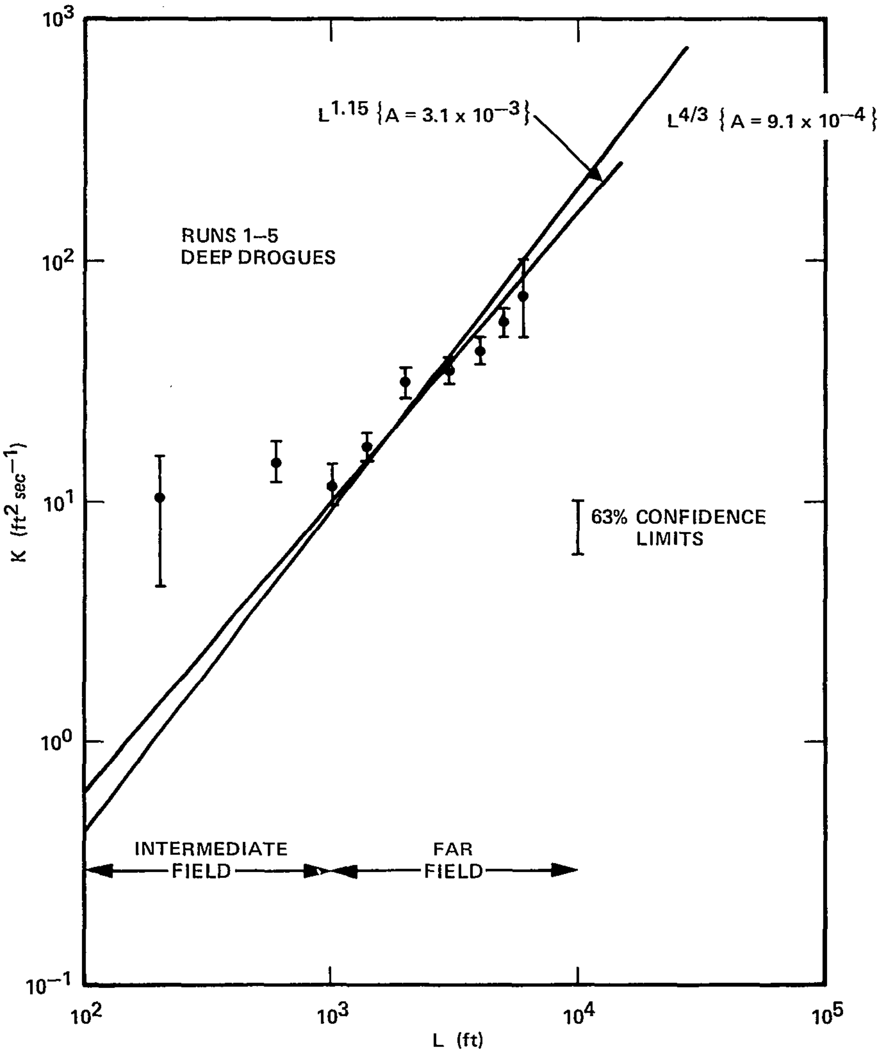


Figure 2.2-5 Horizontal Diffusion Coefficient VS Drogue Separation Deep Depth Drogues.

In a least squares fit of Equation (6) to the data, two values of the exponent B were tried, B = 1.15 as tentatively suggested and used by NOAA (1977) and B = 1.33 (= 4/3) as suggested by Equation (1). For each value of B, values of A could be computed and are given in Table 2.2-3 for deep and mid-depth estimates of horizontal diffusivity.

Depth	B = 1.15	B = 4/3
Mid	5.0×10^{-3}	1.2×10^{-3}
Deep	3.1×10^{-3}	9.1×10^{-4}

Table 2.2-3. Value of A in Equation (6)

Both fits presented in Figures 2.2-4 and 2.2-5 seem to provide at least adequate representation in the far field, in particular for the deep drogues. It seems that values of horizontal eddy diffusivities used by CEDDA/NOAA in preliminary runs of the MIT Brine Diffuser model are appropriate for the environment examined by this drogue study.

As seen in equation (1), an important parameter in the local flow is ϵ which indexes the rate of loss at kinetic energy. Comparing equations (1) and (6) yields $\epsilon = (A/C_1)^3$.

Values of ϵ which result from application of this formula and values given in Table 3 are 1.1×10^{-2} CM^2 SEC^{-3} for deep drogues and 2.5×10^{-2} CM^2 SEC^{-3} for mid-depth drogues. This suggests that the KE is dissipated at mid-depth at twice the near bottom rate.

Lagranian and Eulerian Vertical Current Profiles

During the last two days of the drogue experiment, Lagrangian velocity profiles were measured. This involved placing subsurface drag elements of a group of drogues at 1.5 m incremental depths (5', 10', 15', 20', and 25'). Results of these experiments are summarized in Figure 2.2-6. The movement of these drogue units includes advection, as well as diffusive and dispersive movement.

The Lagrangian velocity profile in Figure 2.2-6 indicates the existence of large, vertical velocity gradients and significant variations in current direction throughout the column, in particular, the upper 2.4 meters (Figure 2.2-6). If an arbitrary coordinate system oriented approximately NE to SW is used, then between 1.2 meters and 2.4 meters a velocity gradient of 27 cm/sec/meter exists. Shear in this layer is therefore particularly strong. Divers working in the same area on several instrument rotation cruises confirmed that finding.

Results of Eulerian current profiling taken during the above drogue study are given in Figure 2.2-7. The instrument used in measuring these current magnitudes did not indicate current direction. However, by examining synoptic drogue displacements, the general direction of the Eulerian velocity vector can be deduced. Figure 2.2-7 is replotted in Figure 2.2-8 with direction, inferred from drogue displacements, taken into consideration.

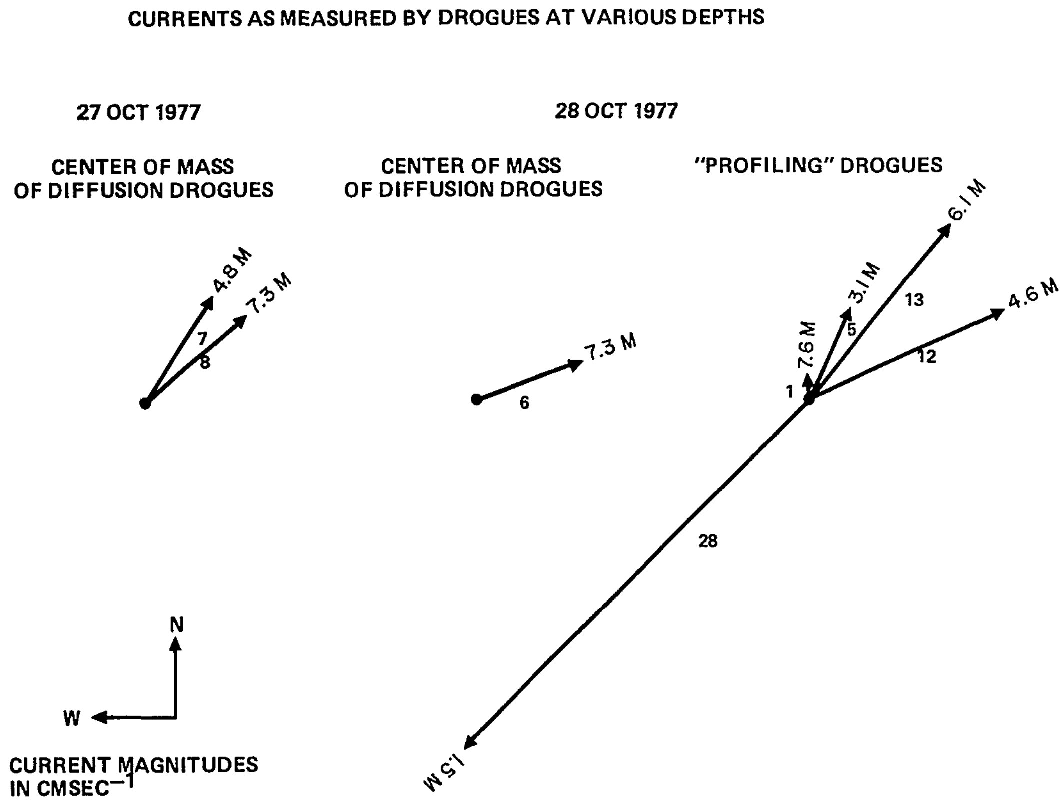


Figure 2.2-6. Lagrangian Currents at Various Depths. Numbers at the end of vectors indicate the depth in meters of the main drag element. The numbers along side the vectors, indicate the velocity in cm/sec.

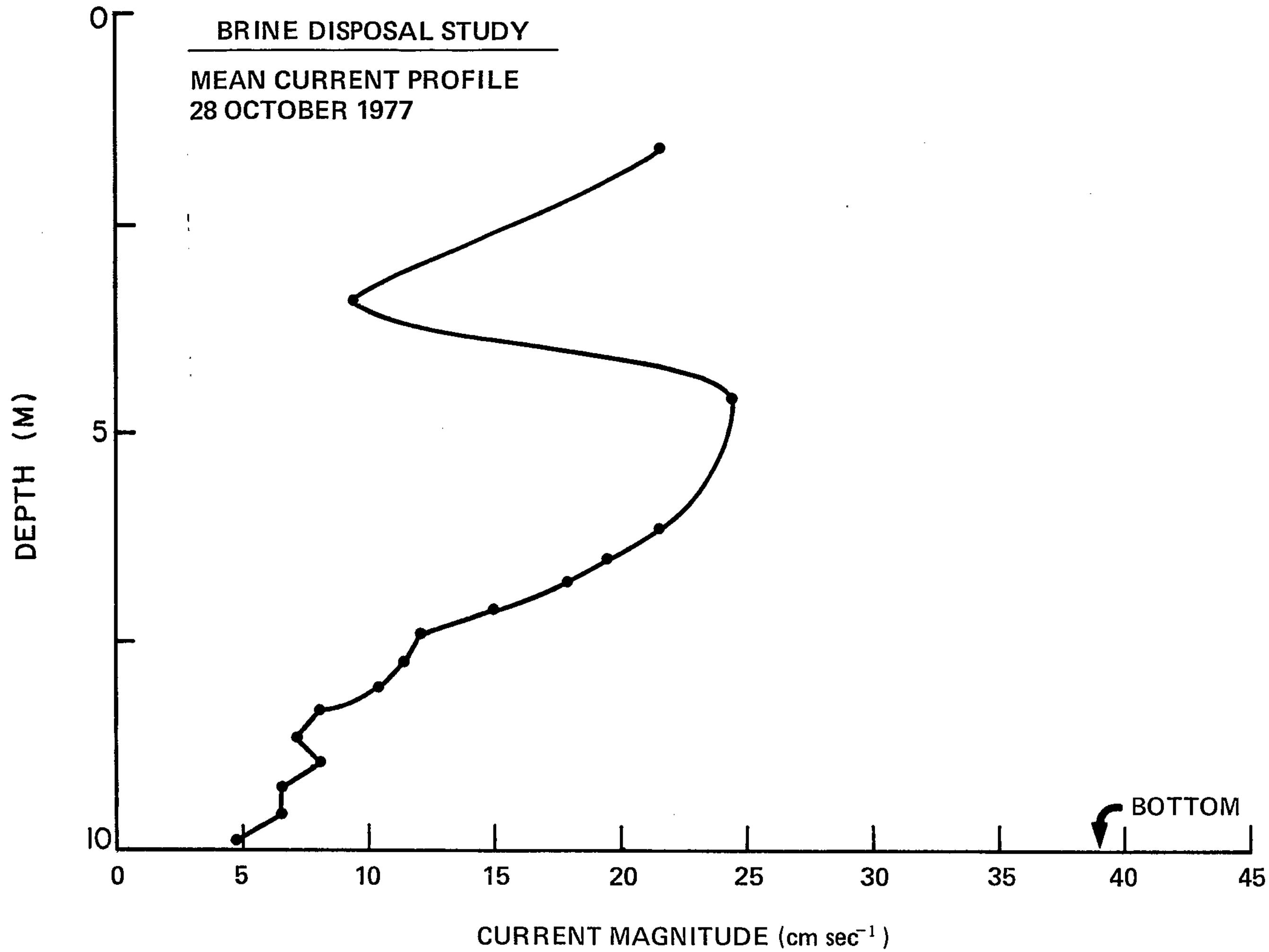


Figure 2.2-7. Mean Eulerian Profile of Current Magnitude Measured On 28 October 1977. This representation does not take into consideration current direction.

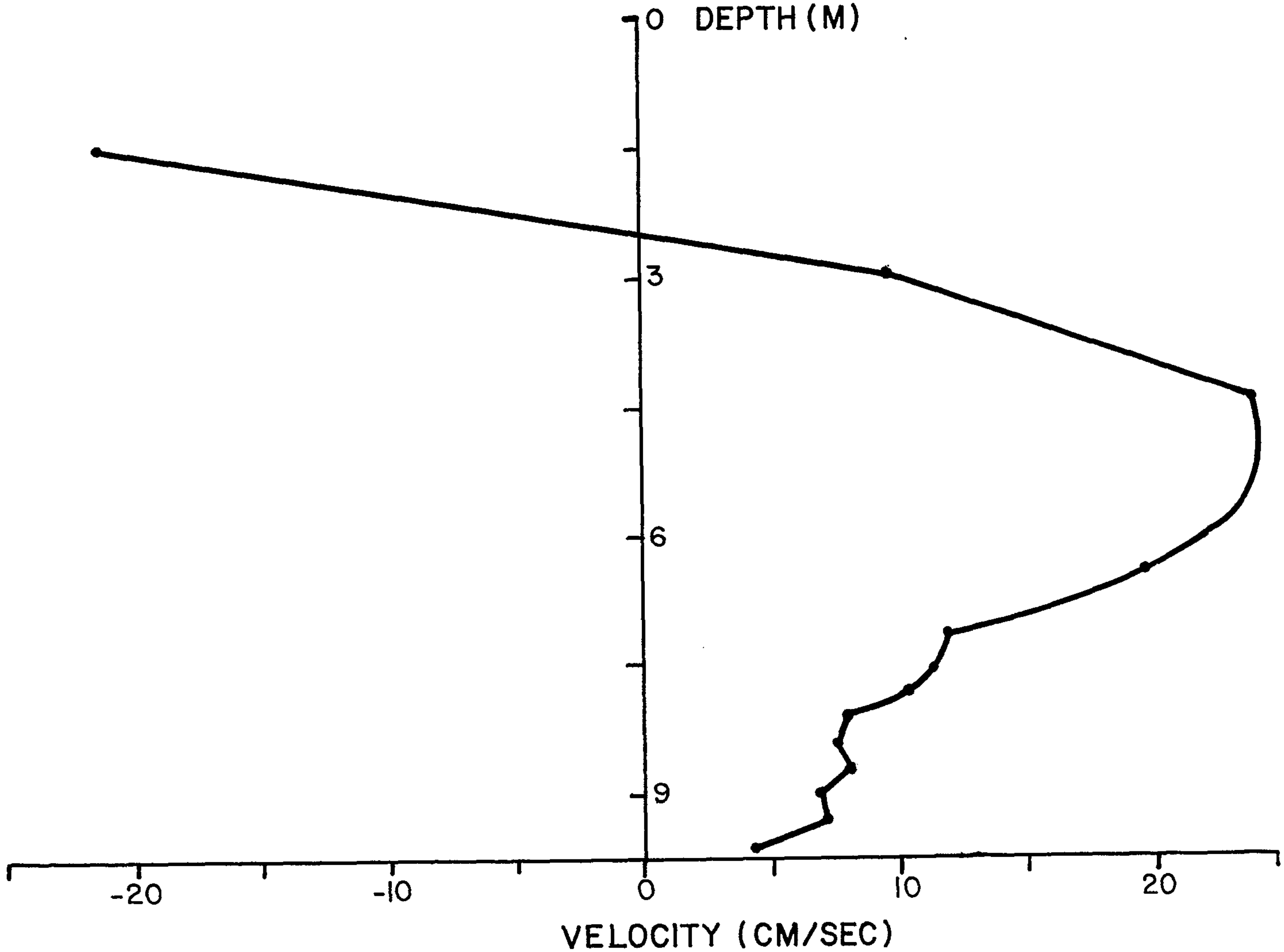


Figure 2.2-8. Mean Eulerian profile of horizontal currents measured on 28 October 1977, replotted to take into consideration current direction inferred from drogue displacements.

Eulerian and Lagrangian velocity profiles (Figures 2.2-8 and 2.2-10 respectively), although similar, present some disparities. However, it must be remembered that the blinds used as primary drag elements were acted upon by currents spanning approximately 1.5 meters. If certain nonlinear types of vertical profile exist, net drag on the blind and hence drogue velocity will not be representative of conditions prevailing at the midpoint of the drag element. Furthermore, although the drogues used in this study were designed to minimize the ratio of drag on surface float to drag on the subsurface element, some surface floatation drag did occur. Figure 2.2-9 presents an estimate of this influence assuming a 25 cm/sec SW directed surface current and that all drogue velocities were oriented SW - NE. It can be shown that the observed negative surface currents could cause drogue displacements to underestimate by approximately 4-5cm/sec the NE directed currents measured below a depth of 3m. This effect of the surface floatation accounts for at least 50% of the discrepancy between Lagrangian and Eulerian velocity profiles shown in Figures 2.2-8 and 2.2-10.

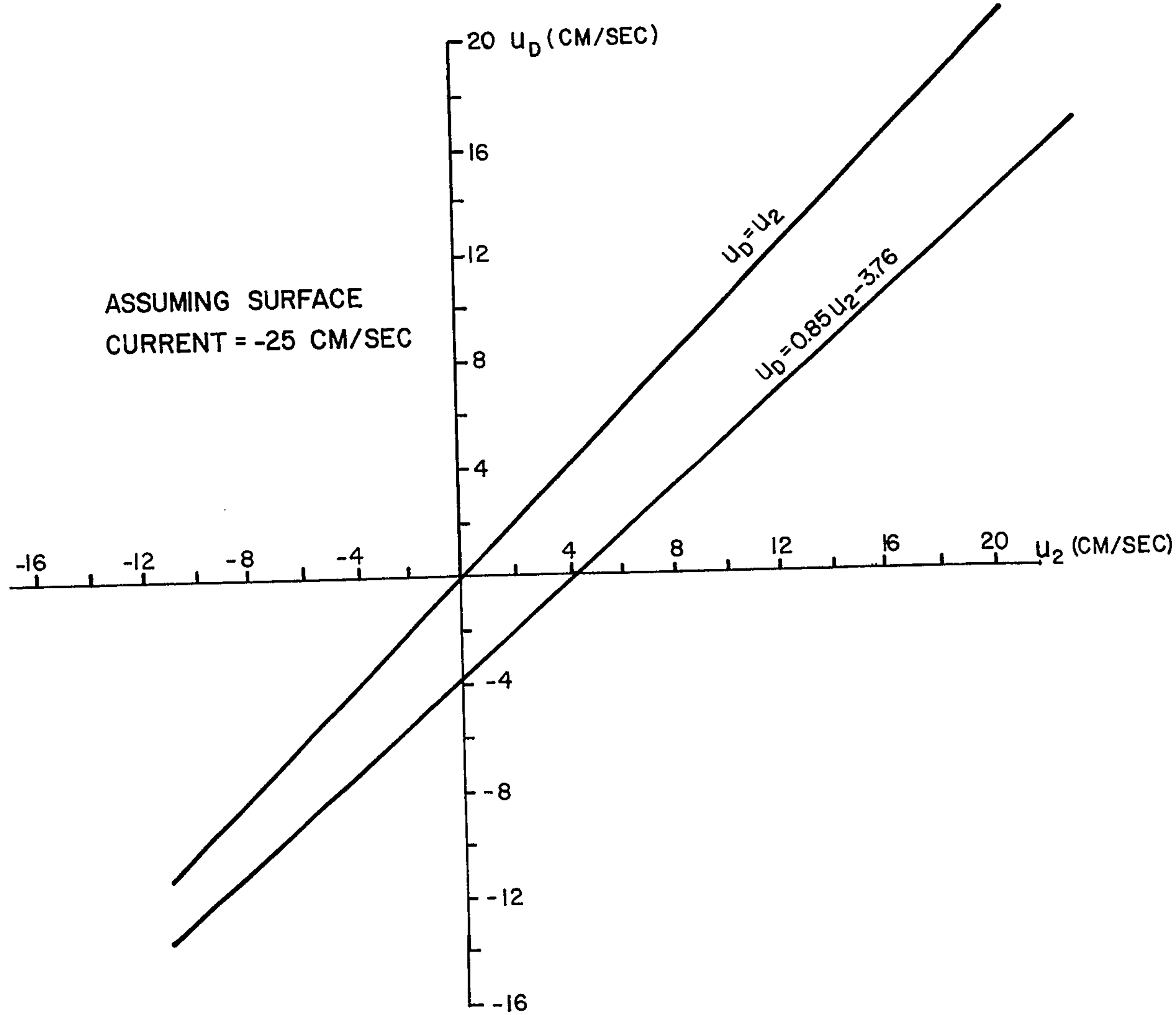


Figure 2.2-9. Possible impact of drag on the surface unit in combination with strong surface currents and shear. U_D = velocity of the drogue unit; U_2 - water velocity in the vicinity of the submerged primary drag element. The upper curve occurs when the drogue unit (including surface float) moves with the velocity at depth U_2. The lower curve shows the relationship between U_D and U_2 when a current of -25 cm/sec is acting on the surface float.

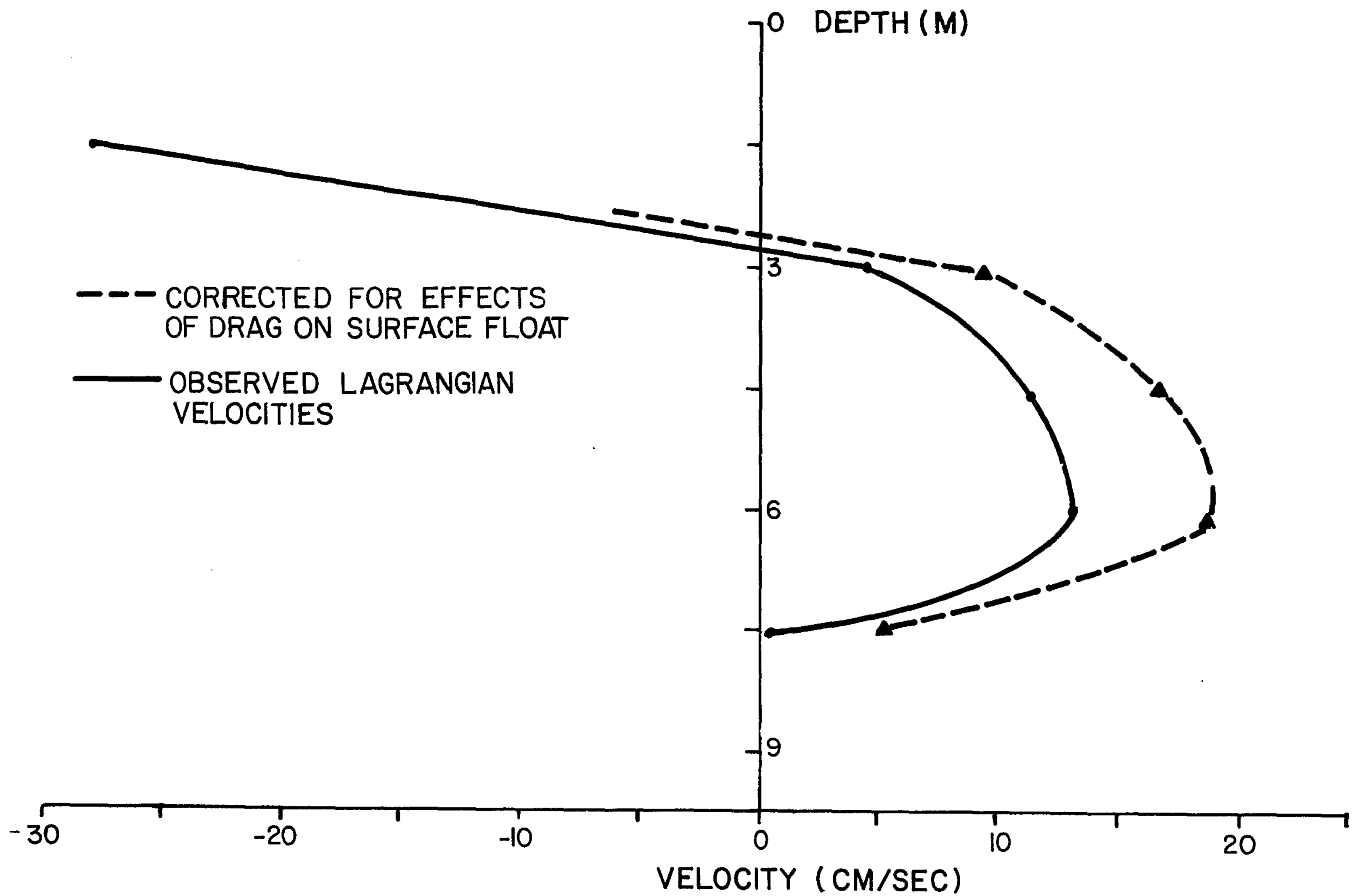


Figure 2.2-10. Graphs of observed Lagrangian velocity as a function of depth (solid line) and Lagrangian velocity corrected for parasitic surface drag.

Bottom Turbulent Layer and Vertical Diffusivity

As corroborated in the Lagrangian profile, Eulerian velocity records from the bottom three meters show relatively small variations in direction. Thus, in the following discussion, it will be assumed that these measured velocities are in the same direction. It is further assumed that a turbulent, constant stress layer exists in the bottom three meters.

Within the constant stress layer, the velocity profile is logarithmic.

$$u(z) = \frac{u_*}{k} \ln \frac{z}{z_0}$$

where $u(z)$ is current velocity as a function of depth, k is von Karman's constant (0.4), z_0 is roughness height which is assumed to be some index of boundary roughness, and u_* is friction or shear velocity, defined by

$$u_* = \left(\frac{\tau_b}{\rho}\right)^{\frac{1}{2}}$$

where τ_b is bottom shear stress, and, ρ, is water density.

A least squares fit of observed velocities to a logarithmic profile provides estimates of u_* and z_0. Figure 2.2-11 shows two such lines: (A) which includes the upper nine measurements, and (B) which includes only the bottom four measurements. Each least squares fit had a correlation coefficient of .82 or higher. Thus, the logarithmic representation accounts for at least 82% of observed vertical variation in velocity.

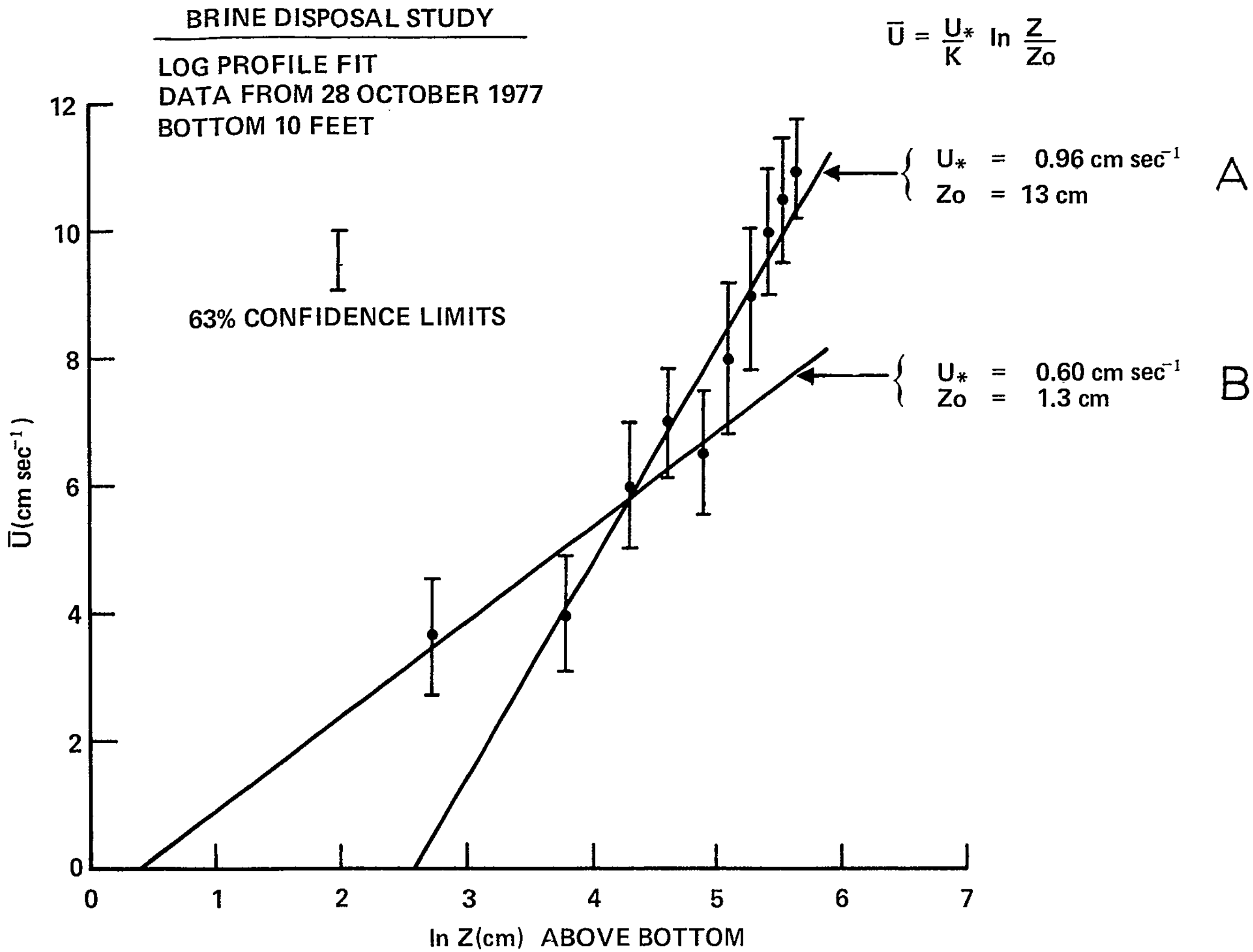


Figure 2.2-11. Current Speed VS ln(z) 28 October 1977.

Using values of friction velocity determined from these least squares fit, it is possible to make some order of magnitude estimates of the near bottom vertical eddy coefficient, K (z),

$$K(z) = k u_* z$$

where K(z) is vertical eddy coefficient and all other symbols are as defined previously. If $u_* = 1$ cm/sec then K (20 cm) = 8 cm^2/sec. If $u_* =$ .6 cm/sec then K(20 cm) = 4.8 cm^2/sec. These are to be considered as order of magnitude estimates for that region near the boundary and within the constant stress layer. Actual brine diffusion would have significant impact on local vertical mixing processes and therefore other estimates of K(z) would have to be made for the discharge environment.

2.2.4.2 Regional Physical Oceanographic Processes

Parts of the initial two-month data set consisting of current speed and direction, wind speed and direction, water level fluctuations, tides, waves, salinity, temperature and dissolved oxygen can be integrated into a coherent scheme which describes some of the major processes occurring within the study area.

Winds, Currents and Water Levels

Figure 2.2-12 show plots of magnitudes of orthogonal velocity components from Black Bayou. From such records, it is difficult to discern any processes which may govern near bottom currents. However, comparisons of stick plots of low pass filtered data suggest certain interactions between currents at successive alongshore stations (Figures 2.2-13, 2.2-14 and 2.2-15).

In Figure 2.2-14, it is apparent that the alongshore, "v", component of current at each station is highly correlated, even between Big Hill Replacement and Calcasieu Pass which are approximately 60 km apart. This similarity suggests that the alongshore scale of lower frequency current variations is at least measured in hundreds of kilometers. Note, however, that the alongshore winds do not visually correlate as well with the alongshore currents, although this improves after day 330 and becomes good after day 340. Note also that residual water level correlates well with alongshore currents.

In Figure 2.2-15, the transself currents at the various sites are not as well correlated, nor do they show as much correspondence in a consistent manner with the transshelf winds or with residual water level. These characteristics will be quantified.

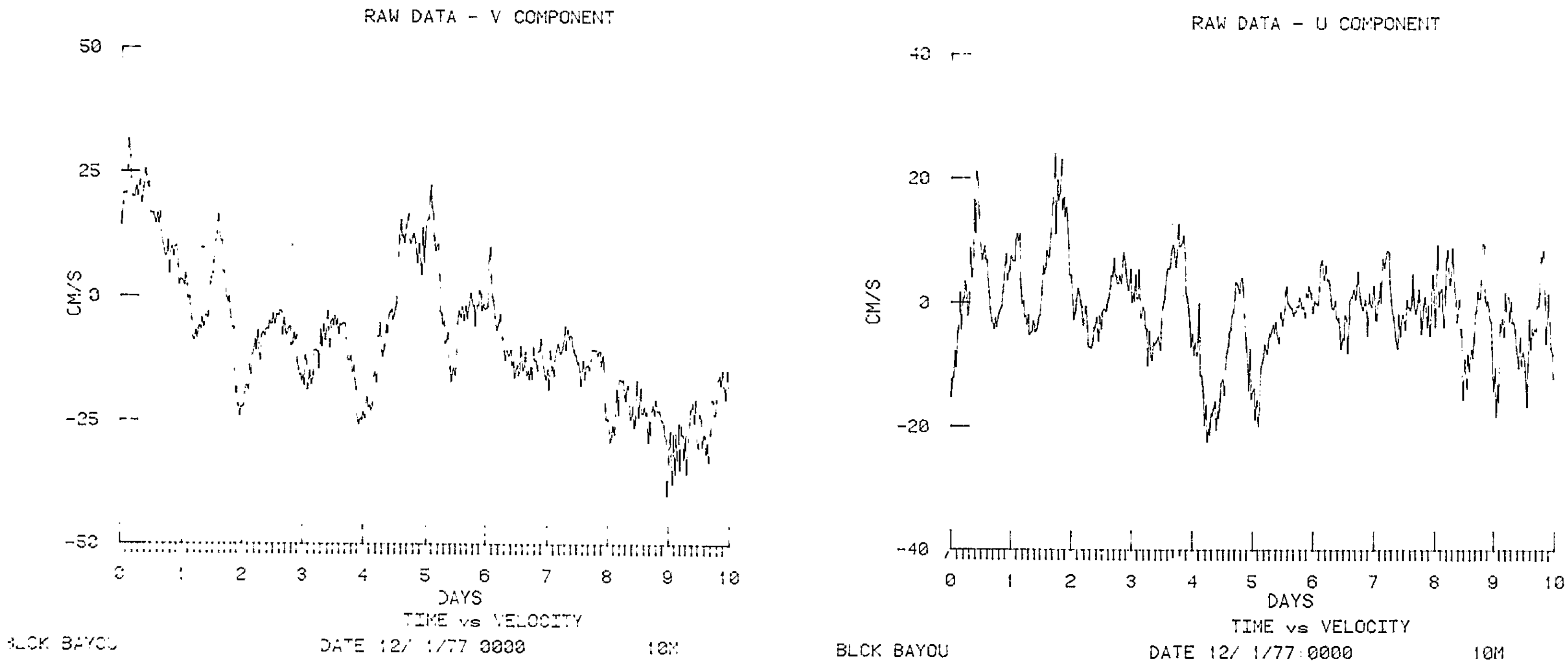


Figure 2.2-12. Time series plot of orthogonal currents

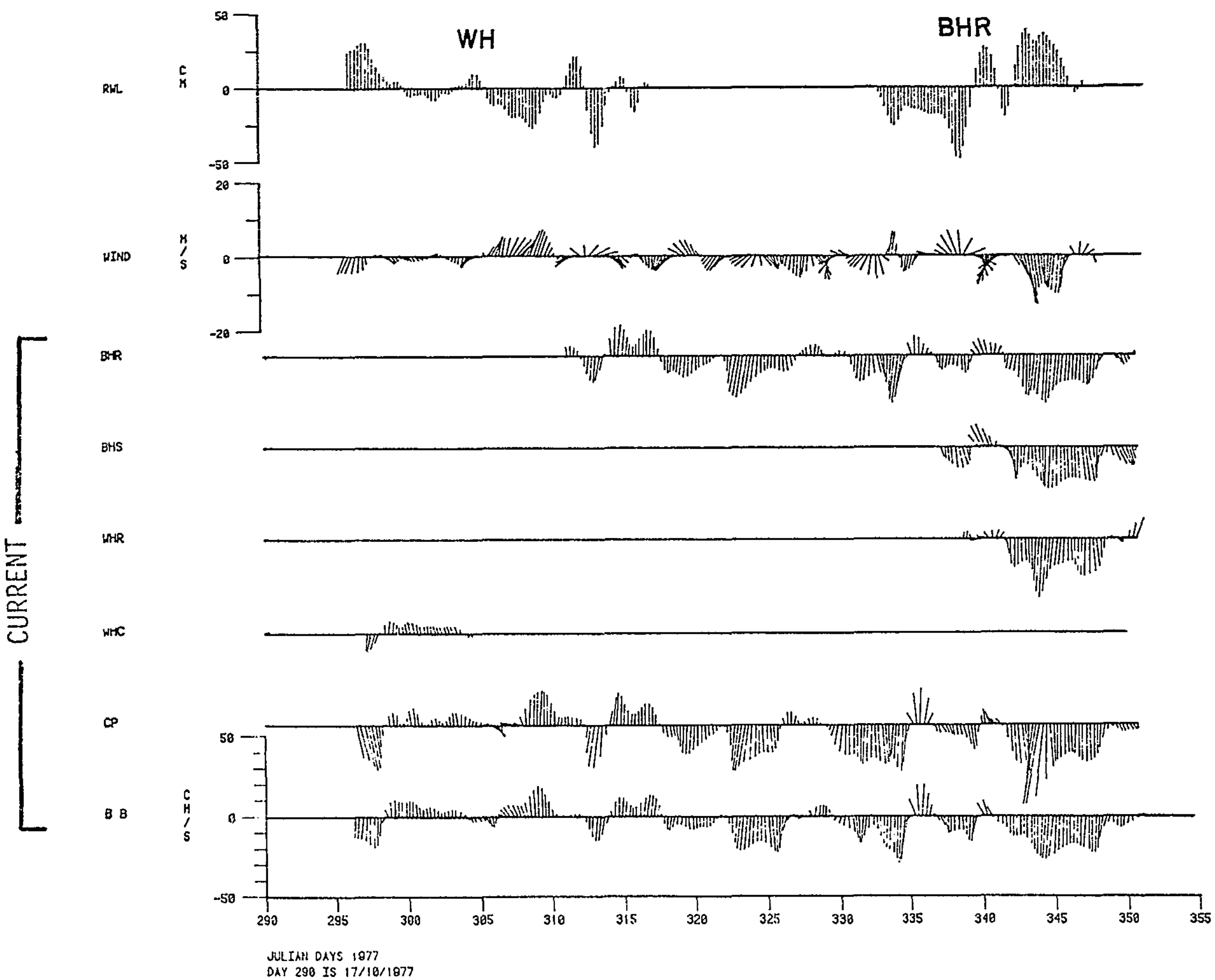


Figure 2.2-13 Stick plots of residual water levels (RWL), winds and currents. In order from top to bottom, these are: (1) RWL from either West Hackberry (WH) or Big Hill Replacements (BHR); (2) a composite wind record taken at High Island (3 months) and West Hackberry (one month); and (3) currents from BHR, Big Hill Secondary (BHS), West Hackberry Replacement (WHR), West Hackberry Control (WHC), Calcasieu Pass (CP), and Black Bayou (BB). Scales are as indicated with all current records having the same scale as given for BB.

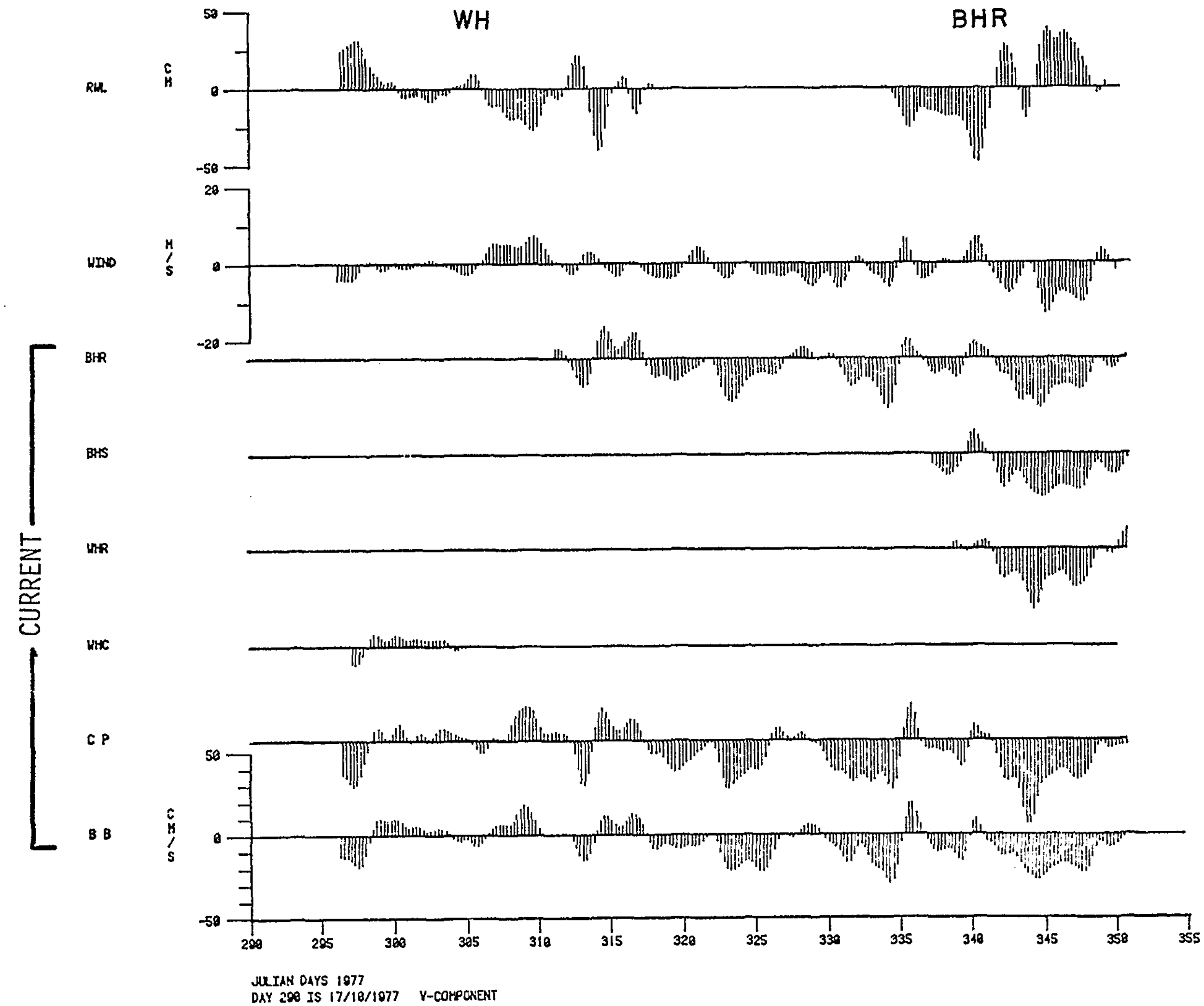


Figure 2.2-14 Stick plots of "v" components of each of the variables presented in Figure 2.2-13. Residual water level is also presented.

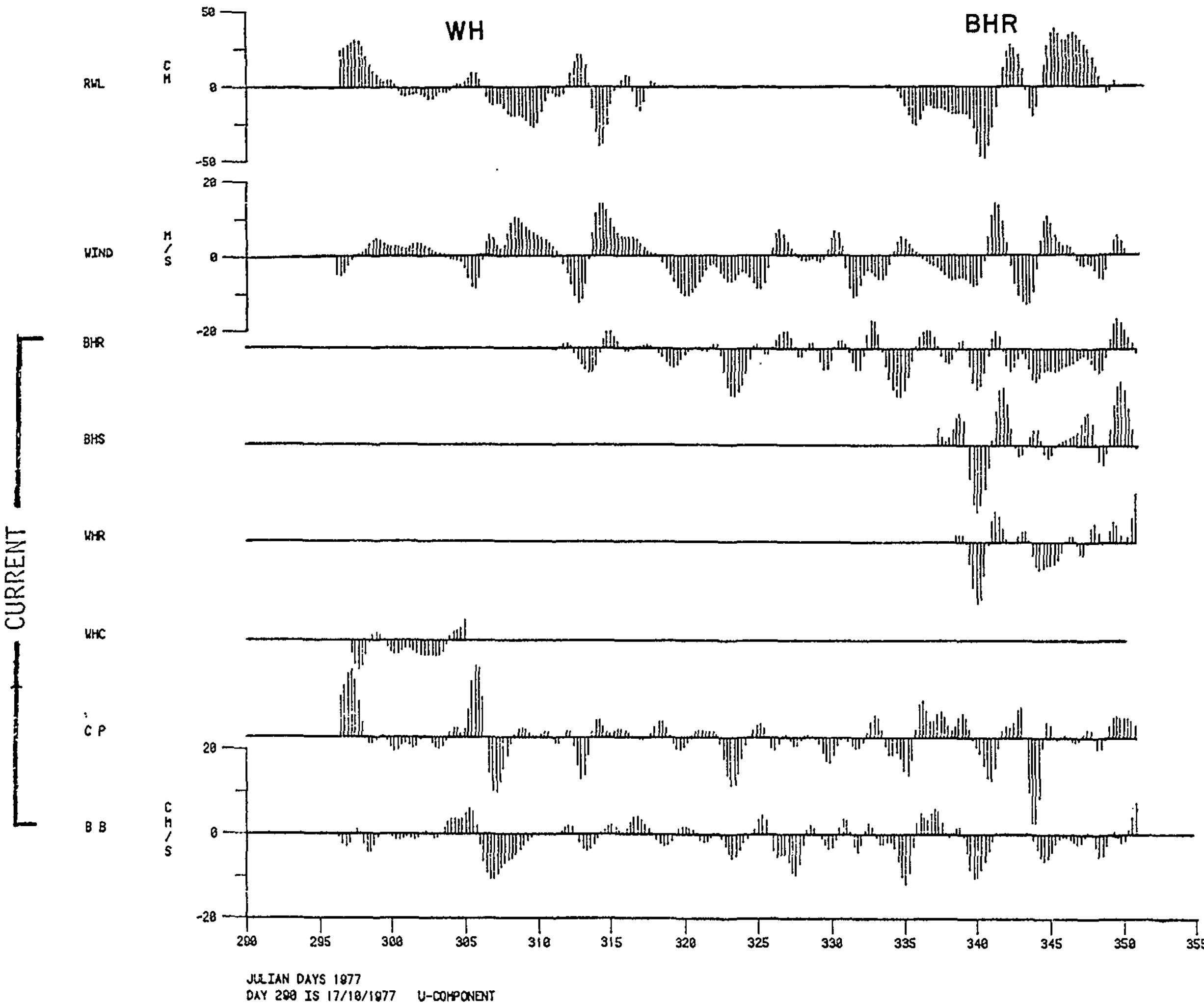


Figure 2.2-15 Stick plots of "u" components of each variable presented in Figure 2.13. Residual water level is also presented.

Cross correlations between these various stick diagrams is given in Table 2.2-4, which presents linear correlation coefficients between the indicated series. Filtered residual water levels exhibit low frequency fluctuations which are associated in large part with variations in winds and atmospheric pressure (inverse barometer effect). Since atmospheric pressure is not considered in this study, some pressure effects will produce error variance in any correlation of winds and water levels, and some pressure effects will be accounted for in this correlation, because regional pressure systems are often associated with characteristic wind patterns.

As seen in Table 2.2-4, residual water levels show a systematic correlation with both components of winds and currents. This correlation is negative for wind, so an offshore or eastward directed wind is associated with a depressed sea surface and an onshore or westward directed wind is associated with a locally raised sea surface. Water levels correlated negatively with alongshore currents and positively with transshelf currents. Thus, a depressed sea surface was associated with both an eastward directed and an onshore directed near bottom current. An elevated sea surface was associated with both a westward and offshore directed near bottom current.

Alongshore components of current velocity all correlate at better than the .90 level. The transshelf component of currents correlate lower averaging about .50. Correlation of wind and currents maintain the same pattern, - alongshore components having higher correlations. However, at a maximum, alongshore components of wind explains 59% of the total variation of alongshore currents.

Time Series	U-Component	V-Component
Water level vs Wind*	- .67	- .67
Water level vs Black Bayou cur.*	.42	- .62
Water level vs Cal. Pass cur.*	.49	- .70
Wind vs BB	.36	.59
Wind vs CP	.16	.59
Wind vs BHR	.39	.50
BB vs CP	.52	.91
BB vs BHR	.53	.92
CP vs BHR	.47	.90

*The magnitude of the residual water level is correlated with the indicated velocity component.

Table 2.2-4. Maximum cross-correlation coefficients for low pass filtered time series.

Absolute and relative magnitudes of means and variances provide important information on local dynamic processes (Table 2.2-5). It should be noted that these values represent time series having differing lengths and differing starting times. In almost each case, the mean alongshore current was towards the west (-). The differences in magnitude can be explained by the intervals sampled. West Hackberry Control records represent only two weeks during the beginning of the study when currents were quite low and may have had a minor eastward trend. Calcasieu Pass and Black Bayou have records covering the entire program and Big Hill Replacement covers all but approximately two weeks at the beginning of the study. These latter three records have quite similar values of their means (-5 cm/sec). West Hackberry Re-Placement and Big Hill secondary have significantly larger westward currents. However, these records reflect conditions during only the last month of the program. This pattern seems to indicate that westward moving currents become more intense and persistant as the measurement program continued. Such a supposition is supported by inspection of the stick plots of alongshore currents.

Daily means for near bottom currents at Calcasieu Pass, Black Bayou, Big Hill Replacement and for wind are given in Figure 2.2-16 through 2.2-19. Calcasieu Pass had larger and more variable means than Black Bayou and Big Hill Replacement, possibly illustrating the effect of tidally controlled estuarine discharge in the vicinity of the pass. Westward directed flows were predominate at all stations while winds tend to show a slight predominance of the on-offshore velocity. At Black Bayou and Big Hill Replacement, there was a slight predominance of onshore directed mean transshelf flows, in particular, for the larger alongshore velocities.

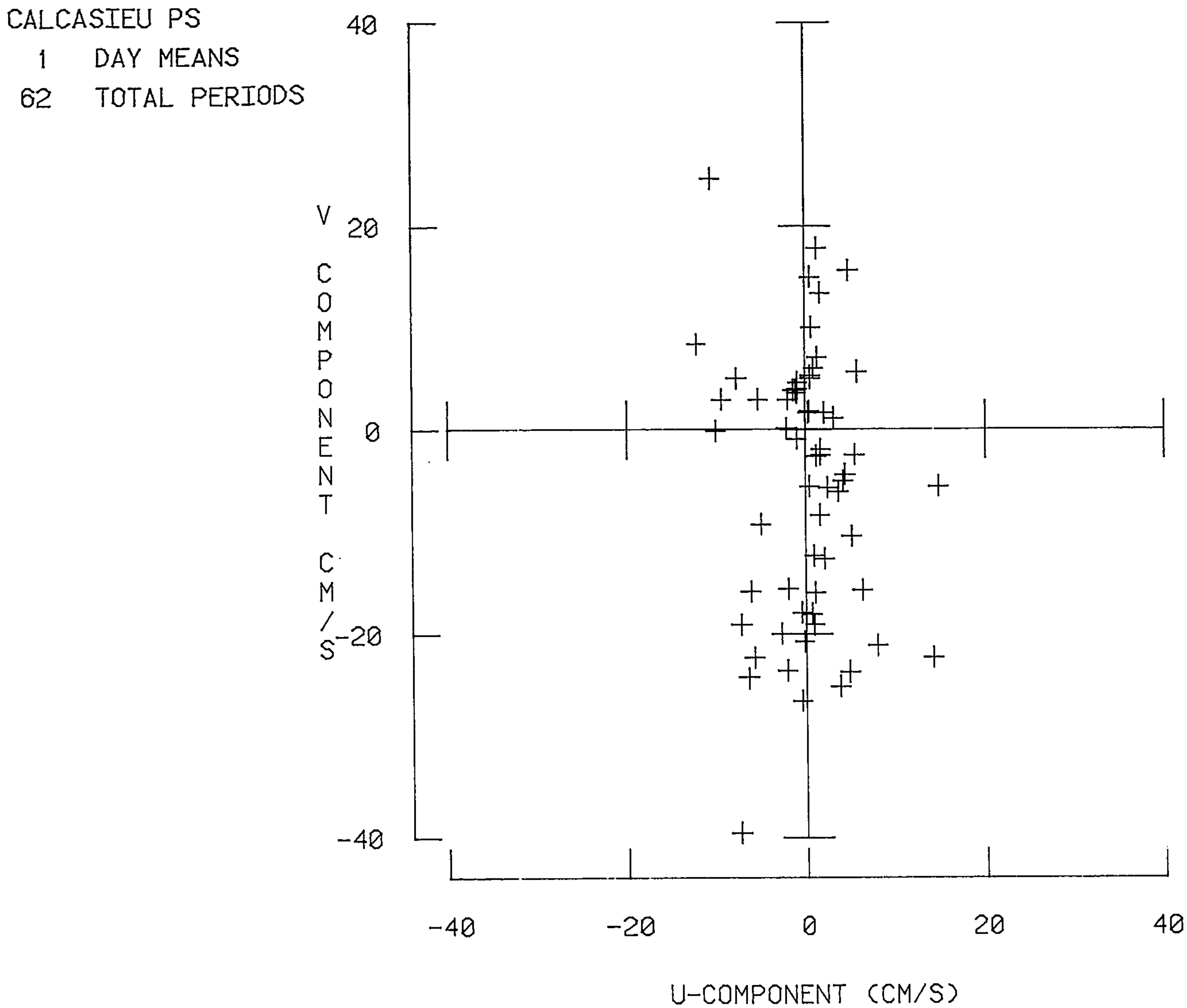


Figure 16a. Plots of daily mean currents at Calcasieu Pass. Each cross identifies the end point of the mean current vector. The alongshore magnitude is measured on the vertical axis and the transshelf component is measured by the horizontal axis. Thus, vectors terminating in the lower left quadrant are oriented toward the west and onshore.

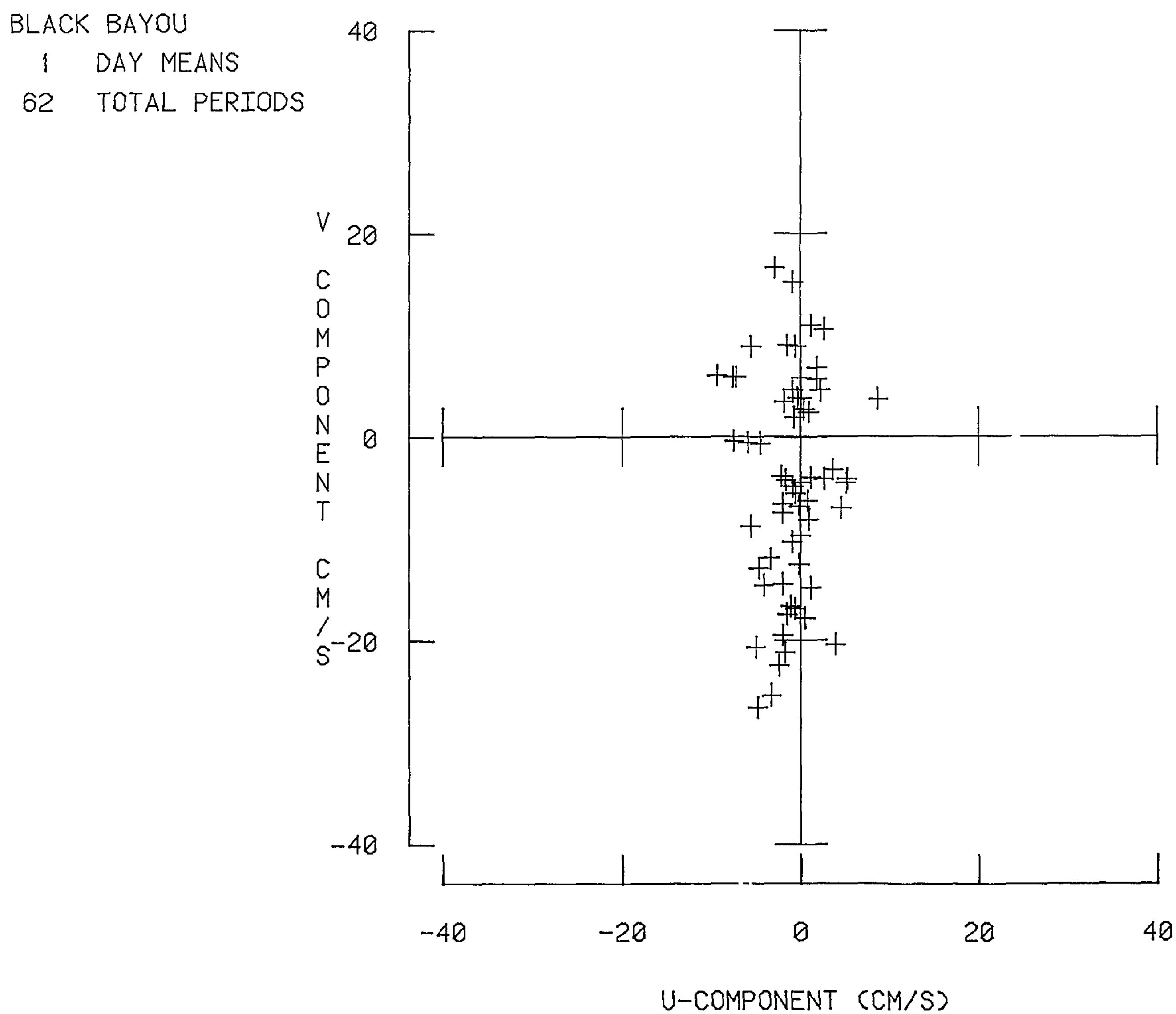


Figure 16b. Plots of daily mean currents of Black Bayou. Each cross identifies the end point of the mean current vector. The alongshore magnitude is measured on the vertical axis and the transshelf component is measured by the horizontal axis. Thus, vectors terminating in the lower left quadrant are oriented toward the west and onshore.

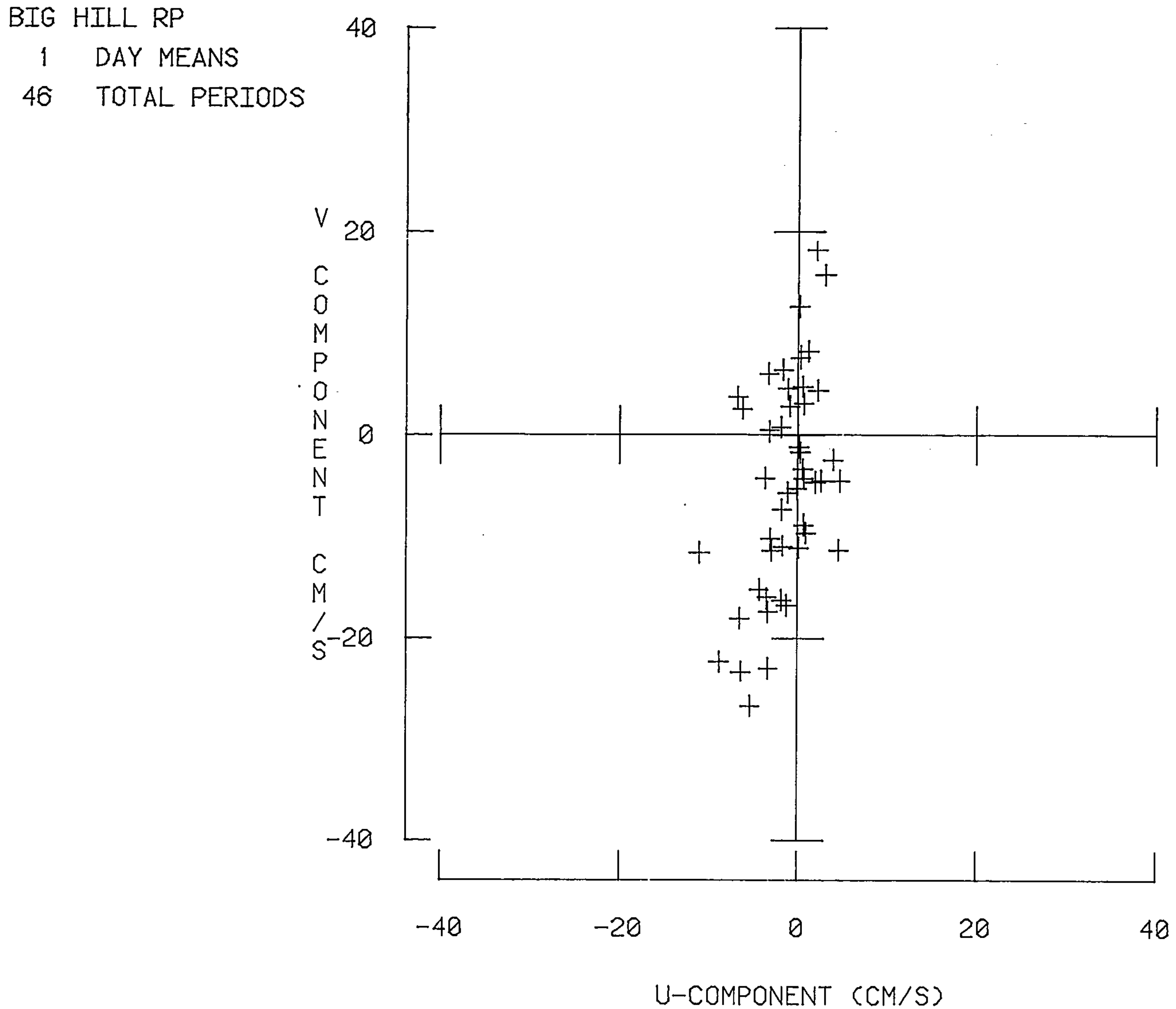


Figure 16c. Plots of daily mean currents of Big Hill Replacement. Each cross identifies the end point of the mean current vector. The alongshore magnitude is measured on the vertical axis and the transshelf component is measured by the horizontal axis. Thus, vectors terminating in the lower left quadrant are oriented toward the west and onshore.

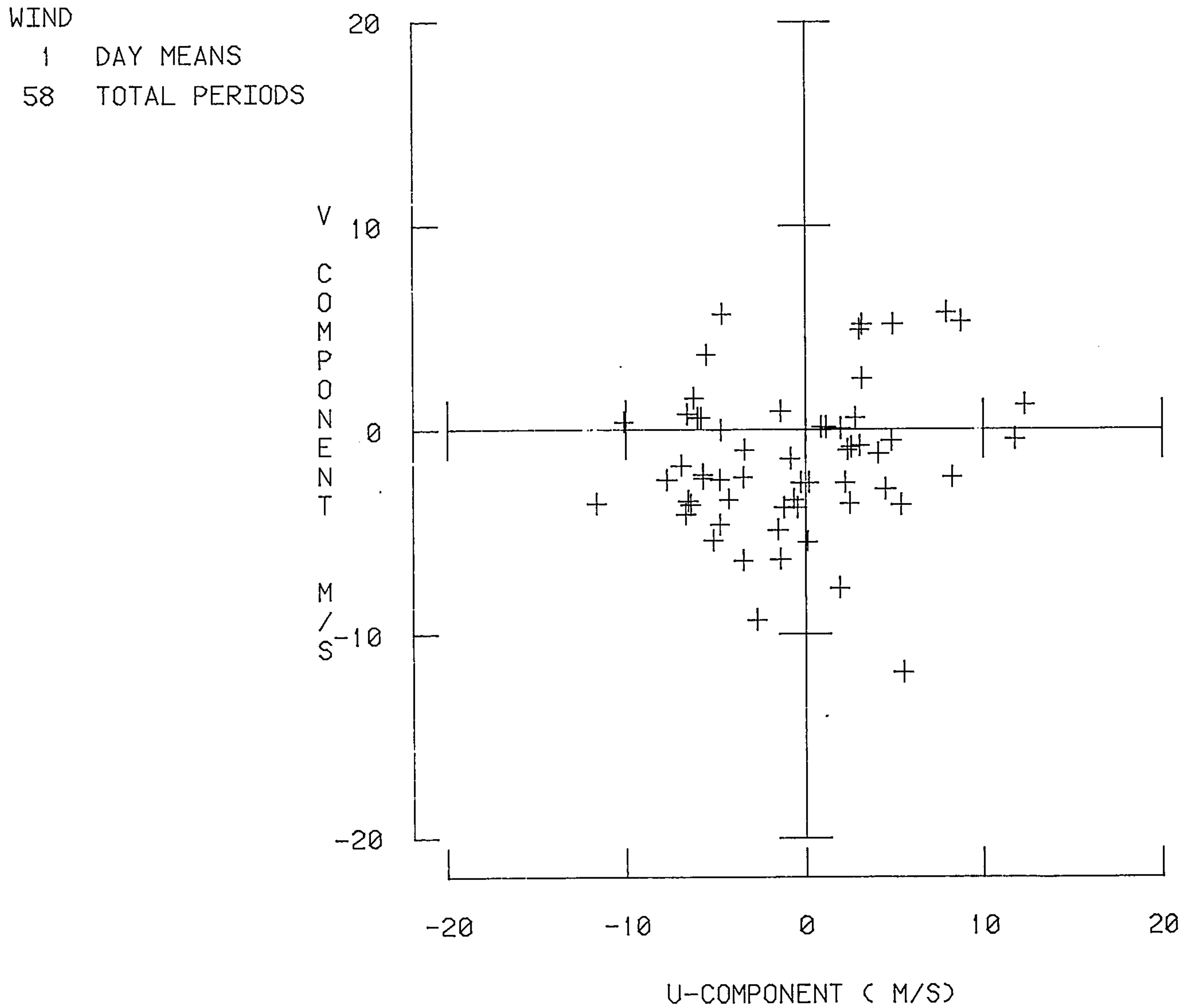


Figure 16d. Plots of daily mean wind vector. Each cross identifies the end point of the mean wind vector. The alongshore magniture is measured on the vertical axis and the transshelf component is measured by the horizontal axis. Thus, vectors terminating in the lower left quadrant are oriented toward the west and onshore.

		U-Component cm/S Mean	S.D.	V-Component Mean	S.D.	Angle Rotation of V component
Black Bayou	BB	-1.3	3.3	-5.2	10.8	79°
Calcasieu Pass	CP	0.4	4.8	-6.4	13.1	106°
West Hackberry Control	WHC	-1.6	2.5	1.7	2.5	84°
West Hackberry Replacement	WHR	0.2	4.4	-10.6	11.2	100°
Big Hill Replacement	BHR	-3.1	5.	-6.2	10.4	83°
Big Hill Secondary	BHS	1.6	6.2	-11.6	10.1	83°
Wind		-0.4 m/s	5.3 m/s	-1.2 m/s	3.24 m/s	80°

Table 2.2-5. Means variances and azimuth angle of alongshore component.

Transshelf currents had uniformly low means with variations in directions. The wind speed has a very low mean and variability, in particular in the on-offshore direction. However, variability of the on-offshore wind is considerably more than the alongshore variability.

Spectra for currents are given in Figures 2.2-17, 2.2-18, 2.2-19, 2.2-20, 2.2-21 and 2.2-22, although only the longer records are used to produce filtered spectra. Examination of these figures show unfiltered spectra had weak energy peaks at diurnal and semidiurnal periods. These are expected because:

- The inertial period in the study area is approximately 25 hours

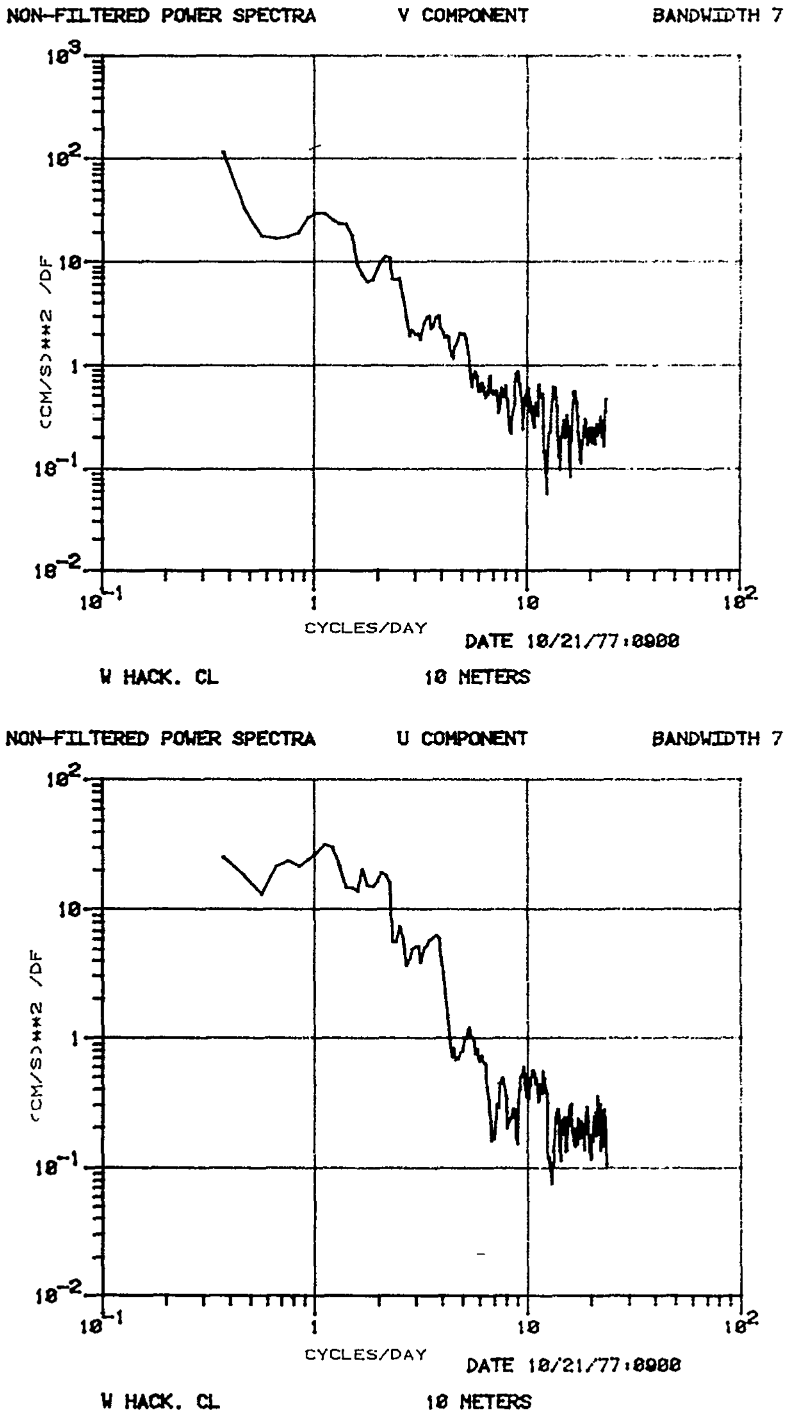


Figure 2.2-17. Energy spectra for West Hackberry Control. Upper spectra is for unfiltered "v" component and lower spectra is for "u" component. Frequency is in cycles/day.

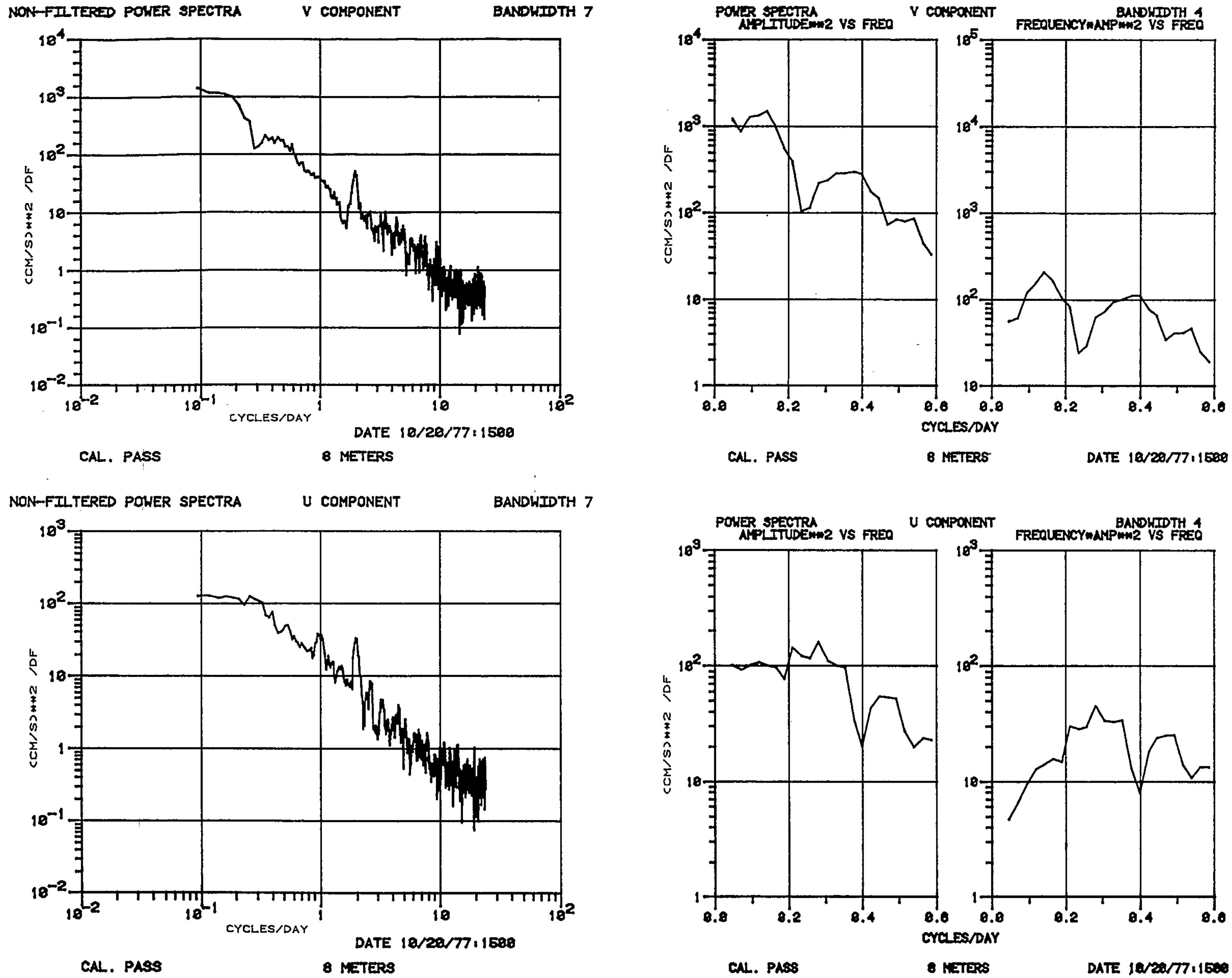


Figure 2.2-18. Energy spectra for Calcasieu Pass. Unfiltered spectra are on the left with "v" component on top and "u" component on the bottom. On the right are spectra and a constant energy spectra for low pass filtered time series.

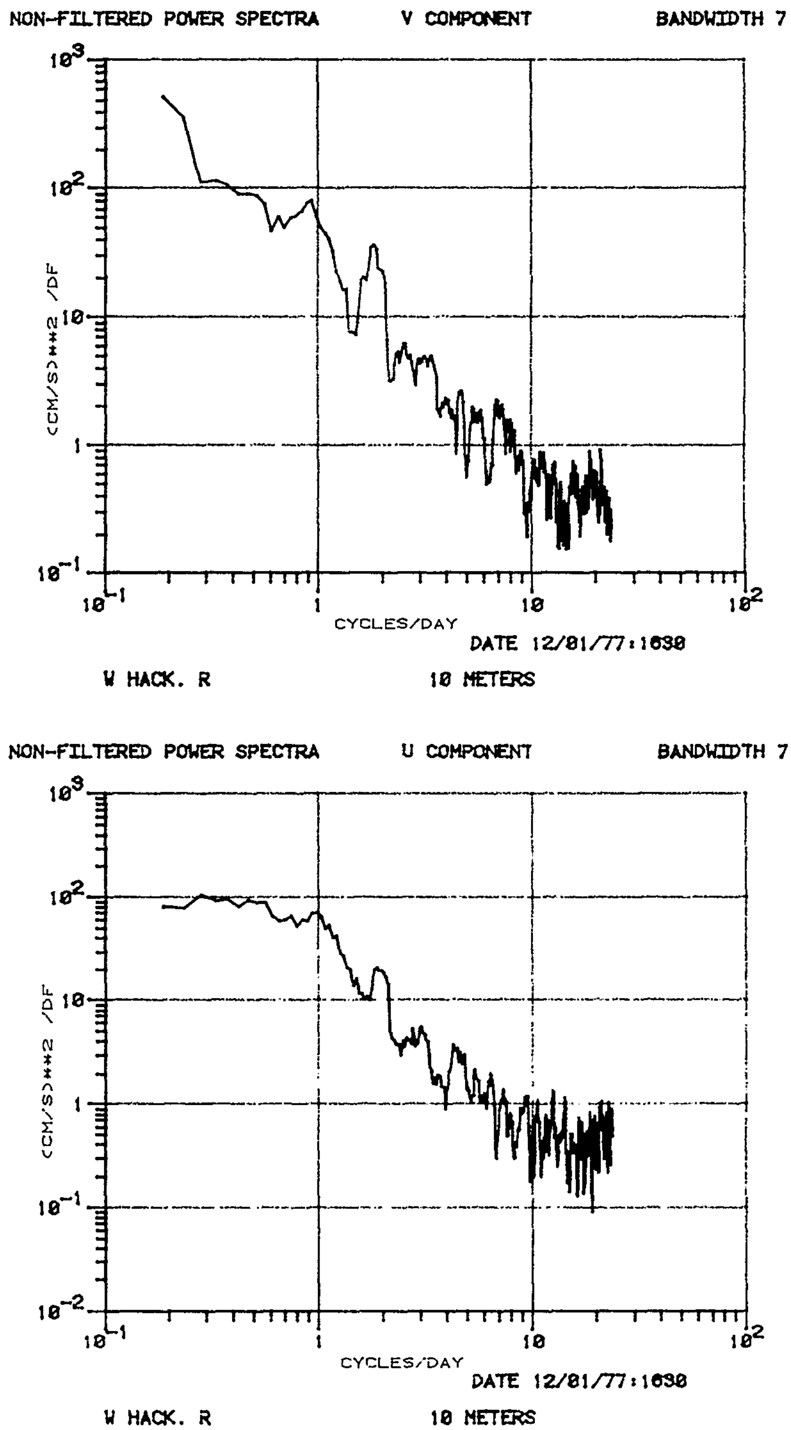


Figure 2.2-19. Unfiltered energy spectra for W. Hackberry Replacement with "v" component on top and "u" component on the bottom.

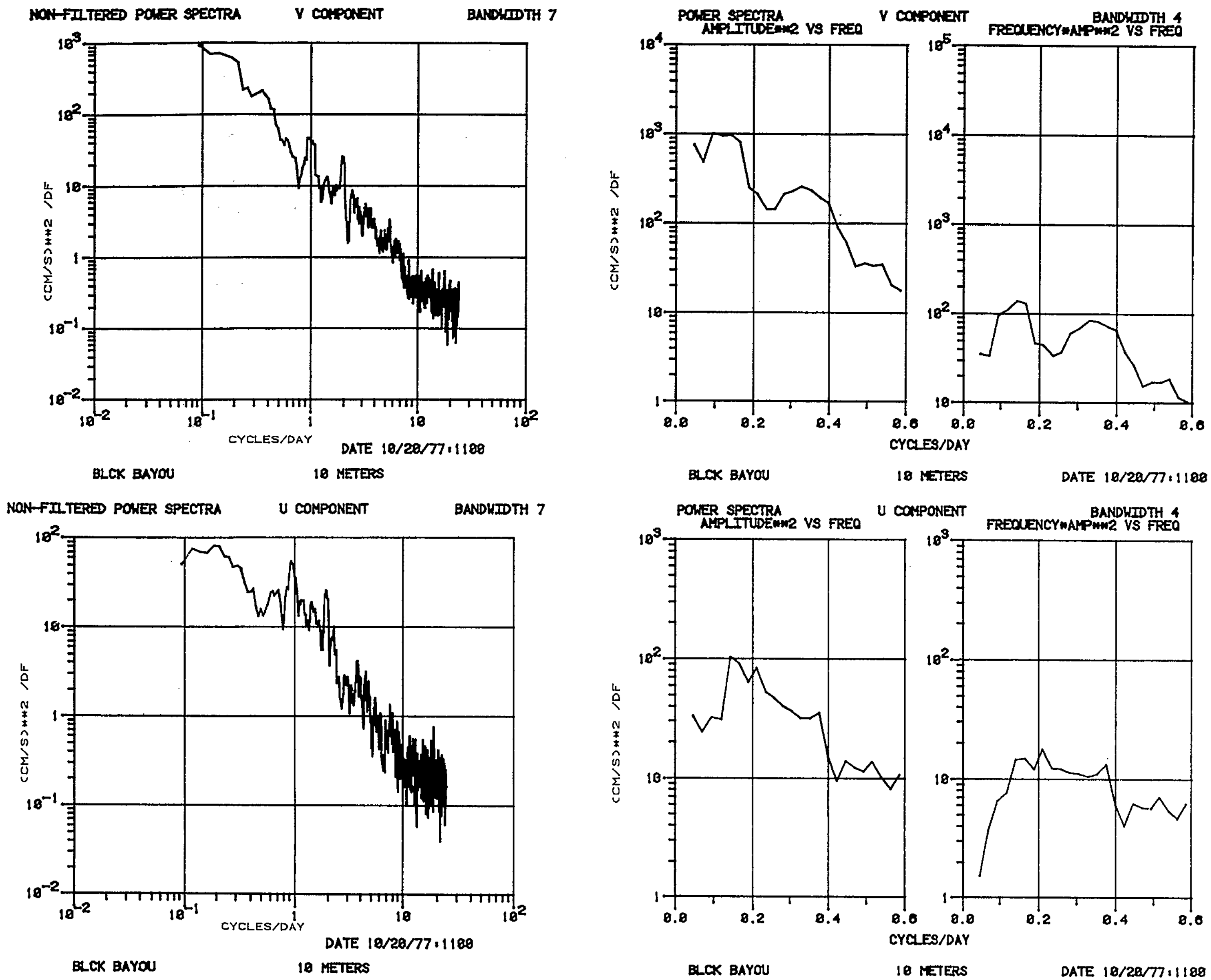


Figure 2.2-20 Energy spectra for Black Bayou. Unfiltered spectra are on the left, with "v" component on top and "u" component on the bottom. On the right are spectra and constant energy spectra of low pass filtered time series.

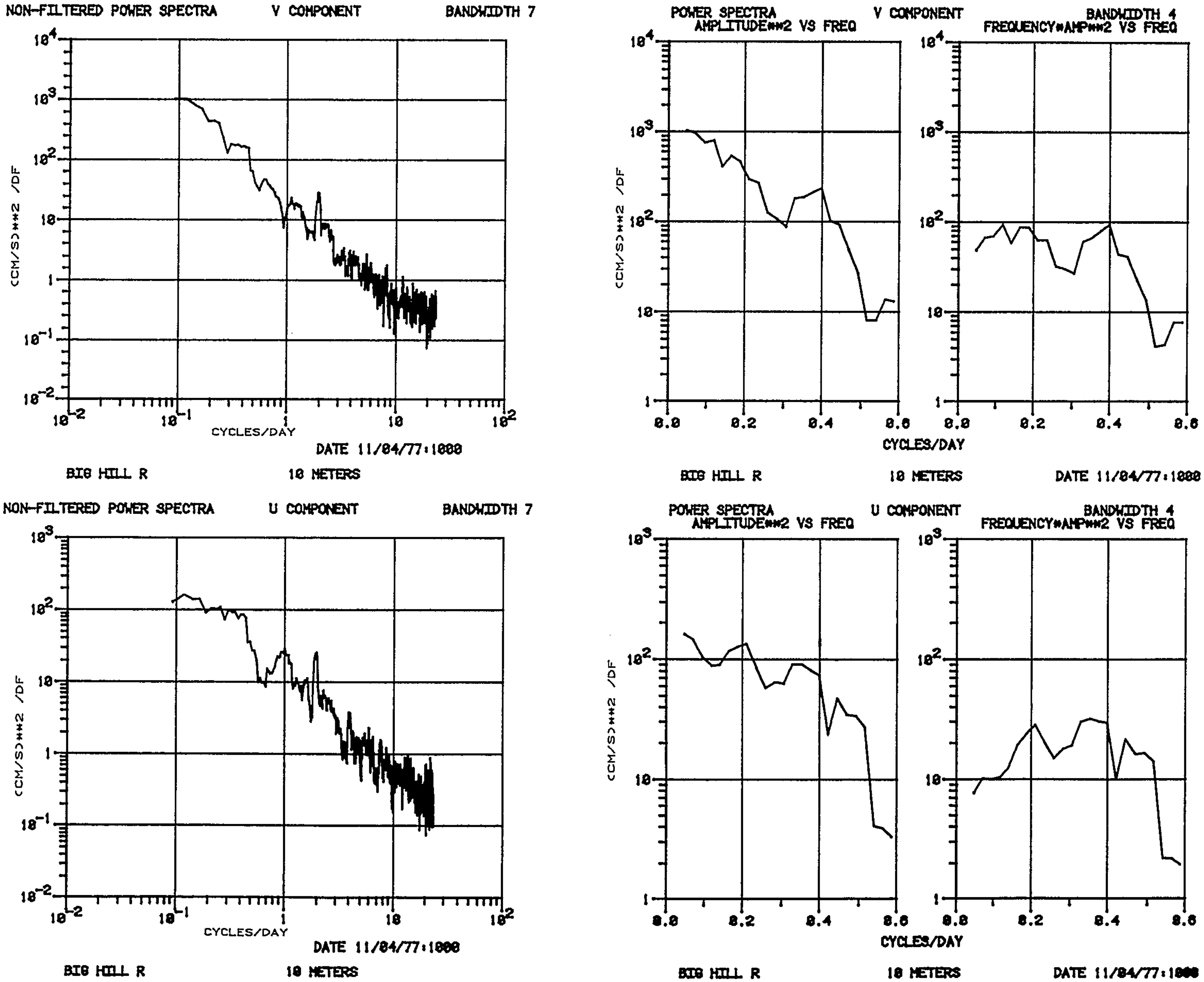
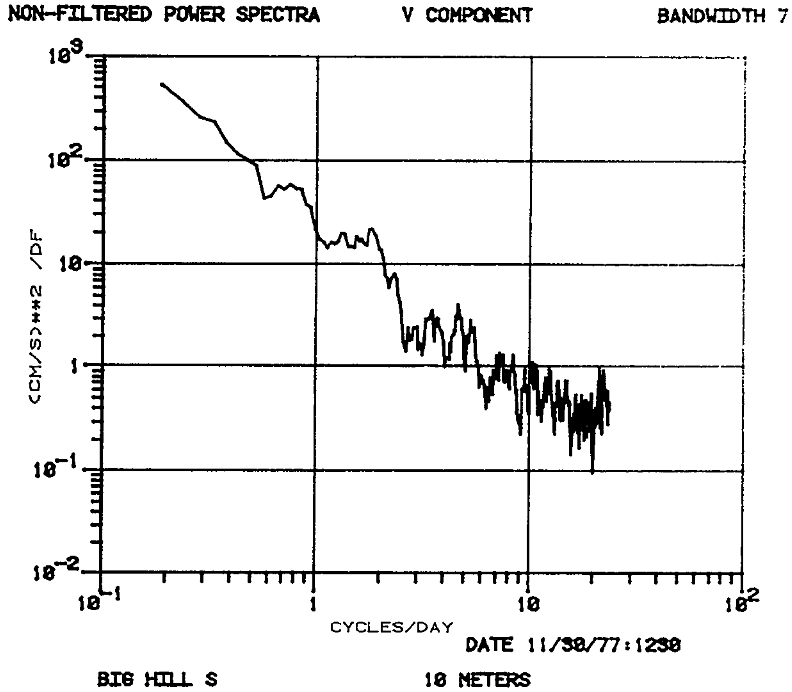


Figure 2.2-21. Energy spectra for Big Hill Replacement. Unfiltered spectra are on the left, with "v" component on top and "u" component on the bottom. On the right are spectra and constant energy spectra of low pass filtered time series.



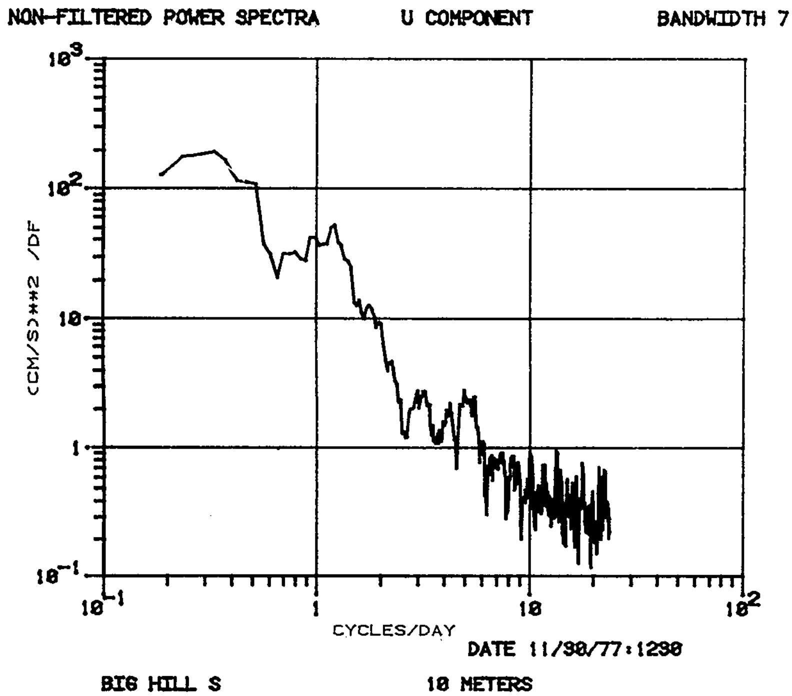


Figure 2.2-22. Energy spectra for Big Hill Secondary. Upper spectra is for unfiltered "v" component and lower spectra is for the "u" component. Frequency is in cycles/day.

- A local diurnal sea-breeze system probably occurs during part of the measurement period.
- Dominant tidal periods on this portion of the coast are diurnal (K_1 and O_1) and semi-diurnal (M_2).

Thus, there are several couplings which may explain these spectra peaks. The short record length and available technique preclude resolving these various contributions. The multiplicity of processes at about the diurnal period may explain in part why the diurnal peak is slightly broader than the fairly well resolved semi-diurnal peak.

Unfiltered wind spectra do not have well resolved diurnal and semidiurnal peaks (Figure 2.2-23). However, examination of subsets of the total wind record suggest that during the first segment of the study, these diurnal systems were fairly well developed. In such a system, wind vectors display a counter clockwise rotation with strongest winds being onshore during mid-day and generally lower magnitude winds blowing offshore at night. Between these extremes, alongshore winds of generally low magnitude exist. Such systems are fairly common on the coast of the Gulf of Mexico and have been documented several times (Sonu, et al. 1973). Wind spectra from such a system should exhibit variance at semi-diurnal and diurnal peaks with the on-offshore components of variance exceeding the alongshore component. Such a pattern was observed in the first half of the study. It is possible that during the latter portion of the study, i.e. mid November to mid December differential diurnal heating and cooling between adjacent land and water no longer occurred. Hence, no pressure gradient was created to drive this wind system.

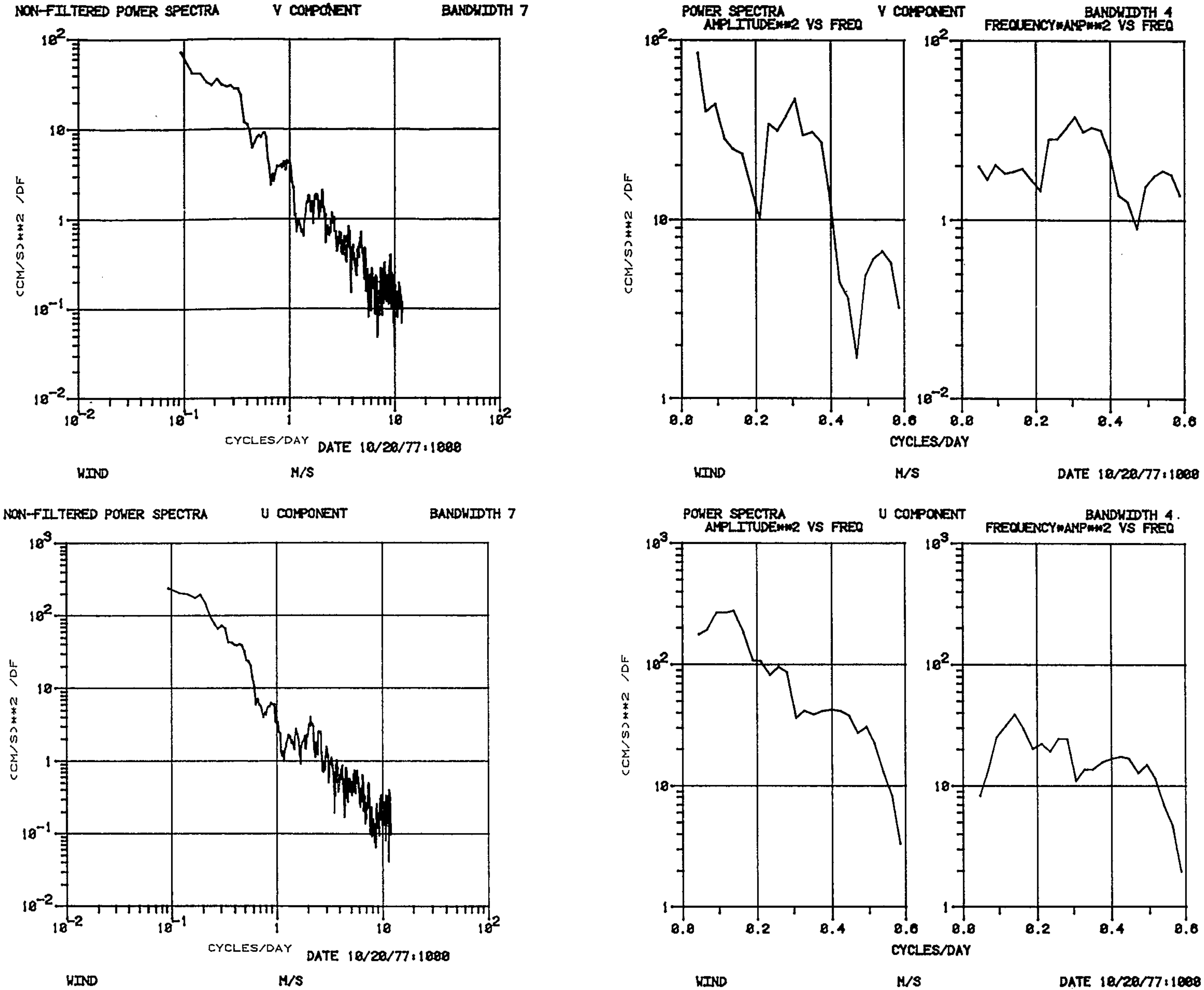


Figure 2.2-23. Energy spectra for wind. Unfiltered spectra are on the left, with "v" component on top and "u" component on the bottom. On the right are spectra and constant energy spectra of low pass filtered time series.

Computed tidal coefficients in Table 2.2-6, show that for the local mixed tides, diurnal and semi-diurnal components are of similar magnitude. Also indicated is a trend toward slightly larger tidal fluctuations when going from Calcasieu Pass to Sabine Pass and beyond. Using information from water level analysis, current records can be similarly analyzed. A tidal hodograph for this data is given in Figure 2.2-24. While the diurnal tidal current can not be differentiated from other processes producing currents at this frequency, the low magnitudes indicate that M_2 and K_1 tidal currents produce only a small amount of the total variability seen in current records. Considering that tidal currents (away from the Passes) are small, and from the examination of low pass filtered stick plots, it must be concluded that filtered currents are dominated by longer period oscillations characteristic of wind driven flow in shallow water (Allen, 1973).

		Amplitude (cm)		
Tide	Period	West Hackberry (23 days)	Big Hill Replacement (17 days)	Calcasieu Pass Channel (Zetler and Hansen 1970)
M2	12.5 hr.	12.5	18.5	16
K1	24 hr	12.8	20.	14

Table 2.2-6 Tidal Components

In Figures 2.2-18, 2.2-20, and 2.2-21, low frequency spectra of the longer current records show that for alongshore currents, energy is dominated by broad peaks at approximately 0.1 cycles/day and between 0.3 and 0.4 cycles/day. For on-offshore currents, energy seems to be more concentrated between 0-2 and 0-4 cycles/day with less energy at higher and lower frequencies. Low frequency

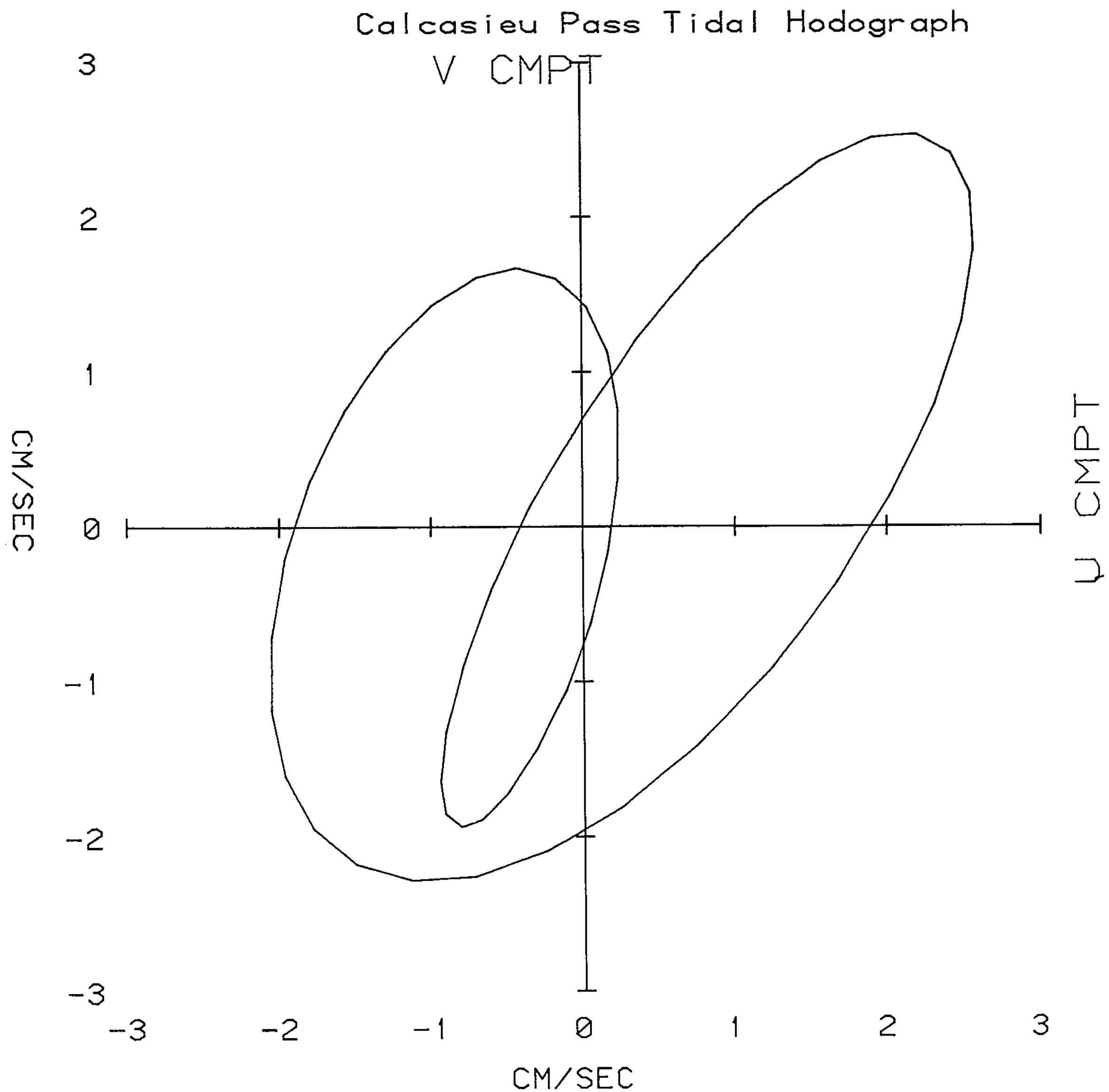


Figure 2.2-24 Tidal hodograph. Represents pattern described by hourly near bottom tidal current velocity vectors for diurnal and semi-diurnal tides.

wind spectra shows the same situation, but with components reversed. Therefore, it is the on-offshore component which has an energy peak at 0.1 cycles/day and longshore component has a broad peak between 0.2 and 0.4 cycles/day. This is an unusual situation for a system driven by local winds. According to both theory and observations off the coasts of Washington and Oregon in such wind-driven systems, alongshore currents are usually highly coherent with local winds (Allen, 1973; Kundu et al., 1975; Huyer, et al., 1976). This difference may imply that part of the response of observed currents may be due to a alongshore propagating trapped coastal wave (Gill and Schumann, 1976). We note that during the event of day 340 to day 349, alongshore currents do mirror alongshore winds. This is the more usual situation for locally wind-driven flows.

Detailed correlations between longer time series (BB, CP, BHR, and Wind) are examined quantitatively by calculating phase and coherence at each frequency (Figures 2.2-25, 2.2-26, 2.2-27). Figure 2.2-25 shows high coherence and low phase difference between alongshore currents at Black Bayou and Calcasieu Pass and Black Bayou and Big Hill Replacement as might be expected from the stick diagrams. Coherence between alongshore currents and winds is not as high as indicated in Table 2.2-4.

Figure 2.2-26 shows the relationship between various on-offshore components of wind and current. Coherence is quite low at all frequencies, indicating that the alongshore length scale in the offshore component of the current is small. This may result, in part, from the influence of brackish water plumes discharged from local tidal passes. The final coherence figure (Figure 2.2-27) is for relationships between the alongshore and on-offshore

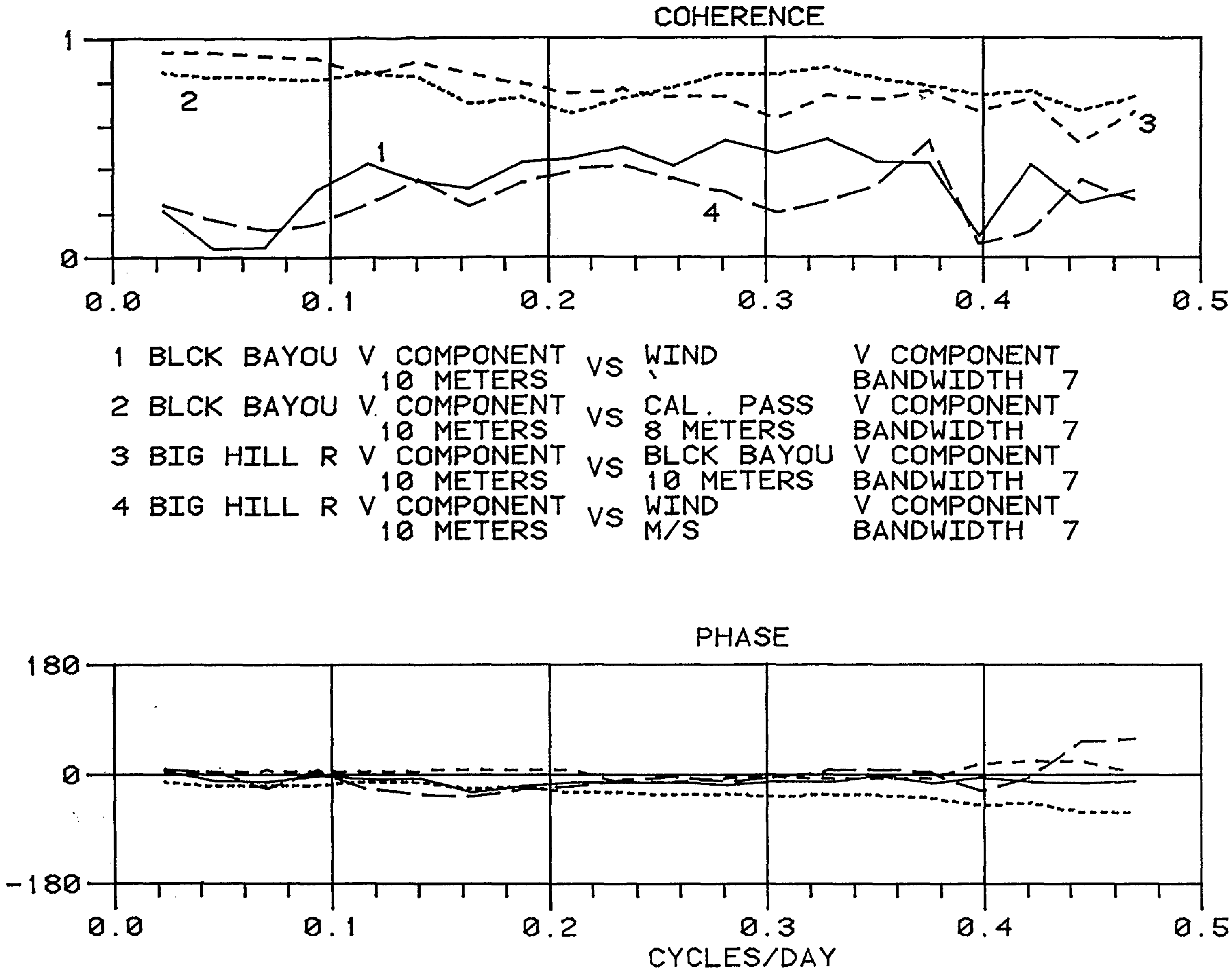


Figure 2.2-25 Phase and coherence between the indicated time series.

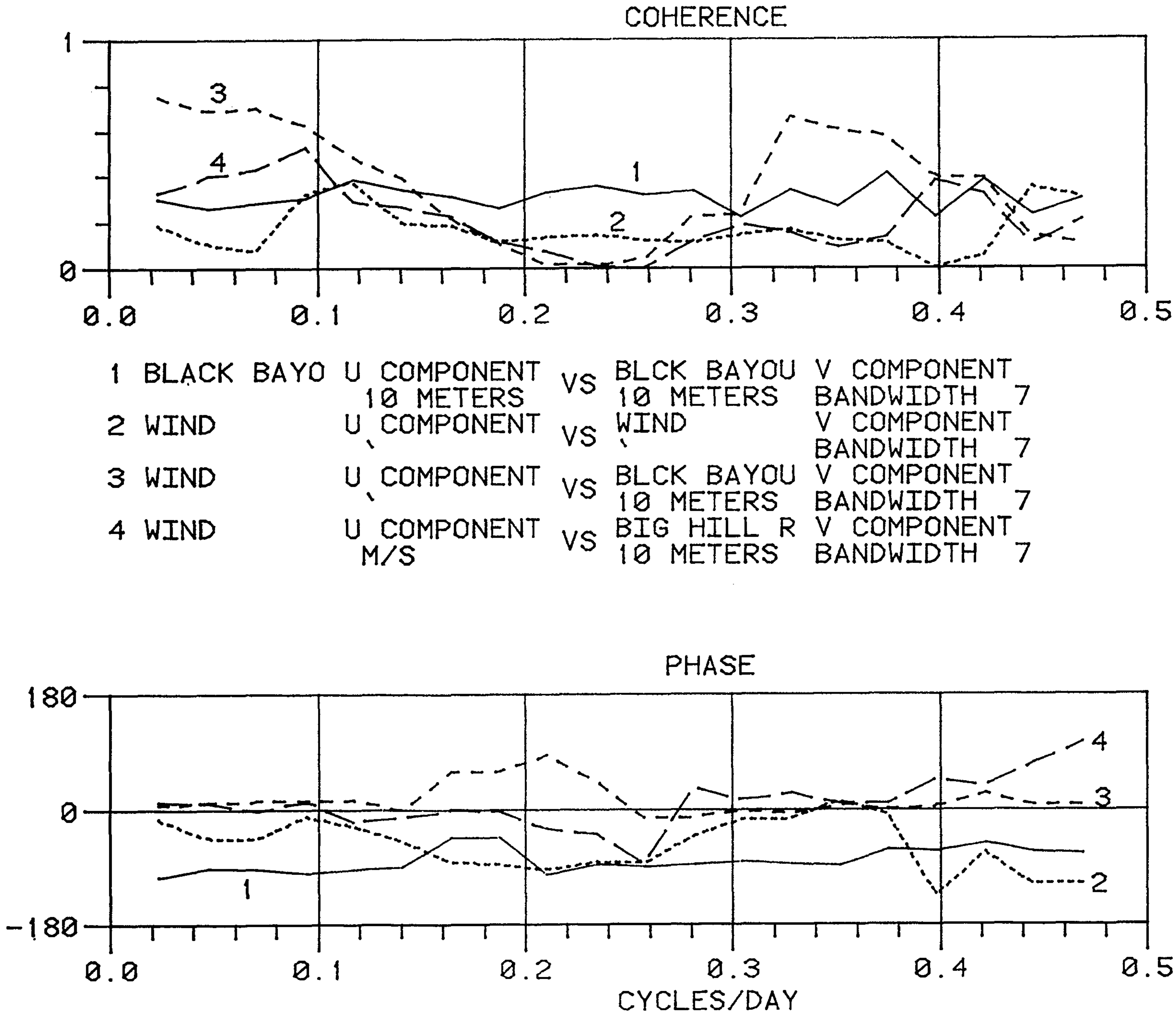


Figure 2.2-26 Phase and coherence between the indicated time series.

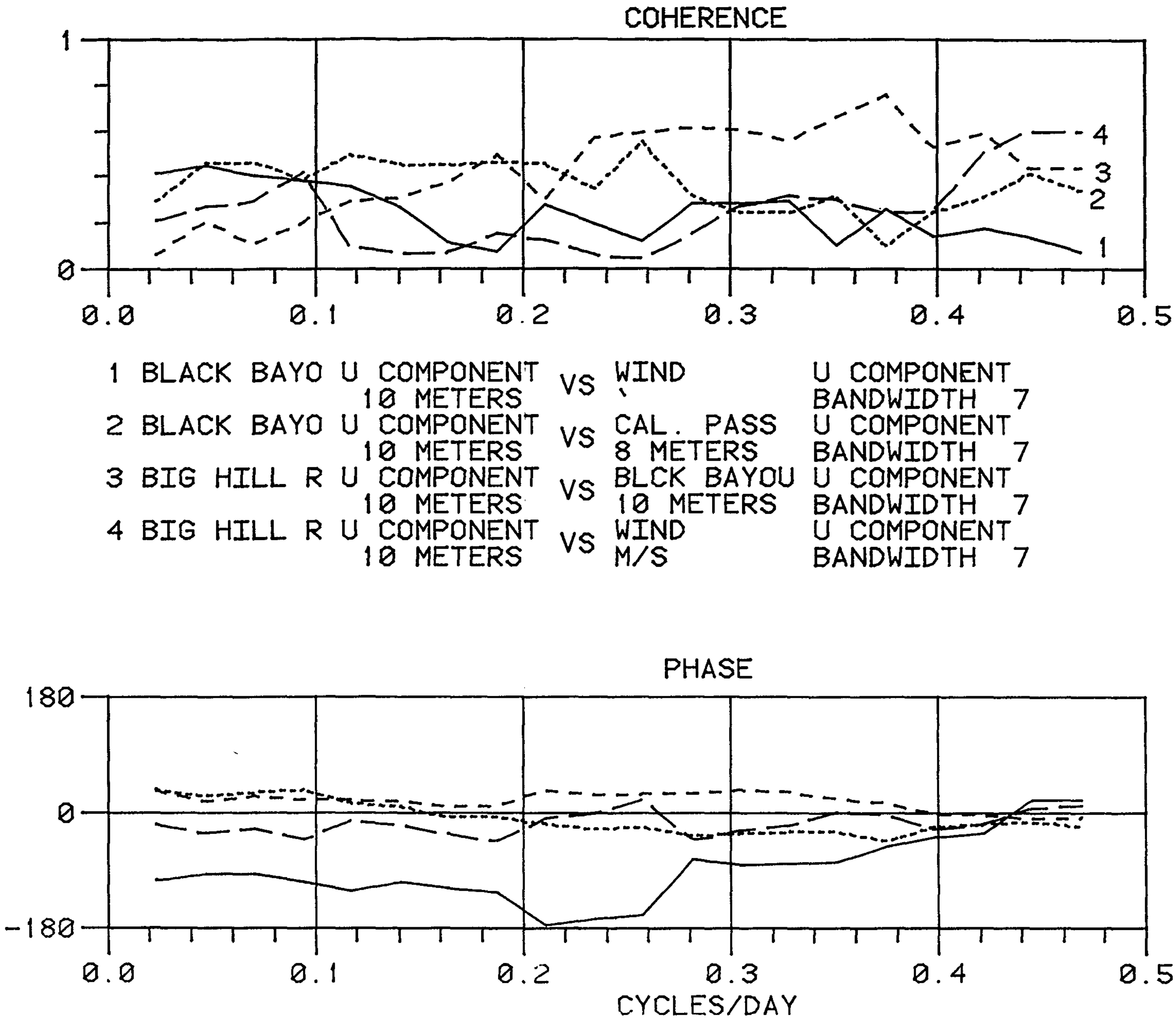


Figure 2.2-27 Phase and coherence between the indicated time series.

components. Again, coherence is low between "u" and "v" components of the wind and the current; however, the "v" component of the current at Black Bayou shows some coherence with the "u" component of the wind below 0.1 cpd and between 0.3 and 0.4 cpd. These frequency bands roughly coincide with peaks in the offshore wind and the longshore current power spectra (Figures 2.2-15 and 2.2-19) Murray (1975) has proposed a mechanism by which an offshore wind could drive a longshore current in very shallow water which may apply here; or as mentioned above, the currents could be influenced by westward propagating coastal trapped waves. Without information on the currents and wind at greater alongshore separations (more or less 100 km) measured in this project, this question cannot be answered.

Density, Salinity, Temperature, and Dissolved Oxygen

Salinity, temperature, and dissolved oxygen were measured at approximately monthly intervals over a series of grids centered around each original current meter station. Using this data, salinity-temperature (S-T), diagrams were constructed for all stations around the West Hackberry site (Figure 2.2-28a) and all stations around the Big Hill site (Figure 2.2-28b). Both diagrams clearly show a seasonal transition from summer toward winter conditions which produced a decrease in mean temperatures of 14-15^{o}C. Excluding Cruise 4 at West Hackberry, salinities showed neither pronounced, sequential seasonal, nor within site variation. Generally, between cruise variation in salinity was comparable to within cruise variation.

In any detailed comparison of data from different stations, consideration must be given to the time between measurements. In most such comparisons, observations are assumed to by synoptic; however, for this assumption to be

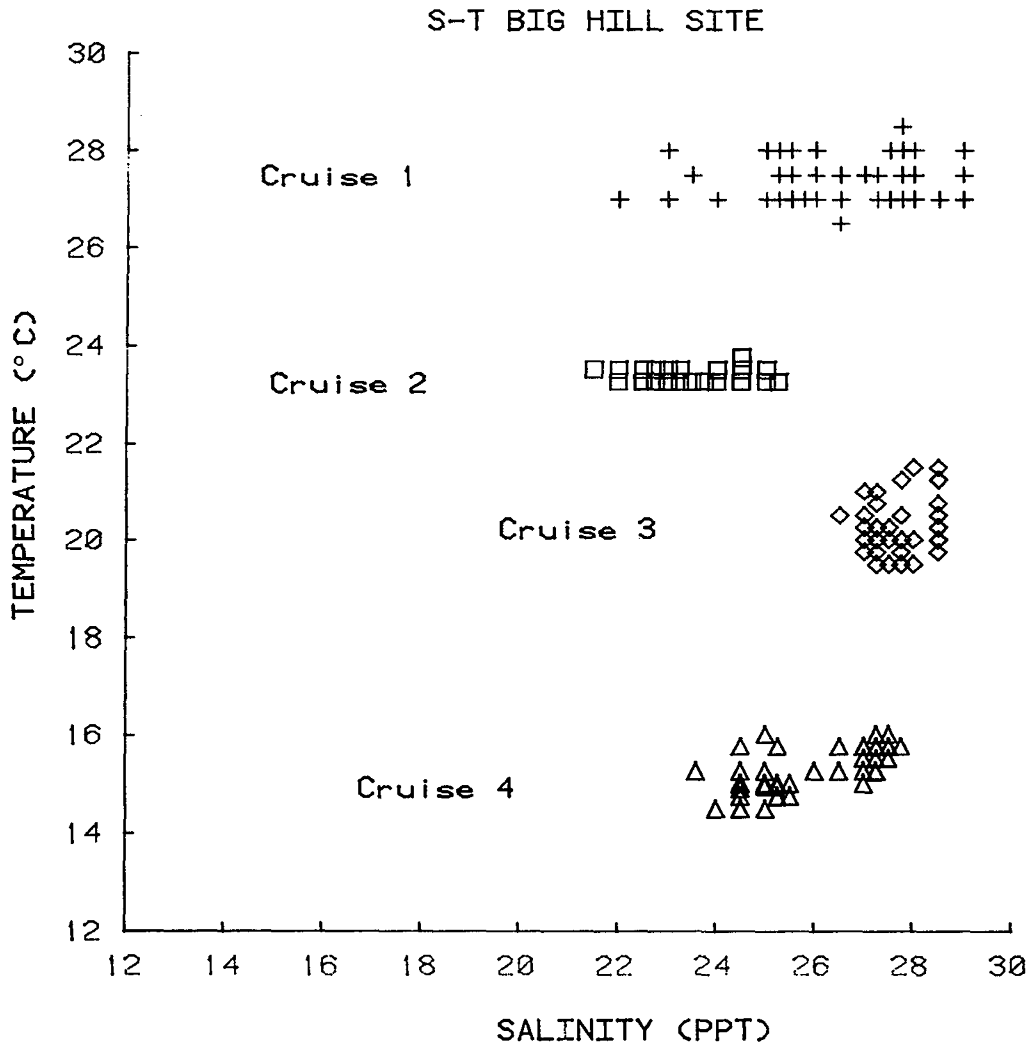


Figure 2.2-28a S-T diagrams including all observations in the vicinity of the West Hackberry Site. Observations for each of the 4 cruises being discussed are identified. Cruise 1 was in 9/77, Cruise 2 in 10/77, Cruise 3 in 11/77, and Cruise 4 in 12/77.

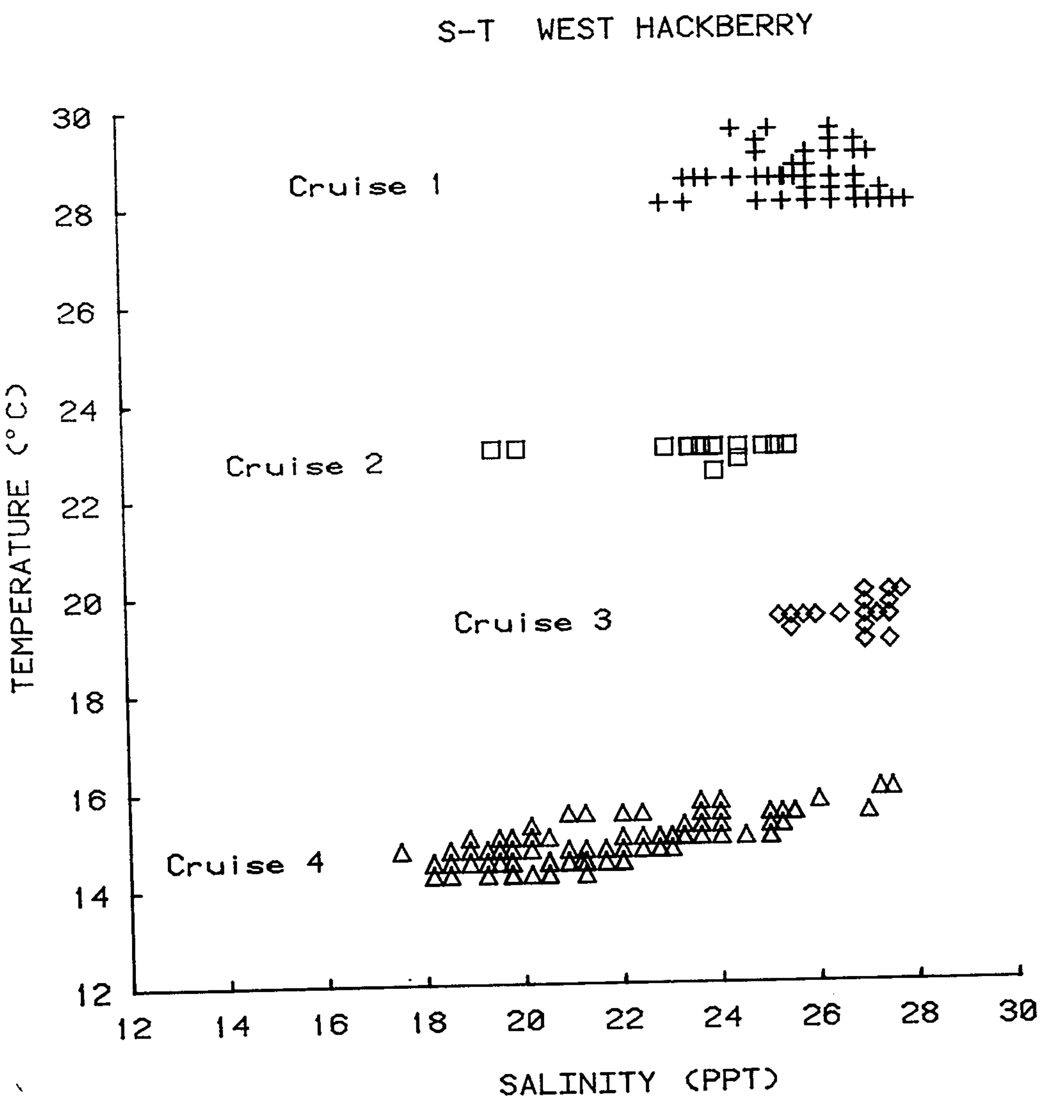


Figure 2.2-28b S-T diagrams including all observations in the vicinity of the Big Hill Site. Observations for each of the 4 cruises being discussed are identified. Cruise 1 was in 9/77, Cruise 2 in 10.77, Cruise 3 in 11/77, and Cruise 4 in 12/77.

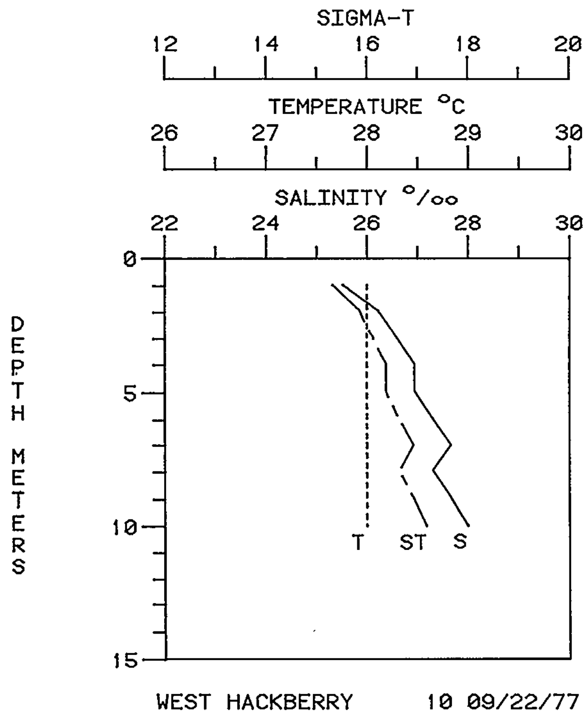
valid, the time scale of processes being examined must be longer than the overall measurement interval. In most CTD observations, the pattern of sampling is developed to facilitate this assumption. At the West Hackberry site and Big Hill site, on certain cruises sampling pattern and elapsed time were such that synopticity could not be assumed.

Vertical profiles of salinity, temperature, density, and dissolved oxygen can often provide insight into which processes are active at the time of measurement. Sequences of profiles at both Big Hill and West Hackberry are presented to illustrate the range of conditions which existed at these two sites. These profiles are representative of conditions found during each cruise.

Conditions during Cruise 1 (September 1977) are given in Figures 2.2-29a and 2.2-29b. At West Hackberry, vertical temperatures were isothermal; however, examination of measurements from other nearby stations taken at different times of day seem to indicate that the near surface layer was responding to solar heating during the day and cooling at night. Big Hill, measured three days later, had a definite two-layered structure with both layers uniform. The low salinity reading at 11 meters probably resulted from the conductivity sensor coming into contact with bottom sediments. This also occurred in some later readings. At both stations, the profile stability is dictated by the salinity distribution.

Lack of vertical mixing is best illustrated in the dissolved oxygen profile which is greatly reduced in the lower several meters. If mixing were occurring, low concentrations at depth would not be maintained because oxygenated water from above would replace near-bottom depletion resulting from organic decay and respiration.

Vertically isothermal conditions existed at both sites during Cruise 2; however, temperatures at West Hackberry were 2.5°C cooler than at Big Hill (Fig. 2.2-30a and 2.2-30b). At both stations, the vertical salinity distribution dictates



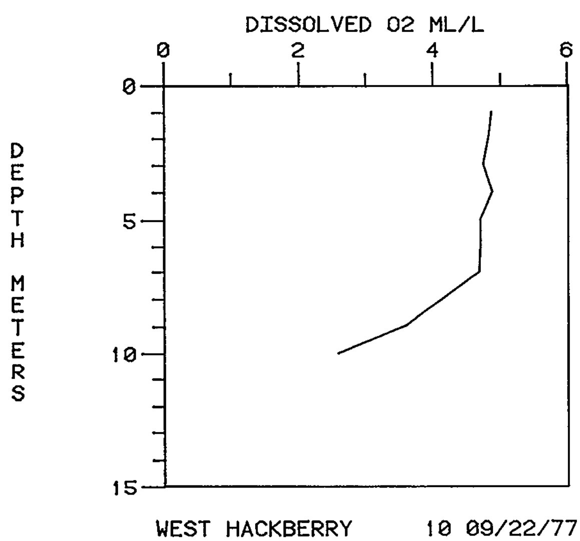
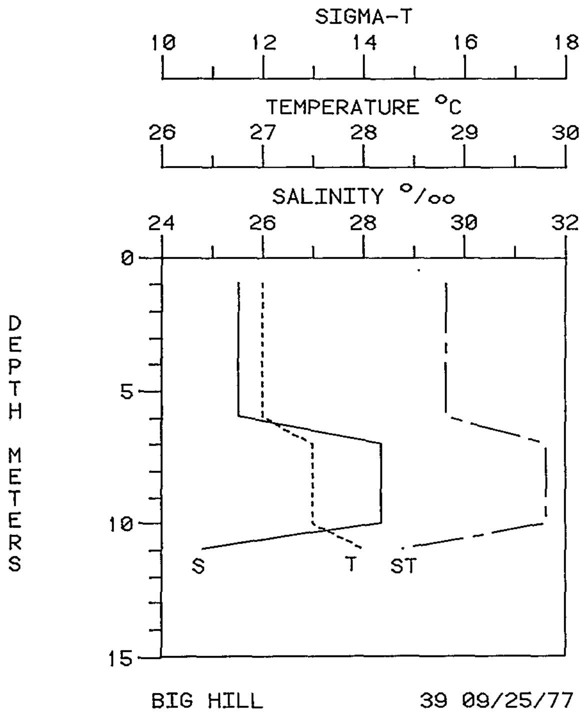


Figure 2.2-29a Vertical profiles of σ_t, temperature (T), Salinity (S), and dissolved oxygen (DO), for Cruise 1, at the indicated sites.



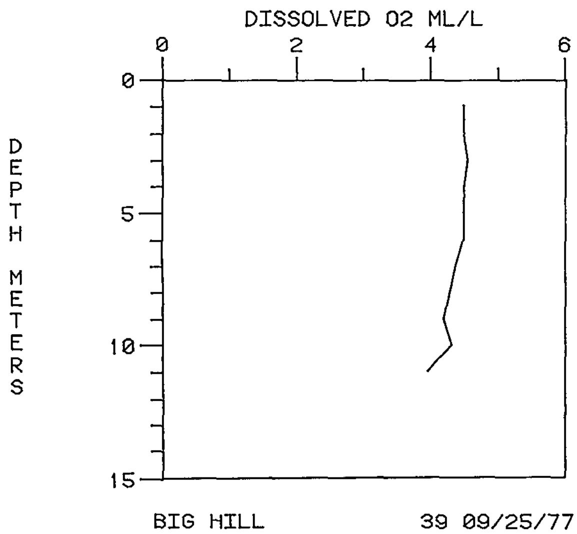
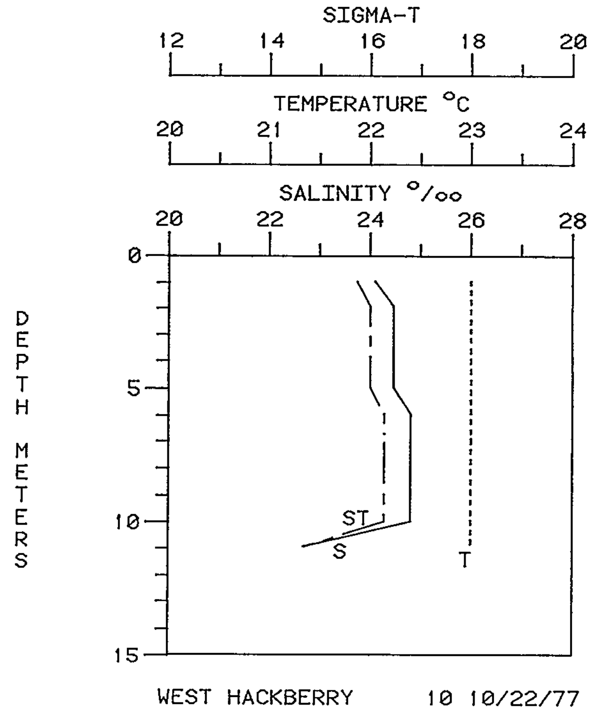


Figure 2.2-29b Vertical profiles of σ_t, temperature (T), Salinity (S), and dissolved oxygen (DO), for Cruise 1, at the indicated sites.



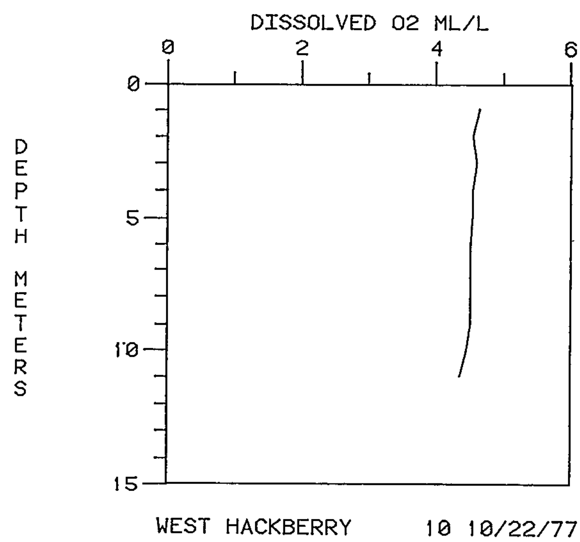


Figure 2.2-30a Vertical profiles of σ_t, temperature (T), salinity (S), and dissolved oxygen (DO), for Cruise 2, at the indicated sites.

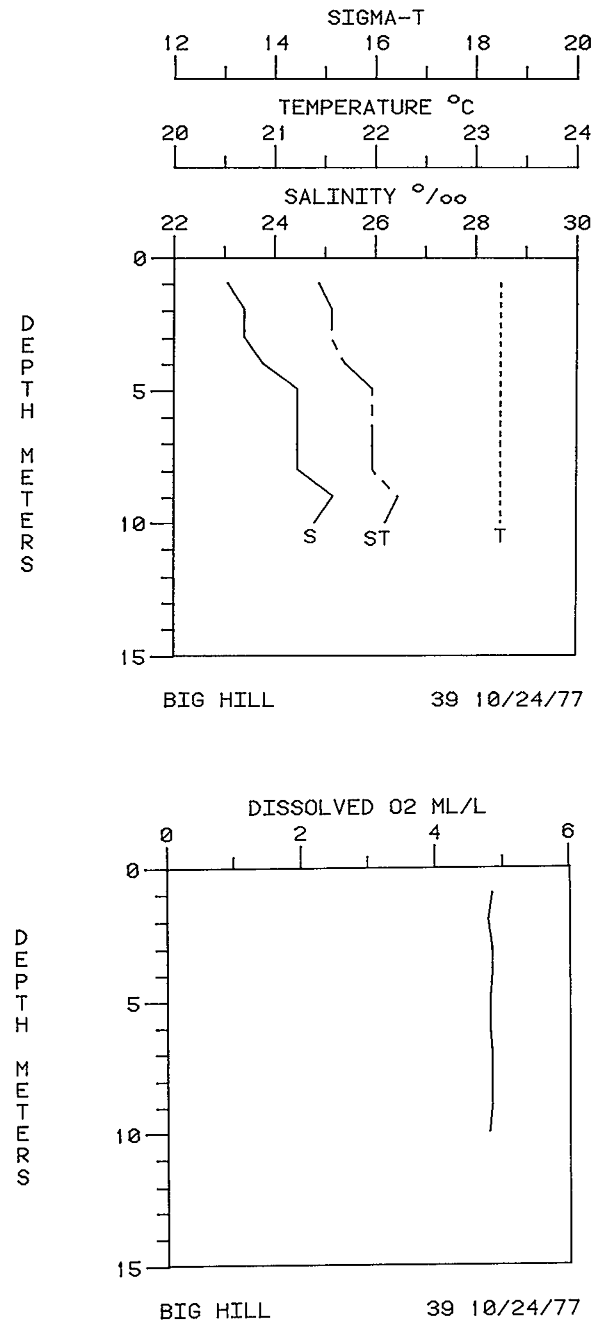


Figure 2.2-30b Vertical profiles of σ_t, temperature (T), salinity (S), and dissolved oxygen (DO), for Cruise 2, at the indicated sites.

density structure, with West Hackberry having almost vertically uniform conditions and Big Hill exhibiting a continuous density gradient from top to bottom. At both sites, dissolved oxygen concentrations were vertically uniform and quite similar in concentration. Note that the West Hackberry station was occupied two days prior to the Big Hill site.

During Cruise 3, the Big Hill station had a slightly warmer surface layer with isothermal conditions in the bottom half of the profile (Figure 2.2-31b) Salinity was continuously and stably stratified. At West Hackberry, measurements indicate a slightly anomalous condition with a slightly unstable vertical structure. This density distribution is dictated by salinity which has a slight decrease (.5°/oo) at 4 meters. If such conditions existed, they were ephemeral or maintained by some undocumented dynamic process. The bottom salinity and hence σ_t minimum probably resulted from the probe coming in contact with bottom sediments.

Two stably stratified layers existed at Big Hill with stability dominated by salinity. The surface was cooler, yet less saline than the layer below. At the time of the measurements, mixing between layers did not appear to be intense, since a relatively steep salinity gradient existed at the density interface. In addition, conditions in the lower layer were rather uniform. There may have been some mixing between near-surface and mid-depth, as suggested by the shape of the temperature and salinity profiles for these depths. Note that the surface layer was cooler than the water at depth.

West Hackberry showed an increase in temperature with depth; however, the salinity completely dominated the density field. During Cruise 4, the most extreme salinity variations were encountered around Calcasieu Pass.

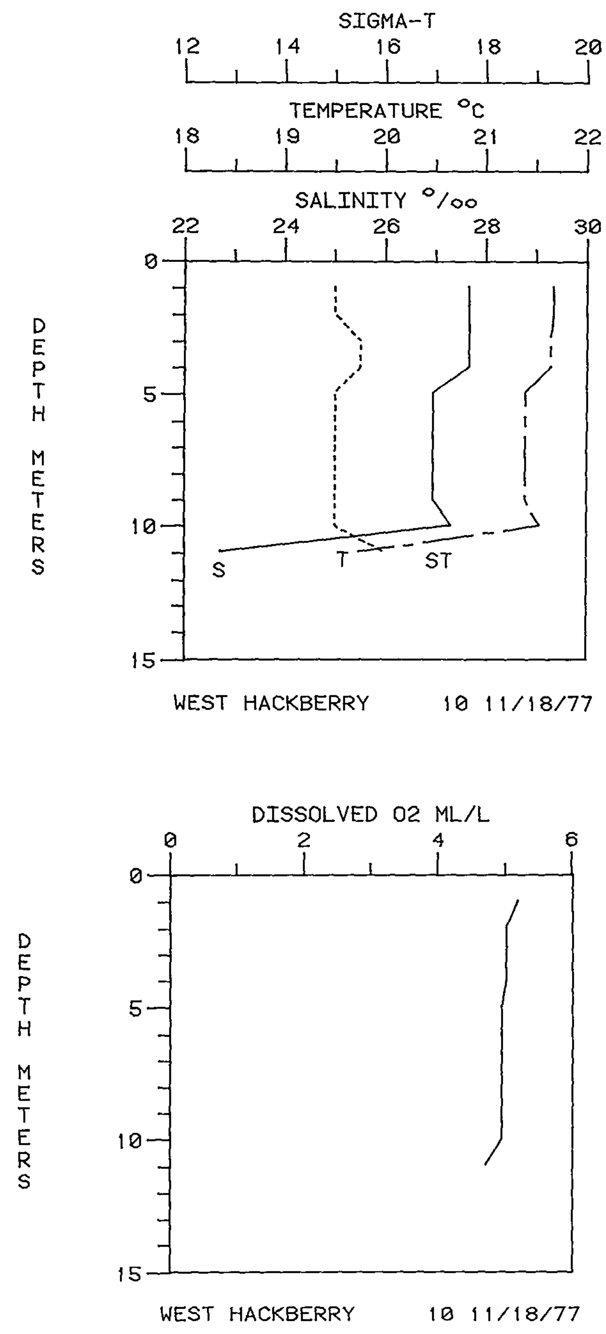
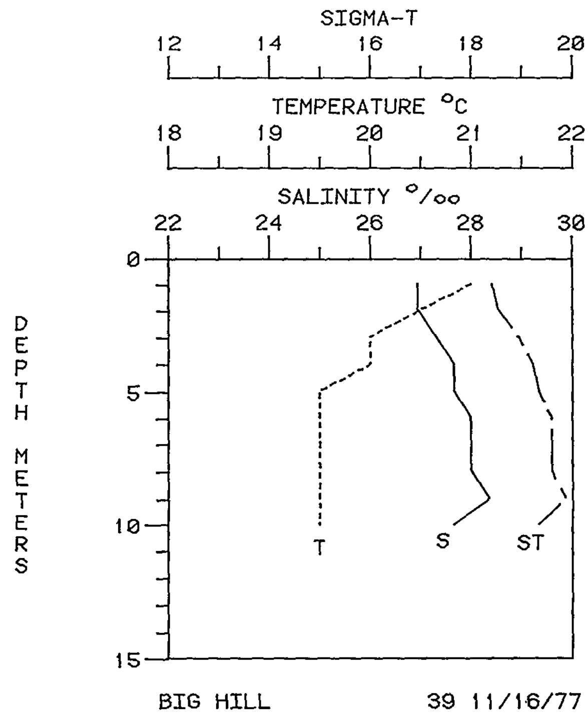


Figure 2.2-31a Vertical profiles of σ_t, temperature (T), salinity (S), and dissolved oxygen (DO) for Cruise 3, at the indicated sites.



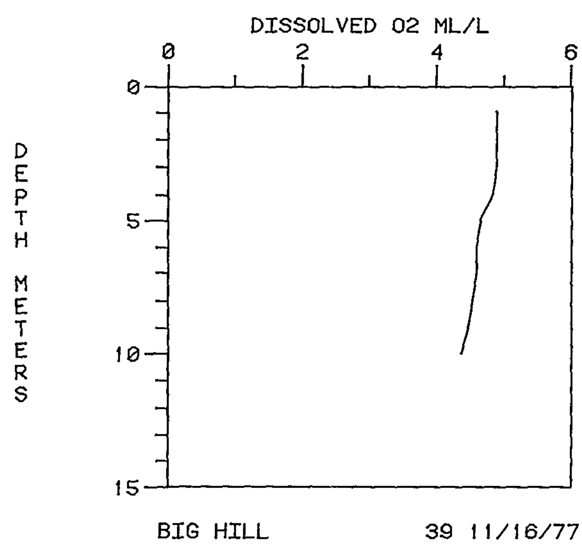
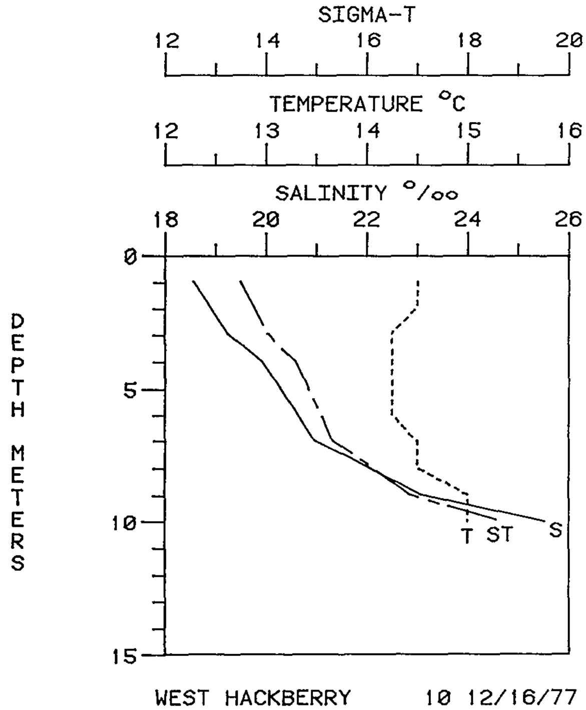


Figure 2.2-31b Vertical profiles of σ_t, temperature (T), salinity (S), and dissolved oxygen (DO) for Cruise 3, at the indicated sites.



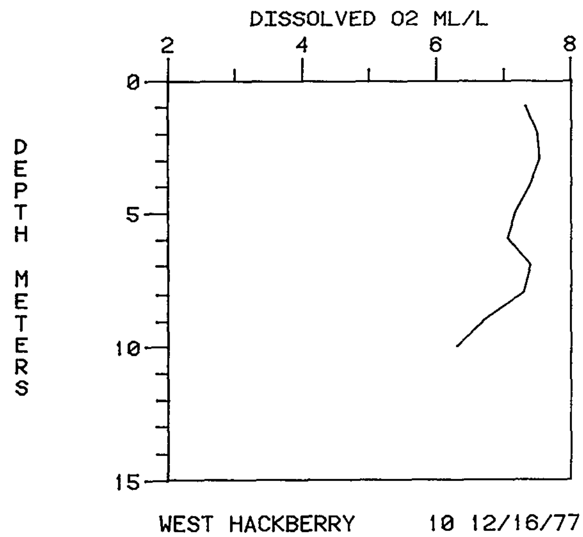
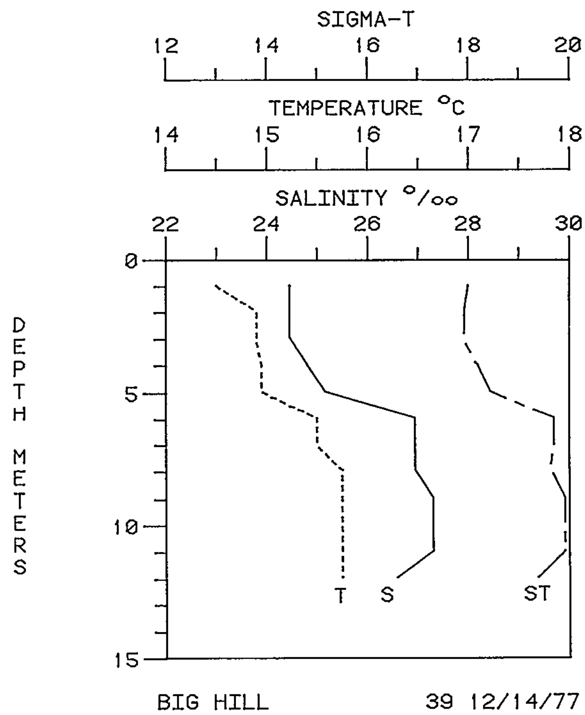


Figure 2.2-32a Vertical profiles of σ_t, temperature (T), salinity (S), and dissolved oxygen (DO), for Cruise 4, at the indicated sites.



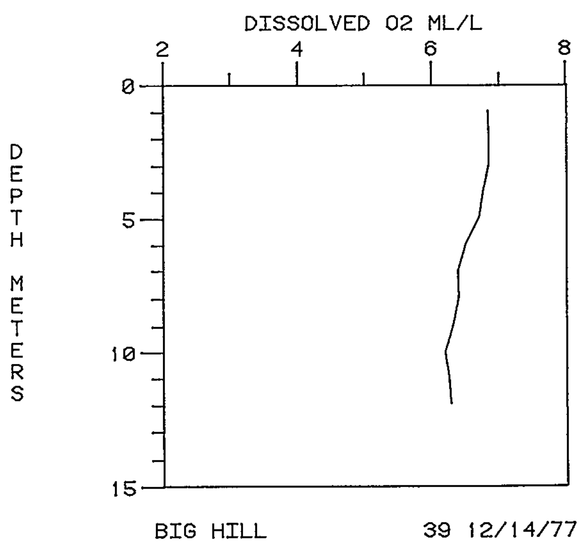


Figure 2.2-32b Vertical profiles of σ_t, temperature (T), salinity (S), and dissolved oxygen (DO), for Cruise 4, at the indicated sites.

A difference of approximately $6^{o}/oo$ from surface to bottom occurred at West Hackberry and $10^{o}/oo$ at West Hackberry control. The extreme stability of the vertical column could be of considerable importance as an inhibitor to local mixing processes, especially if it coincided with a period of low current velocity and hence low sheer.

One possible explanation of what appears to be a brackish water zone close to the coastline results from local tides and the possible seasonal discharge from Calcasieu Pass. Periodically, conditions along this particular section of coast combine to produce very low tidal ranges for the locally mixed tides. As a result, the flooding stage is weak and variable or completely inhibited. Under these conditions, essentially ebbing tidal currents dominate the flow from the tidal passes. Because the ebb flow results from fresh water input to the estuary behind the pass, the discharge would be considerably less saline than when stronger flooding tides could mix the estuarine and more saline coastal waters within the estuary. It is also possible that during certain winter months, freshwater inflow to the local estuary is somewhat higher because less water is drawn off for irrigation.

Plumes of less dense water have been seen coming from both Sabine Pass and Calcasieu Pass, although plumes from Calcasieu Pass have been seen in the vicinity of the West Hackberry site. Boundaries of the plume were well defined by fronts, so the plume extent can be readily determined (Garvine, 1974). These fronts are usually strongly convergent with an associated foam line across the front. A distinct color change existed with more turbid water on the inside of the front. The impact of such plumes on local conditions and mixing processes has not been documented or examined.

2.2.5 Summary and Conclusions

Between October 20 and December 18, 1977, a physical oceanographic field measurement program was successfully conducted. This effort resulted in:

- Establishing a characteristic current record to be used as input to the MIT Brine Diffuser Model. This record was delivered to CEDDA/NOAA.
- Estimates of local horizontal eddy diffusivity to be used as input into the MIT Model. This information has been supplied to CEDDA/NOAA.
- Identification and a general description of significant local physical oceanographic processes occurring in the vicinity of the potential brine diffuser sites.

Measurements taken included speed and direction of currents and wind, water level fluctuations, significant wave height and period, and the areal and vertical distribution of salinity, temperature, and dissolved oxygen. Additionally, a Lagrangian profile study was conducted to determine estimates of horizontal eddy diffusivity as a function of a spatial scale and supplement Eulerian measurements.

Initial results from two months of observations suggest that:

- Tides in the area are mixed tropic tides with approximately equal amplitudes of the diurnal and semi-diurnal components.
- Tidal currents in the area (away from tidal passes) are of low magnitude and thus provide only a relatively small amount of the total current variability.
- During certain periods which are more prevalent during summer conditions, a local sea breeze system exists.
- Winds typically had a component directed toward the west and the north. For only a small portion of the study period was a component of the wind toward the east.

- The dominant energy band of winds and currents is at approximately .1 cycles/day with lesser concentrations at about .25-.33 cycles/day.
- For lower frequency variations, a pattern of cross-correlations exist which suggest that near bottom currents are in part driven by a sloping sea surface which is produced directly or indirectly by wind shear at the surface.
- Alongshore coherence of the alongshore currents is very high, suggesting that the dominant low frequency processes have alongshore spatial scale which exceeds the lateral extent of the study area.
- There is preliminary evidence of seasonality of winds, currents and the density field.
- Local vertical density structure responds seasonally and to events which cause the well-mixed layer to extend throughout the vertical column.
- Visual observations and some C, T, D data indicate that at least at the Calcasieu Pass and West Hackberry Site, tidal discharge plumes and associated fronts have a direct impact on the local environment.

The continuing field program presently underway will allow for better identification of interrelationships. Two months of data provides only six repetitions of a ten-day cycle. As the total record length increases, confidence intervals in the computed parameters will converge. Additionally expected measurements will allow for characterization of seasonal patterns associated with the end of the oceanic and atmospheric summer season, transition to the winter season, the winter season, and a significant portion of the winter to summer transition.

Preliminary conclusions indicate that regional dynamics are in part systematically related to a wind-shear-induced depression or elevation of the sea surface which creates pressure gradients and drives the bottom currents. This system has a period of 3-4 days and 10 days. Regional conditions such as the distribution of density and land-sea breezes may cause perturbations on this system, but the coupling of longer period phenomena dominates the regional current variability.

2.3 FAR-FIELD MODELING

2.3.1 West Hackberry Far-Field Modeling

2.3.1.1 Introduction

As described in Section 4.3.2.1, Appendix C.3.1.2.1, and Appendix D.25, the MIT Transient Plume Model has been used to estimate the changes in salinity in the Gulf of Mexico in the vicinity of the brine disposal site for the West Hackberry facility. The initial results obtained with the model, as discussed in the sections noted, were based on estimated values for the currents and diffusion coefficient. More recently, both current and diffusion data have been obtained in the vicinity of the West Hackberry brine disposal site, as part of Phase I of the Off-Shore Sampling Program described elsewhere in this document. These data have been used by NOAA as inputs to the MIT Model to generate additional estimates of the salinity distribution in the vicinity of the brine disposal site.

Four additional test cases have been carried out by NOAA as follows:

Run #	Current Meter	Time Period Covered	Condition
WH-1	West Hackberry Control	1200, 11/2/77 to 2100, 11/2/77	Initial data
WH-2	Calcasieu Pass	1300, 11/2/77 to 2200, 11/2/77	Initial data
WH-3	West Hackberry Replacement	1200, 1/3/78 to 0000, 1/6/78	Typical current
WH-4	West Hackberry Replacement	0000, 1/25/78 to 0000, 1/27/78	Storm passage

For Runs WH-1 and WH-2 approximately two weeks of current data were available and the time period covered by each run was taken near the end of the corresponding two-week period. For Runs WH-3 and WH-4 a time series consisting of approximately 62 days of current data was available. The time period covered by Run WH-3 commenced on the 34th day of this series and corresponds to a typical current condition. The time period covered by Run WH-4 commenced on the 54th day of the same series and corresponds to the passage of a storm through the region. The remaining subsections provide a detailed description of the inputs used and the results obtained for the four additional test cases.

2.3.1.2 Inputs to MIT Transient Plume Model

A complete description of input variables for the original test cases is provided in Appendix D.25. For the four additional test cases (Runs #WH-1 through #WH-4) all inputs were the same as those used for the Base Case (Run #7), except for the currents.

Measured maximum currents in the longshore direction for Runs #WH-1 and #WH-2 indicated a magnitude of about 30 cm sec^{-1} while maximum currents offshore were about 20 cm sec^{-1}. Such values are of the same order of magnitude as the values used for the original test cases but the measured longshore value is about 60% of the value used in the original cases while the measured offshore value is more than twice the value originally used. The actual time series representing the "U" and "V" input currents are shown in Figures 2.3-1 and 2.3-2 for Run #WH-1. The corresponding time series for Run #WH-2 are presented in Figures 2.3-3 and 2.3-4.

Maximum measured currents for Runs #WH-3 and #WH-4 in the longshore direction were 46 cm/sec while maximum measured currents in the offshore direction were 11 cm/sec. The longshore value is essentially equal to that used in the original test cases and the offshore value is slightly greater than the value originally used. Presentations of time series for Runs #WH-3 and #WH-4 are provided in Figures 2.3-5 through 2.3-8.

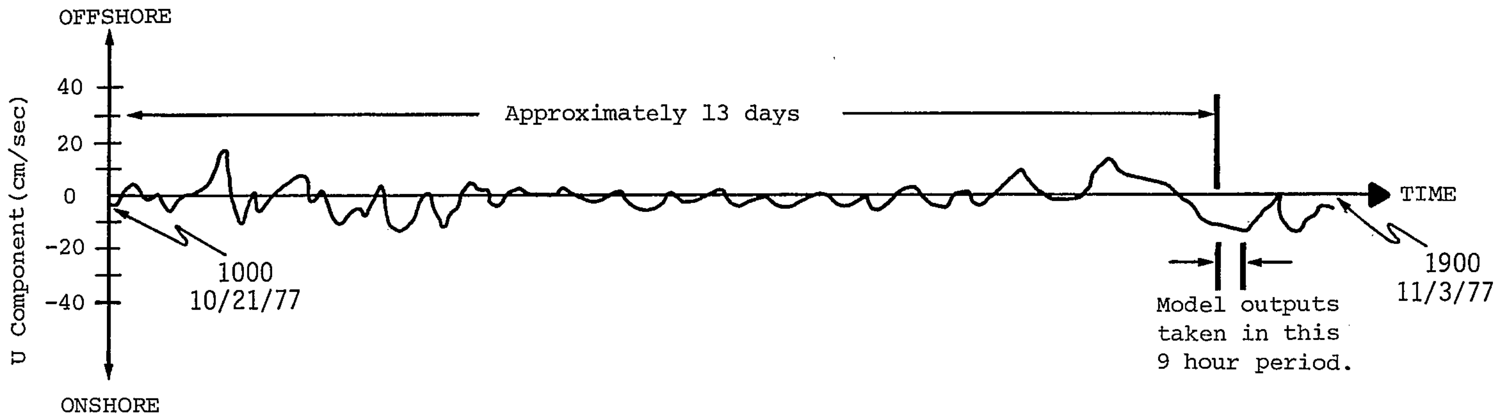


Figure 2.3-1 Time Series of Observed Offshore Current Component, U, From West Hackberry Control Current Meter for Run #WH-1.

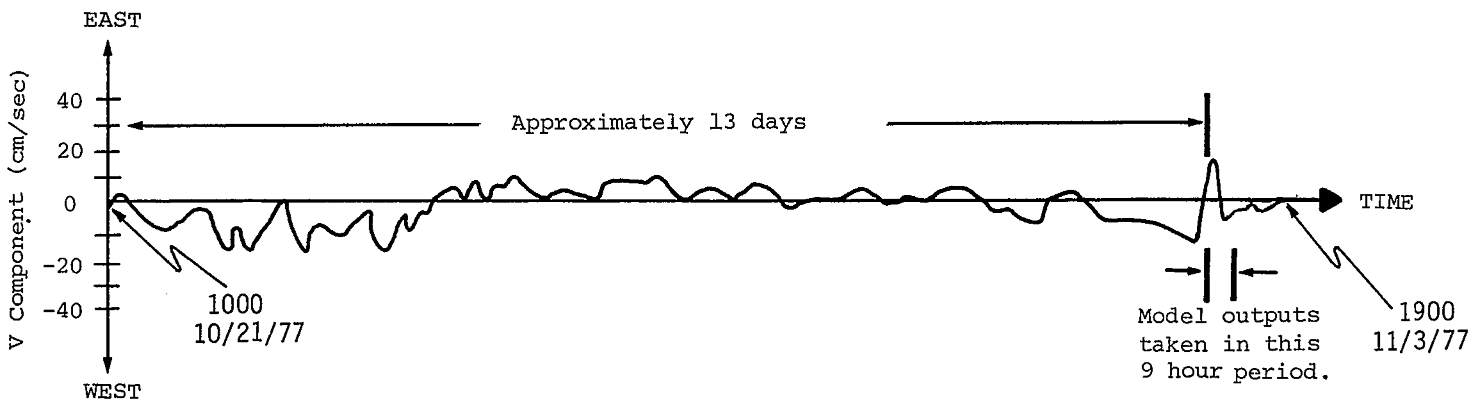


Figure 2.3-2 Time Series Observed Longshore Current Component, V, From West Hackberry Control Current Meter for Run #WH-1.

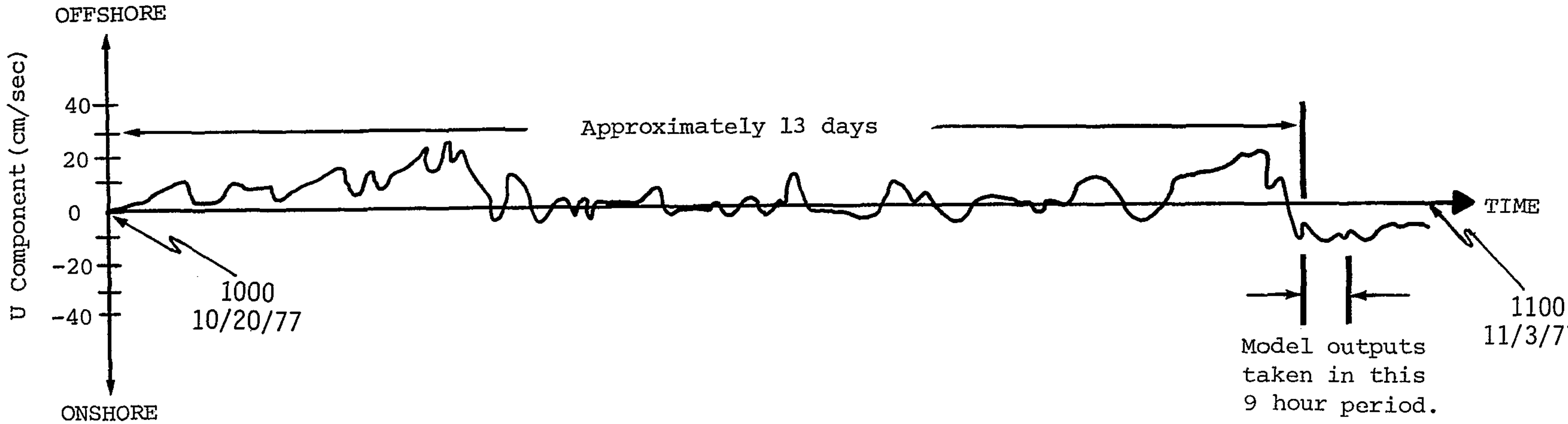


Figure 2.3-3 Time Series of Observed Offshore Current Component, U, From Calcasieu Pass Current Meter for Run #WH-2.

Figure 2.3-4 Time Series of Observed Longshore Current Component, V, From Calcasieu Pass Current Meter for Run #WH-2.

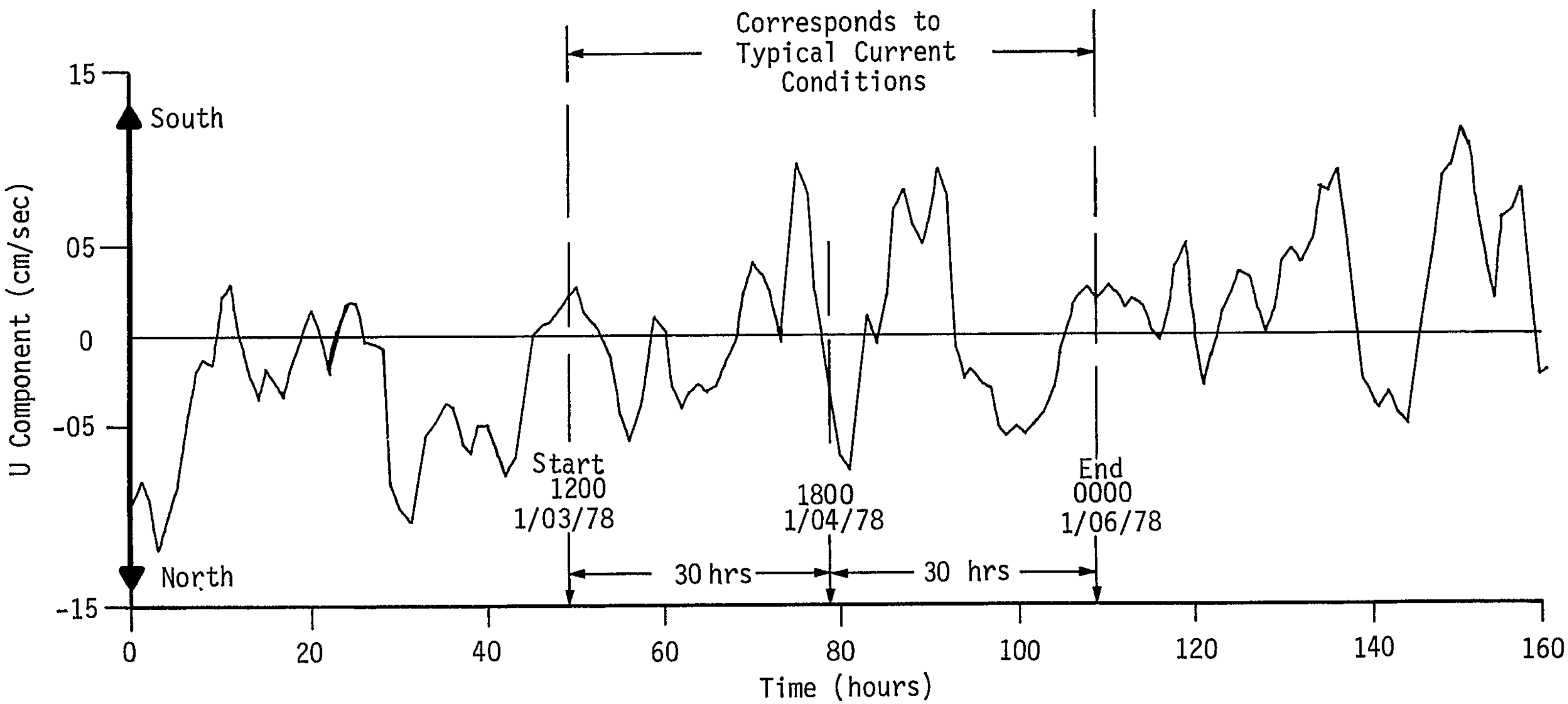


Figure 2.3-5 Time Series of Observed Offshore Current Component, U, from West Hackberry Replacement Current Meter for Run #WH-3

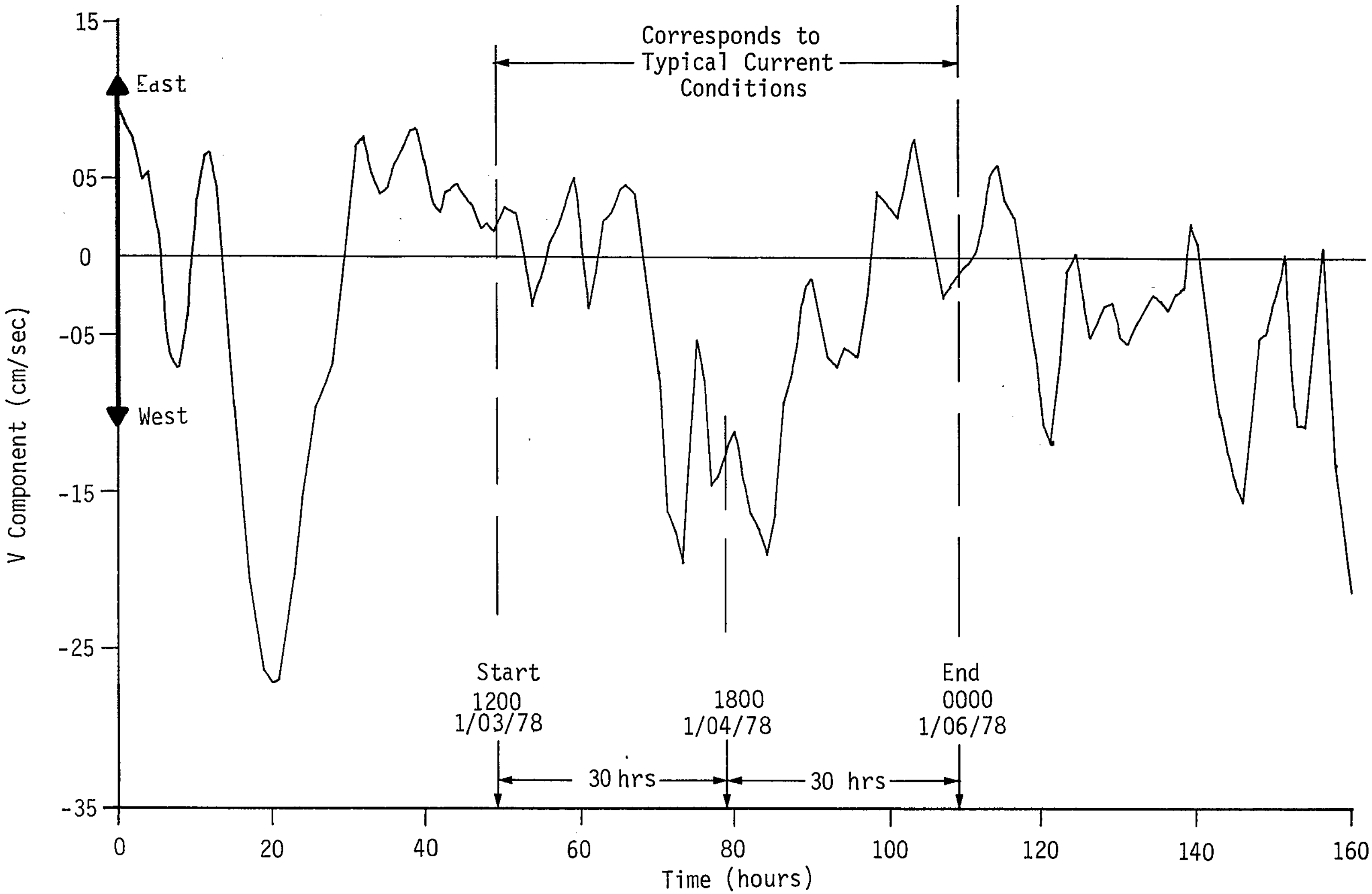


Figure 2.3-6 Time Series of Observed Longshore Current Component, V, from West Hackberry Replacement Current Meter for Run #WH-3

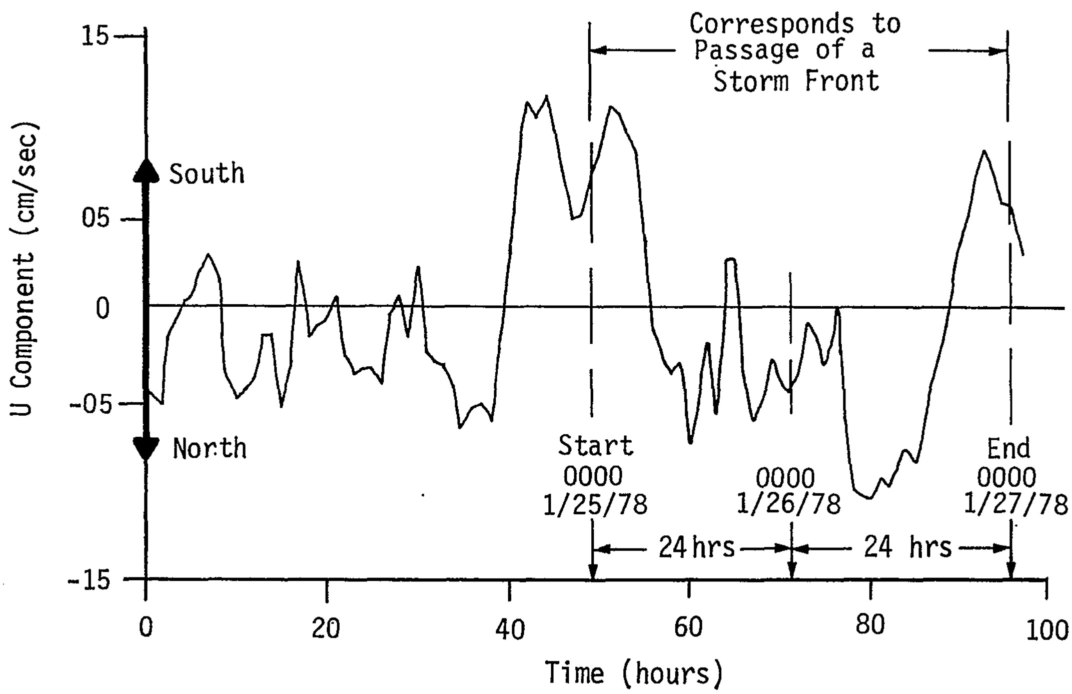


Figure 2.3-7 Time Series of Observed Offshore Current Component, U, from West Hackberry Replacement Current Meter for Run #WH-4

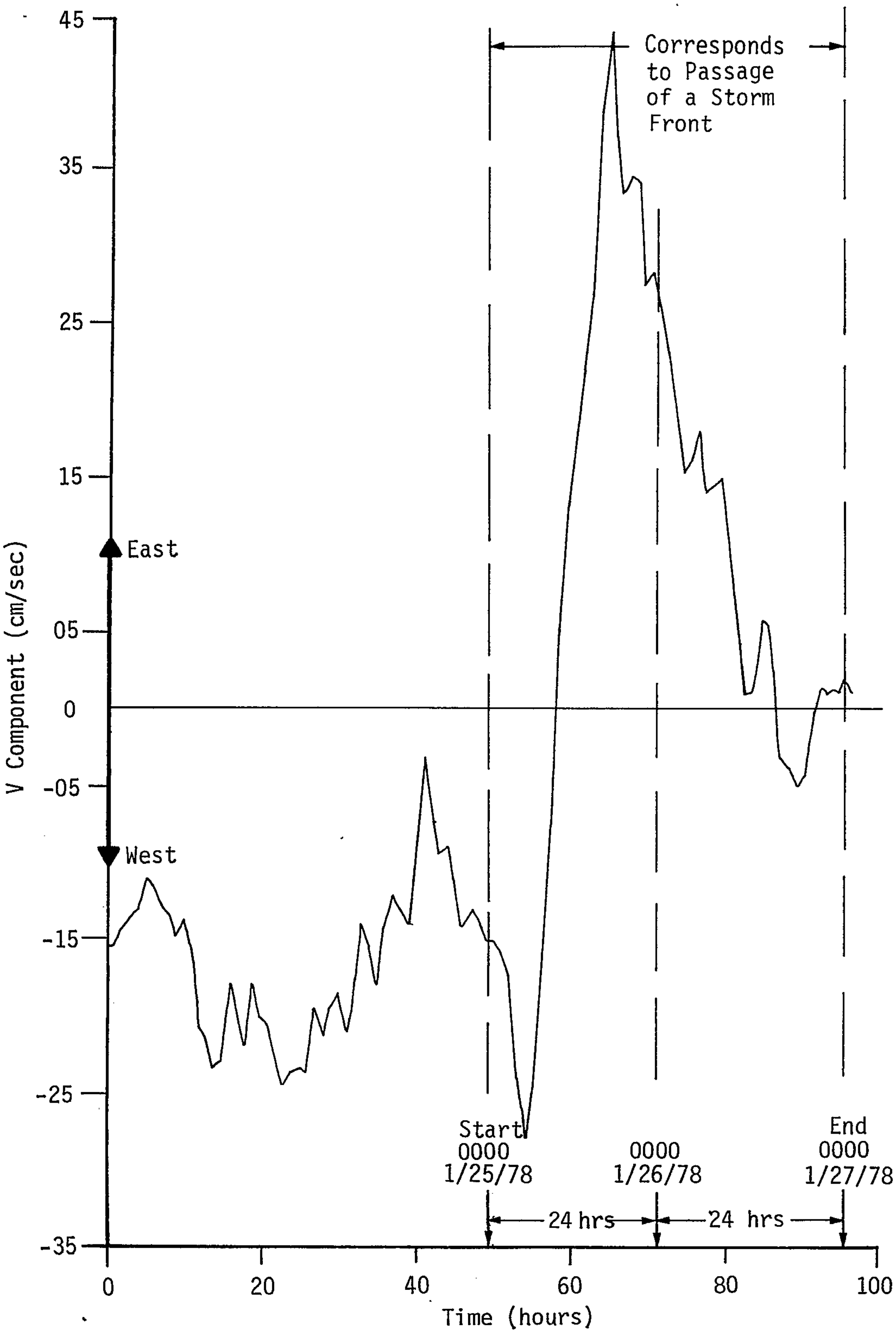


Figure 2.3-8 Time Series of Observed Longshore Current Component, V, from West Hackberry Replacement Current Meter for Run #WH-4

In addition to current data, as described elsewhere, horizontal diffusion coefficients, E_h, were also measured in the vicinity of the disposal site. Such coefficients were observed to obey the power law

$$E_h = 0.003 \, L^{1.15}$$

Where L is the scale of diffusion (which is equivalent to the patch size, σ_h). Because this power law is identical to that originally used in the model, no changes to the horizontal diffusion inputs were made.

Measurement of vertical diffusion coefficients, E_z, was not called for as part of the Phase I of the Offshore Sampling Program. For this reason the vertical diffusion values used in original test cases were retained for the four additional cases.

2.3.1.3 Results of Runs #WH-1 and #WH-2

With the inputs described, Runs #WH-1 and #WH-2 were undertaken. In general, the first 12 days of data were used to allow the model to reach quasi-equilibrium. For Run #WH-1 outputs were taken at times corresponding to 1200, 1500, 1800 and 2100 of the 12th day. For Run #WH-2 outputs were taken at times corresponding to 1300, 1600, 1900 and 2200 of the 13th day.

The resulting salinity contour (isopleth) plots are presented in Figures 2.3-9 through 2.3-16. A comparison of the orientation of these plots with those provided in Figures 41a and 42 through 45 of Appendix D.25 for the Base Case indicates that the plumes generated in runs #WH-1 and #WH-2 are generally oriented along the onshore-offshore axis as compared with the general east-west orientation of the plumes in the Base Case.

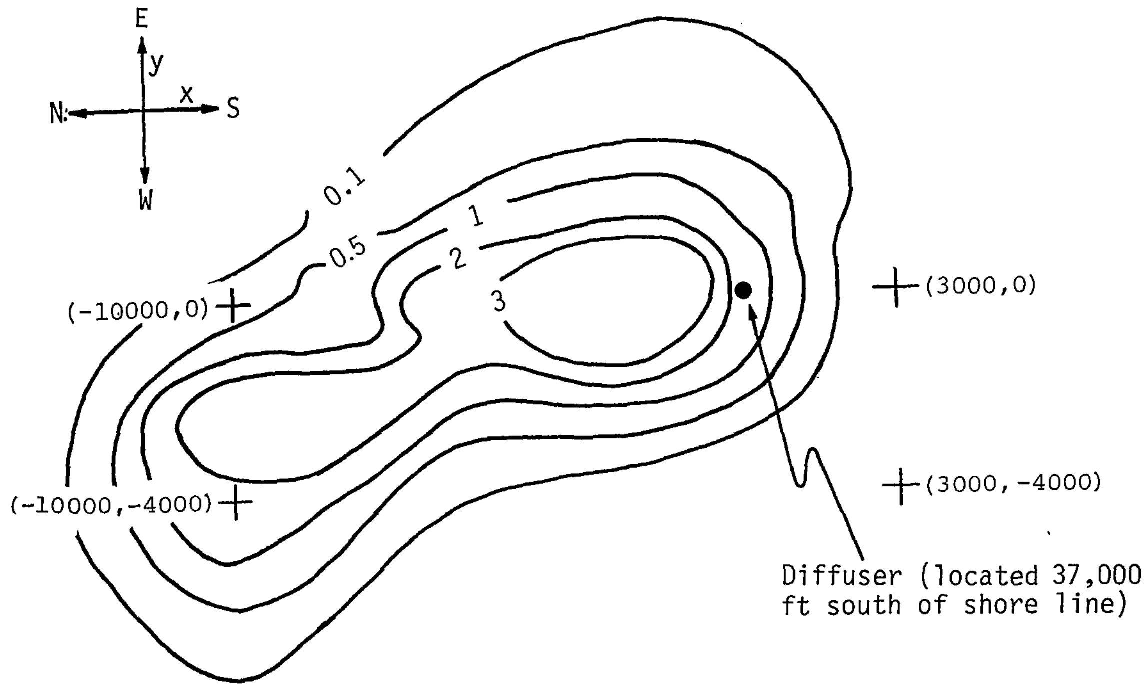


Figure 2.3-9 Contours of Excess Salinity Concentrations (ppt) for Run #WH-1 at T = 0000 Hours on the Bottom.

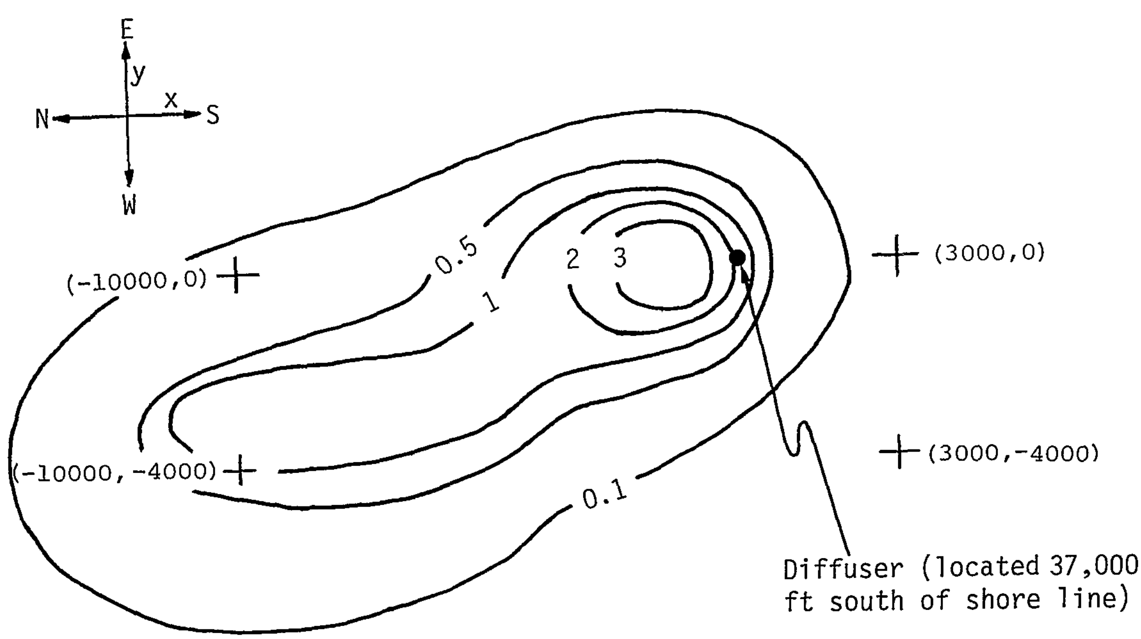


Figure 2.3-10 Contours of Excess Salinity Concentrations (ppt) for Run #WH-1 at T =0300 Hours on the Bottom.

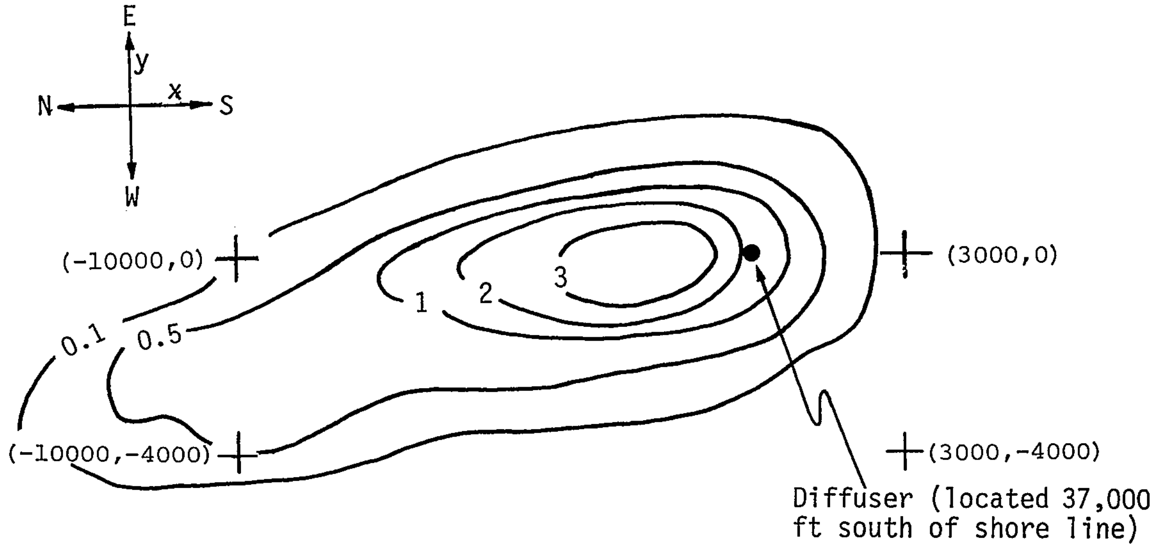


Figure 2.3-11 Contours of Excess Salinity Concentrations (ppt) for Run #WH-1 at T = 0600 Hours on the Bottom.

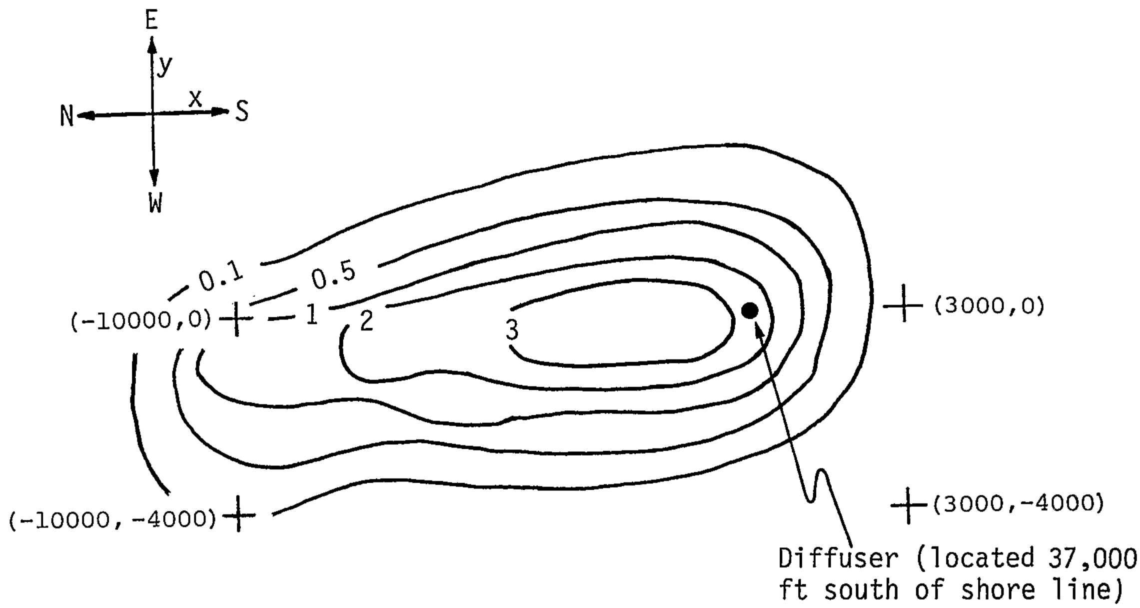


Figure 2.3-12 Contours of Excess Salinity Concentrations (ppt) for Run #WH-1 at T = 0900 Hours on the Bottom.

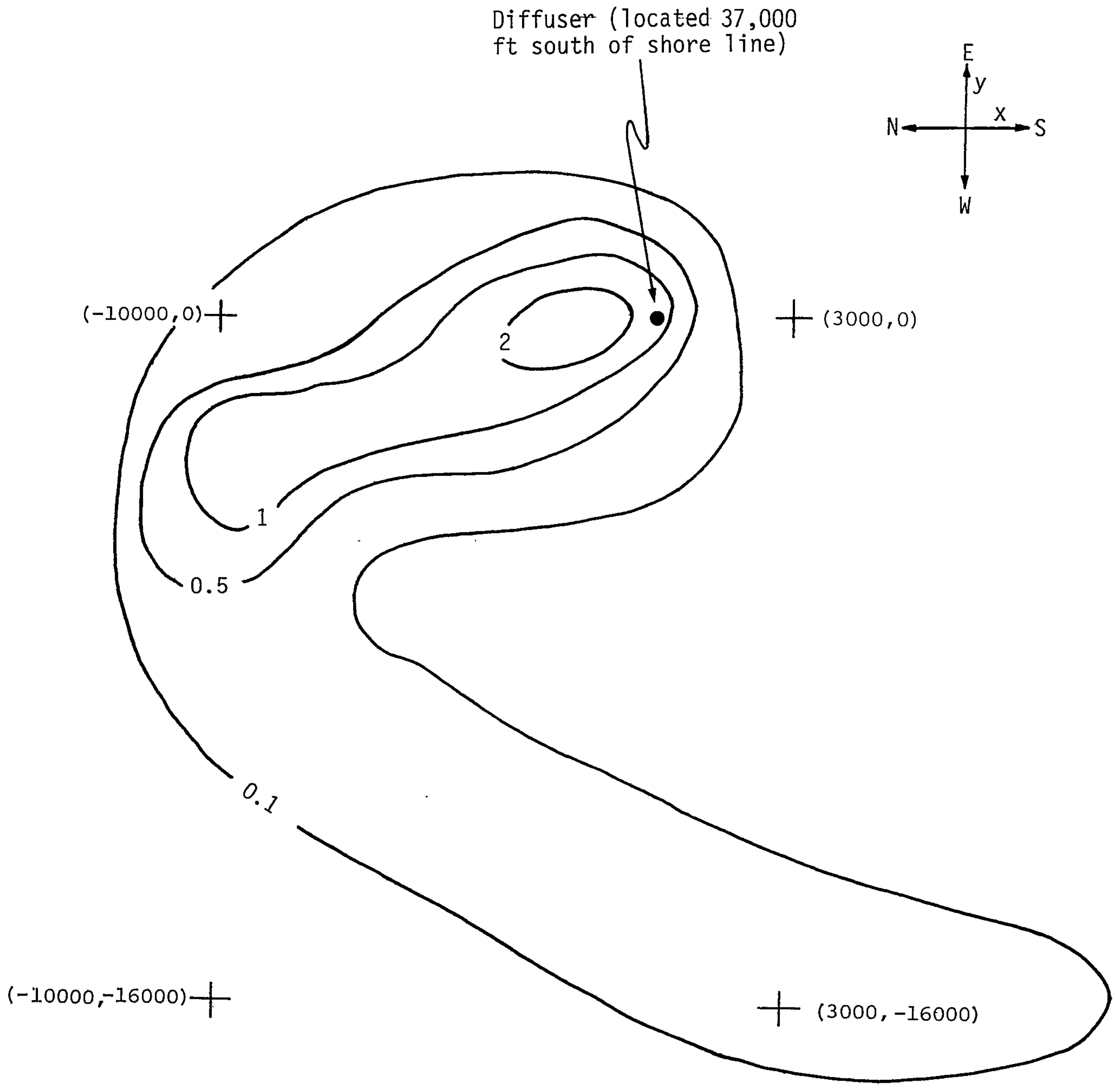


Figure 2.3-13 Contours of Excess Salinity Concentrations (ppt) for Run #WH-2 at T = 0300 Hours on the Bottom.

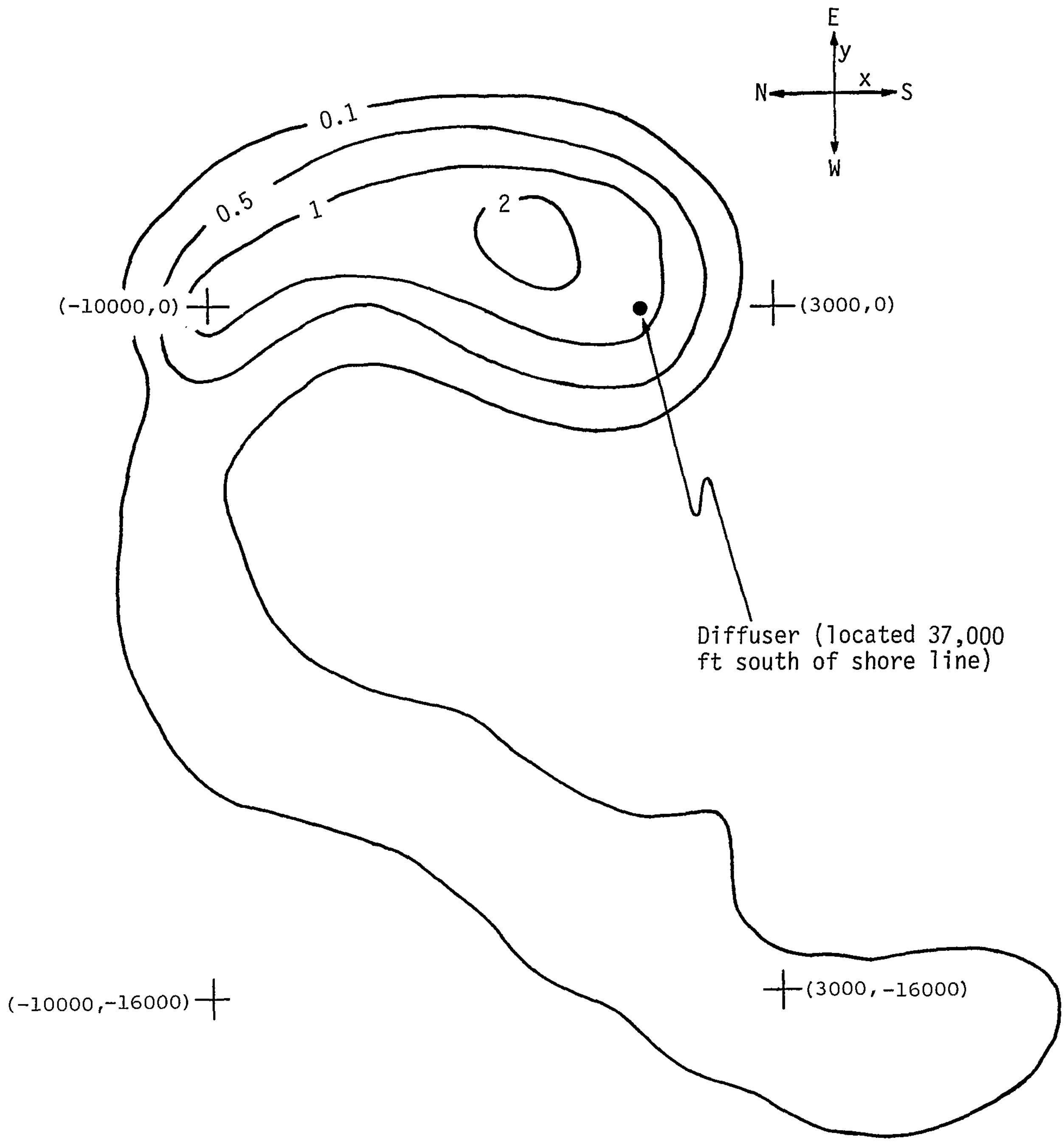


Figure 2.3-14 Coutours of Excess Salinity Concentrations (ppt) for Run # WH-2 at T = 0300 Hours on the Bottom.

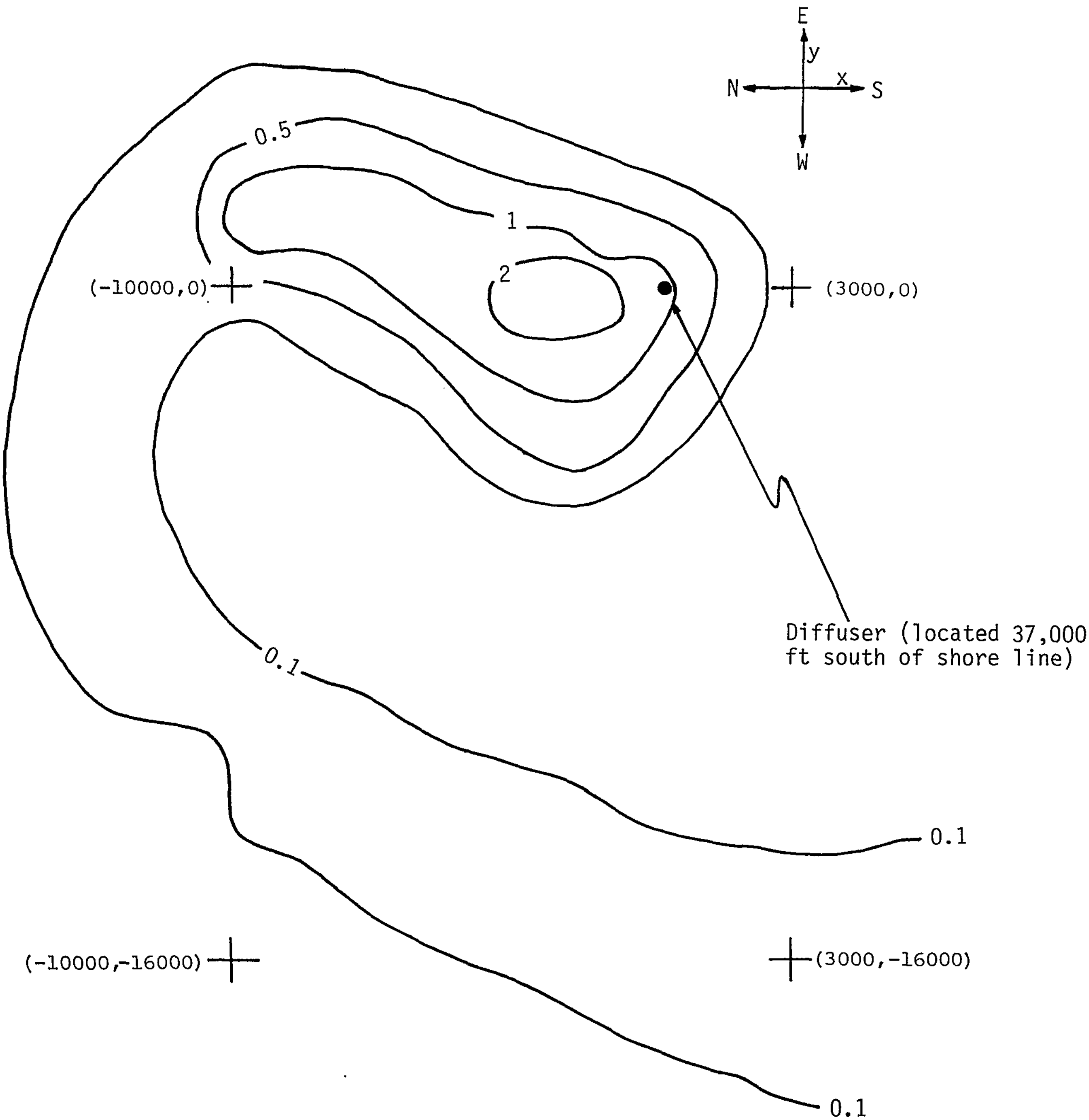


Figure 2.3-15 Contours of Excess Salinity Concentrations (ppt) for Run # WH-2 at T = 0600 Hours on the Bottom.

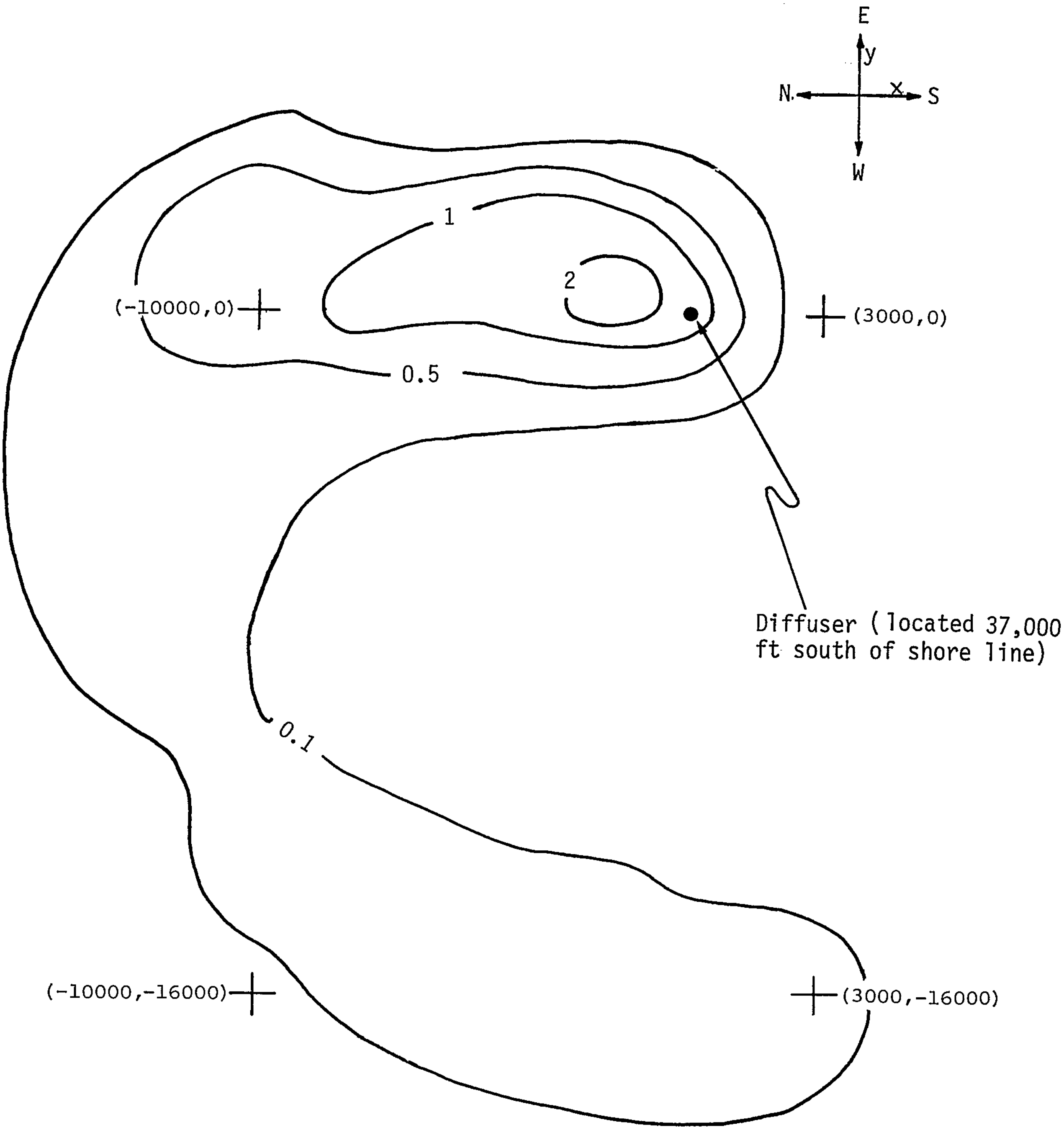


Figure 2.3-16 Contours of Excess Salinity Concentrations (ppt) for Run #WH-2 at T = 0900 Hours on the Bottom.

With regard to the area enclosed by the various salinity contours, Figure 2.3-17 provides a comparison between the Base Case and Run #WH-1. Examination of this figure indicates that the currents measured at West Hackberry Control produced plumes which, for salinities in excess of approximately 1.2 ppt, covered larger areas than covered by the corresponding portions of the Base Case plume. For salinities less than 1.2 ppt, the area covered by the Base Case was equal to or greater than that produced for Run #WH-1. A similar comparative plot of area versus salinity for the Base Case and Run #WH-2 is provided in Figure 2.3-18. In this case, the areas covered by the plume produced by the Calcasieu Pass currents were consistently less than or equal to the corresponding areas covered by the Base Case plume. These differences in area coverage can generally be explained by the fact that the measured currents seem to be about half as strong as those used in the earlier current simulations. Weaker currents would tend to provide less dilution and higher concentrations in the near and intermediate fields. Such a condition is not considered desirable.

The conclusion is reached that the results previously obtained with simulated currents differ to some degree in both orientation and area from the results of Run #WH-1 and #WH-2 which are based on actual measurement.

2.3.1.4 Results of Runs #WH-3 and #WH-4

The time series shown in Figures 2.3-5 through 2.3-8 represent portions of a single 62-day series measured by the West Hackberry Replacement current meter from 12/1/77 to 2/1/78. The entire series, along with

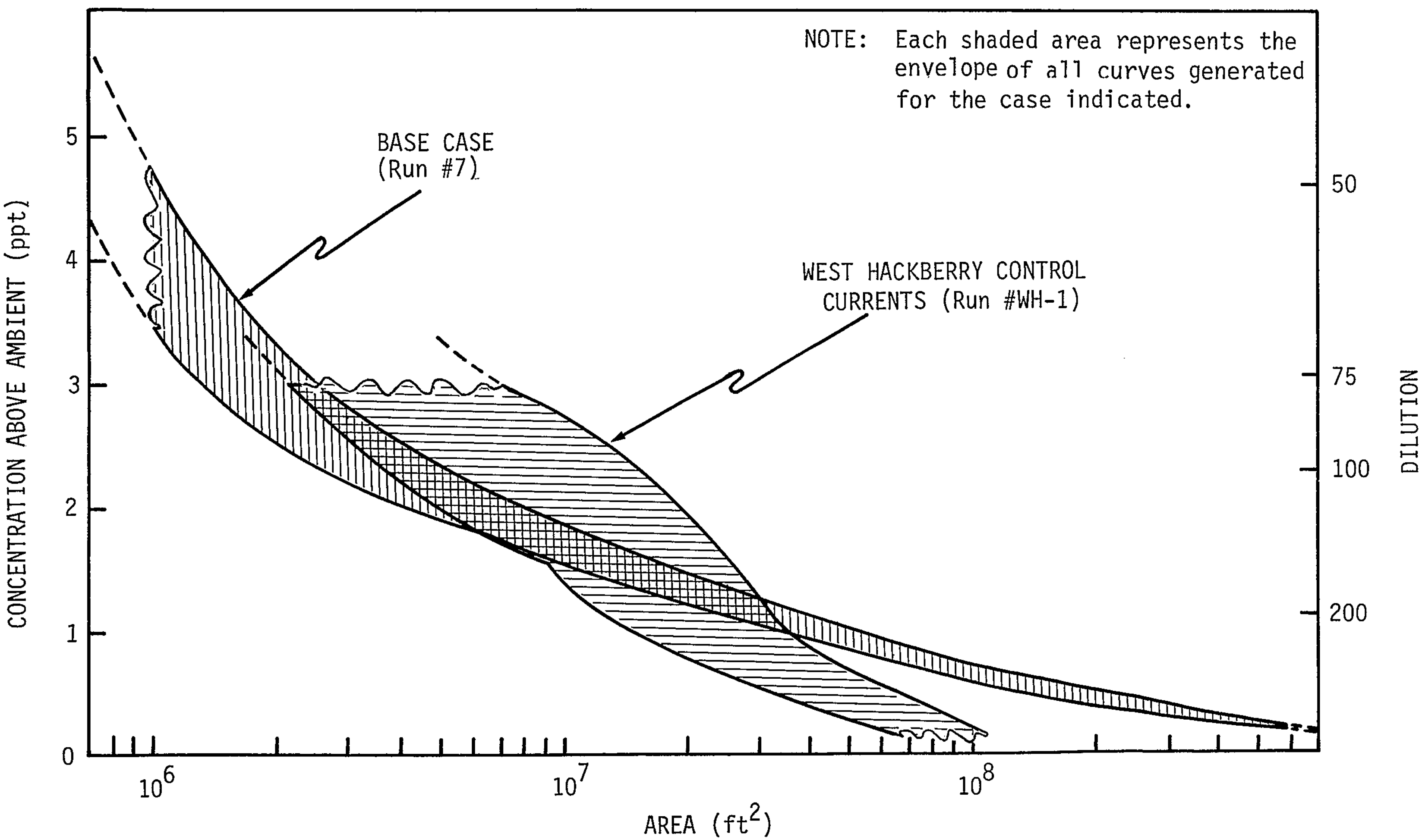


Figure 2.3-17 Excess Salinity versus Exposed Bottom Area for Run #WH-1.

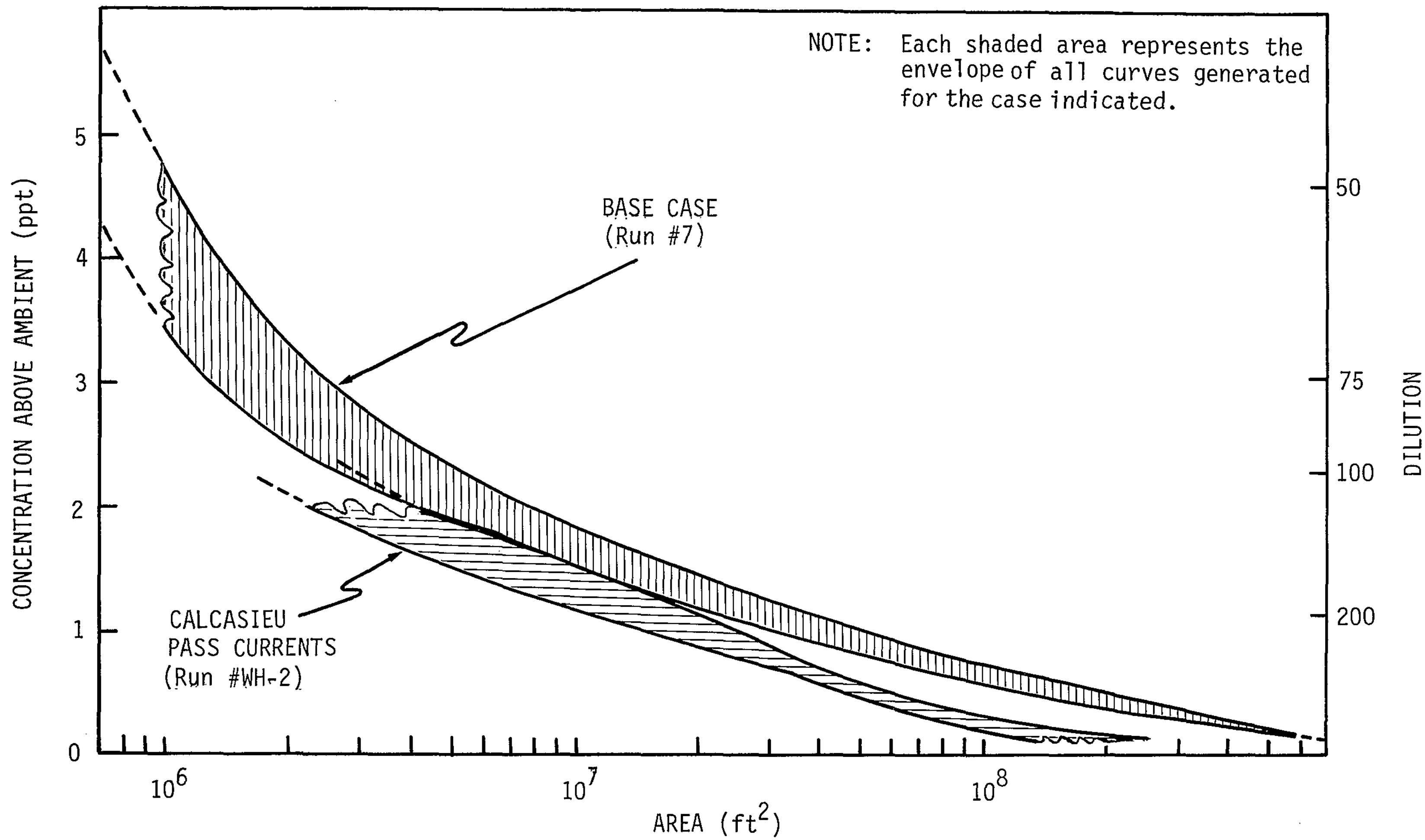


Figure 2.3-18 Excess Salinity versus Exposed Bottom Area for Run #WH-2.

the other parameters previously noted, was used as input to the MIT Transient Plume Model. As before, the first 12 days of the series were used to allow the model to reach quasi-equilibrium. Run #WH-3, representing a typical current condition, commenced at 1200 on the 33th day and extended for 60 hours. Run #WH-4, representing the passage of a storm front, commenced at 0000 on the 54th day and extended for 48 hours. Outputs were taken for Run #WH-3 corresponding to 0, 30, and 60 hours measured from the commencement time for the run. Likewise for Run #WH-4 outputs were obtained corresponding to 0, 24, and 48 hours measured from the commencement time.

The excess salinity contours for the case of Run #WH-3, corresponding to typical current conditions, are presented in Figures 2.3-19 through 2.3-21. In Figure 2.3-19 at the commencement of the run, the plume has a double-lobe shape which appears to be rotating clockwise in the presence of a current setting toward the southeast. Thirty hours later as shown in Figure 2.3-20, in the presence of a westward-setting current the double-lobe shape remains, but the plume displays westward-drifting "tongues" within the lobe surrounding the diffuser. In the final plot shown in Figure 2.3-21, corresponding to 30 hours later, the double-lobe shape is again observed. The contours in the lobe surrounding the diffuser have a major axis in either the northeast or southwest direction. This orientation reflects the recent shift of the current from the northeast to the southwest.

For Run #WH-4, corresponding to the passage of a storm front, the salinity contour plots are presented in Figures 2.3-22 through 2.3-24.

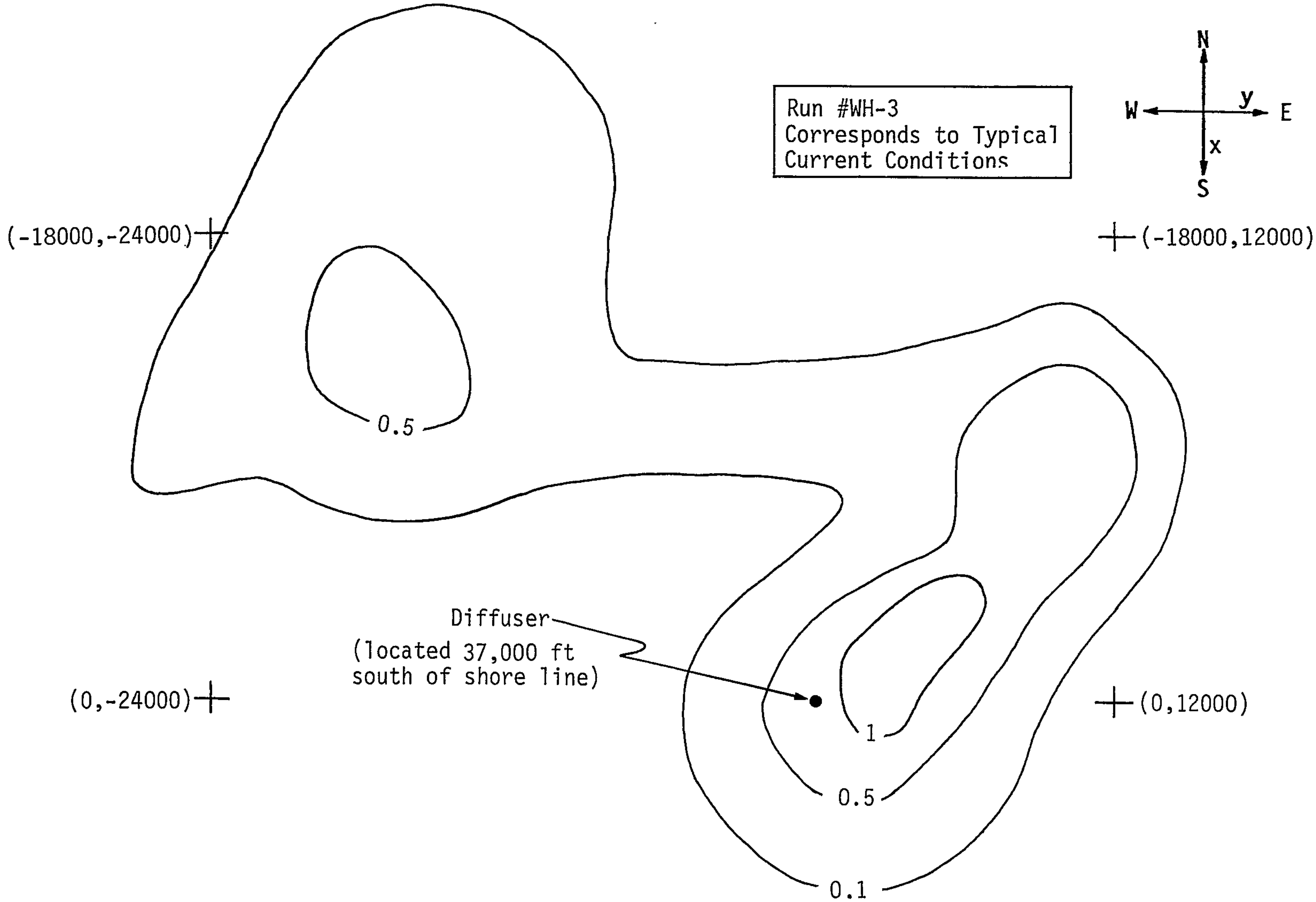


Figure 2.3-19 Contours of Excess Salinity Concentrations (ppt) for Run #WH-3 at Time = 0 Hours on the Bottom (1200, 1/03/78)

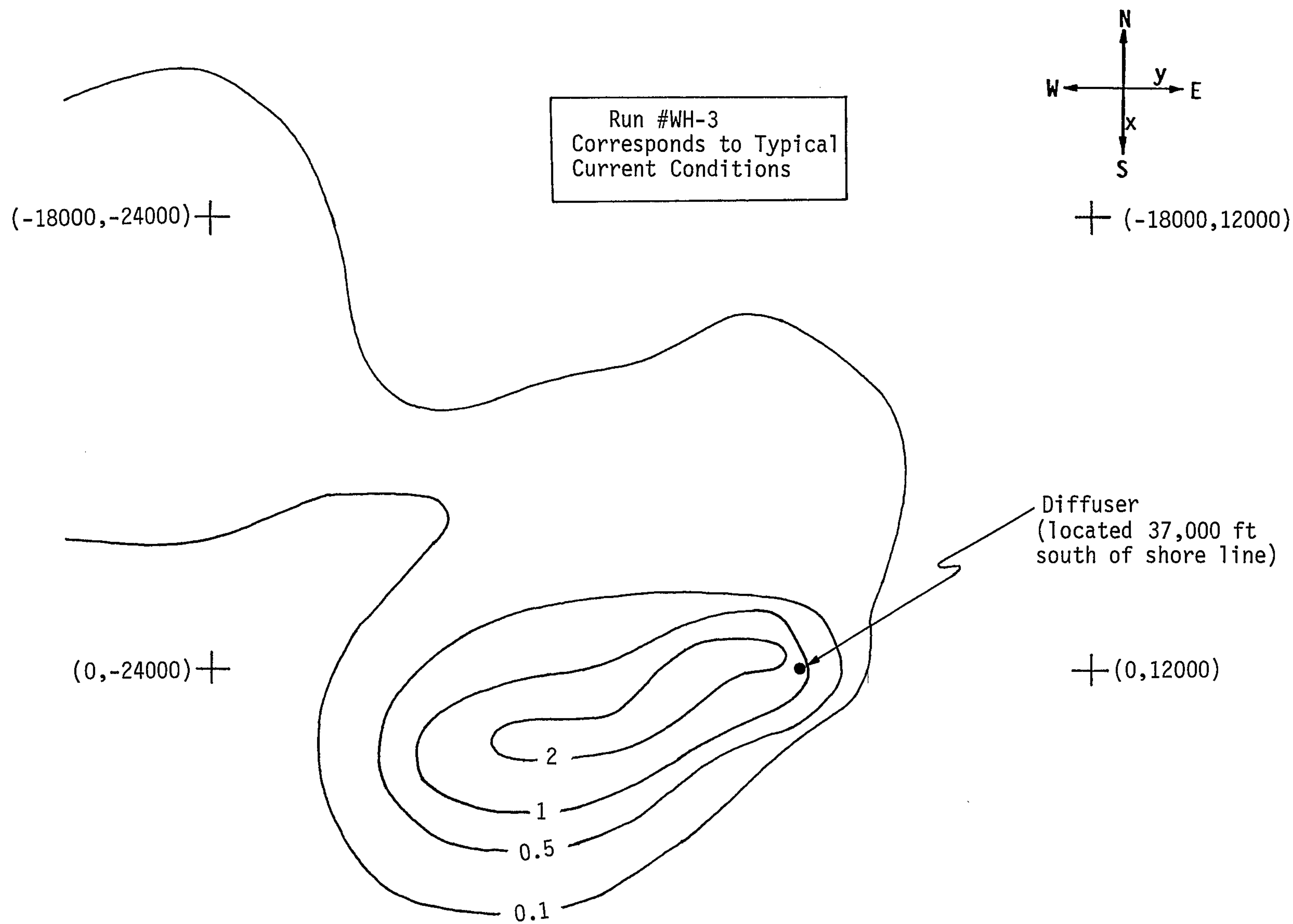


Figure 2.3-20 Contours of Excess Salinity Concentrations (ppt) for Run #WH-3 at Time = 30 Hours on the Bottom (1800, 1/04/78)

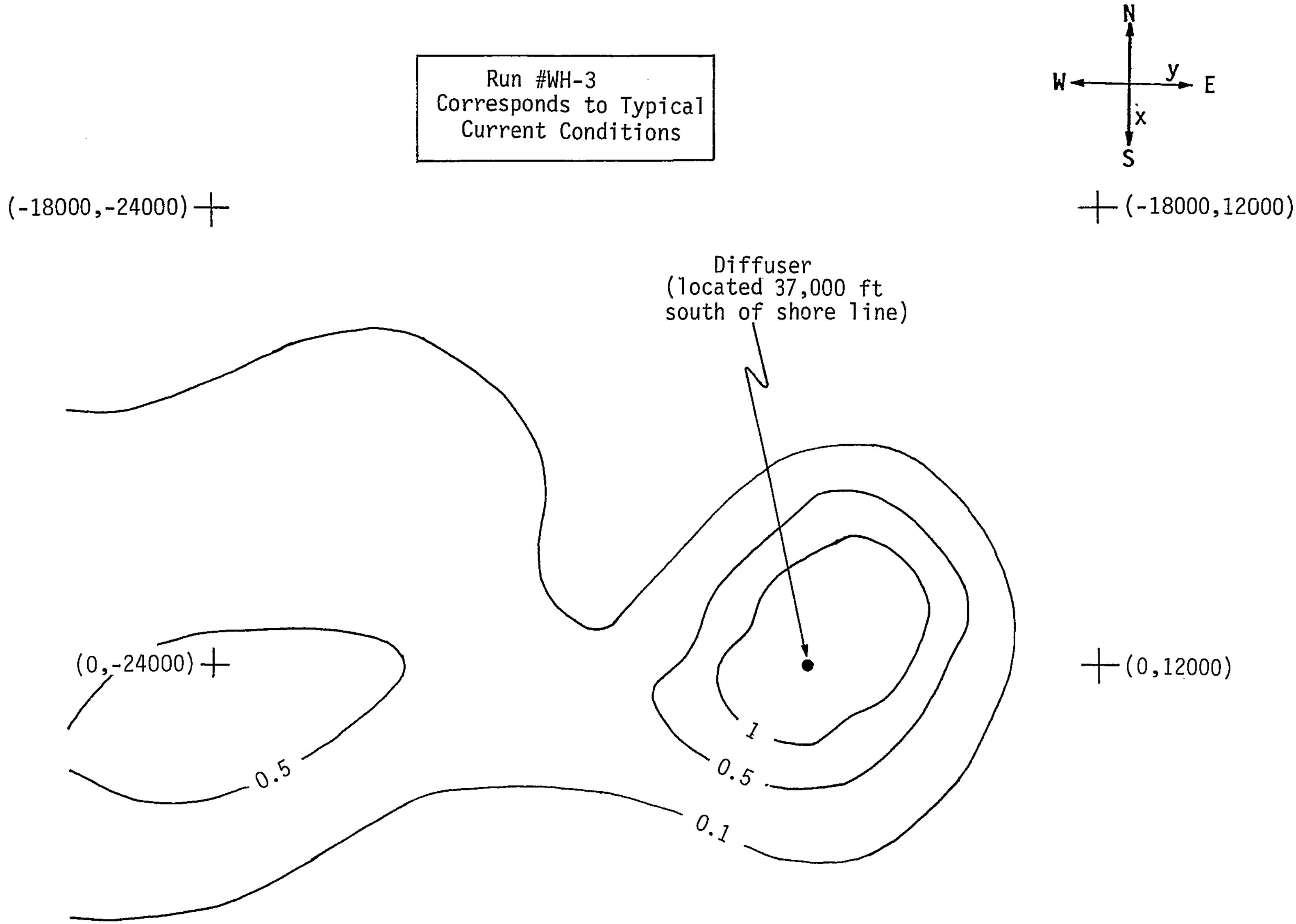


Figure 2.3-21 Contours of Excess Salinity Concentrations (ppt) for Run #WH-3 at Time = 60 Hours on the Bottom (0000, 1/06/78)

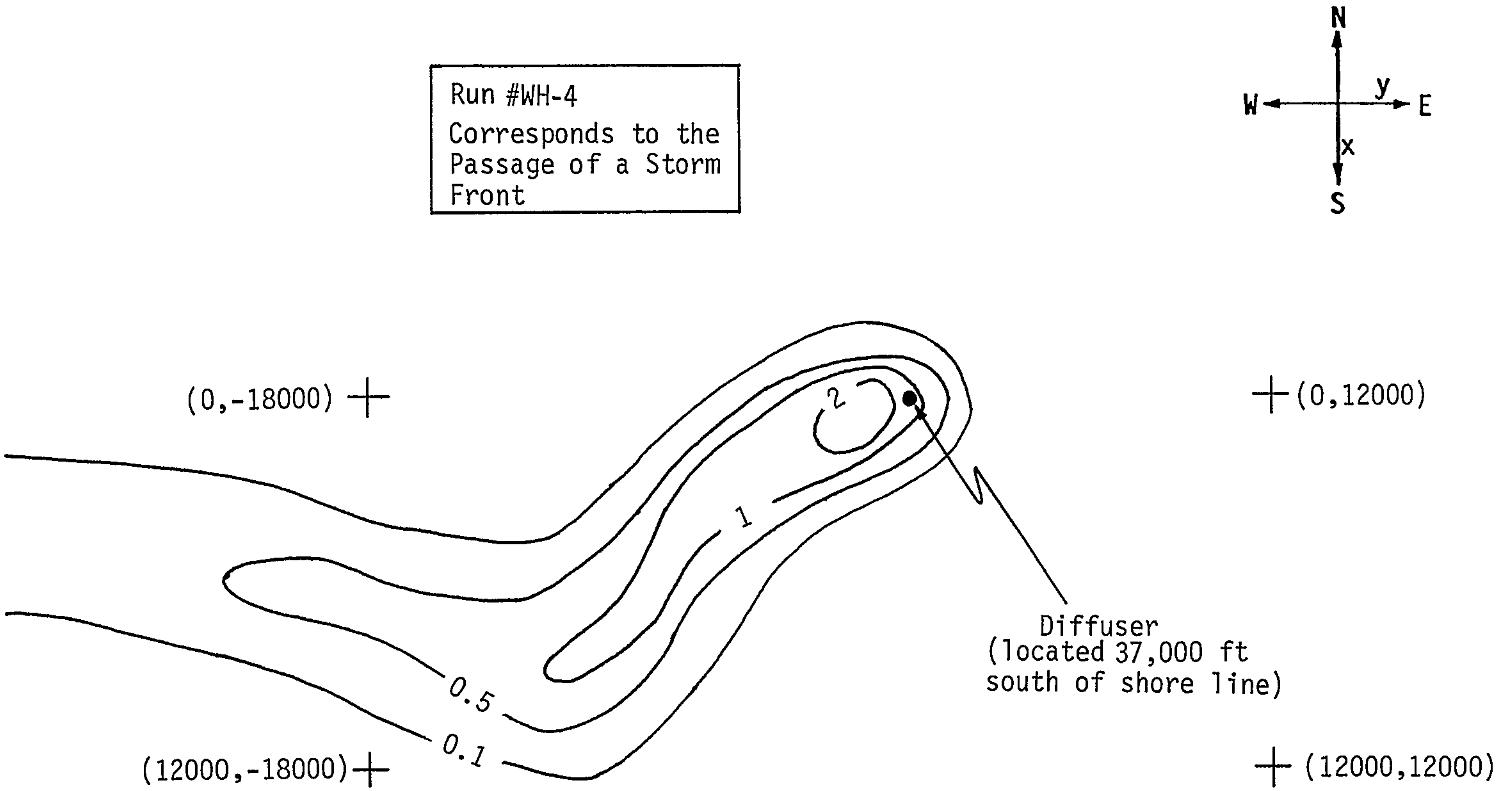


Figure 2.3-22 Contours of Excess Salinity Concentrations (ppt) for Run #WH-4 at Time = 0 Hours on the Bottom (0000, 1/25/78)

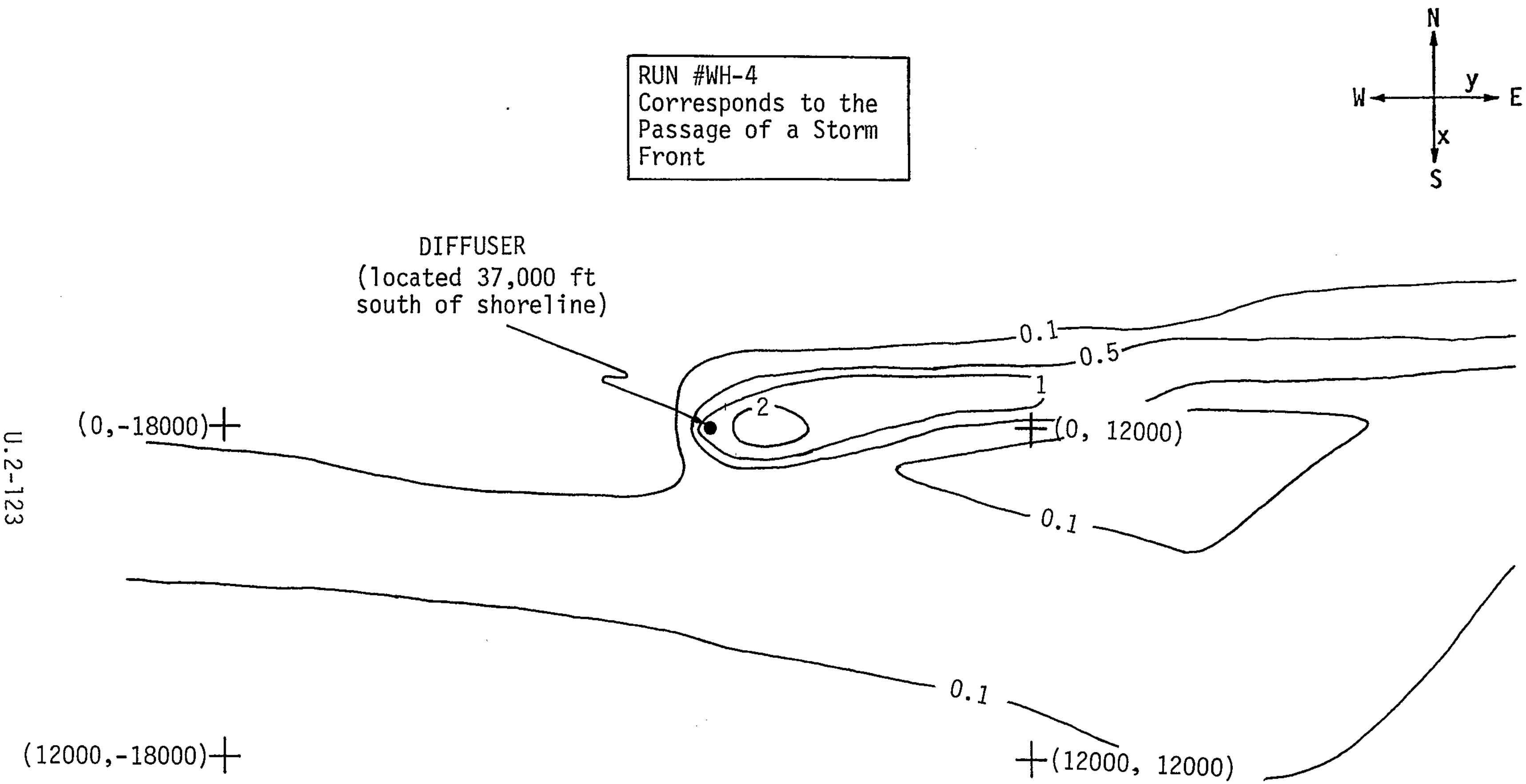


Figure 2.3-23 Contours of Excess Salinity Concentrations (ppt) for Run #WH-4 at Time = 24 Hours on the Bottom (0000, 1/26/78)

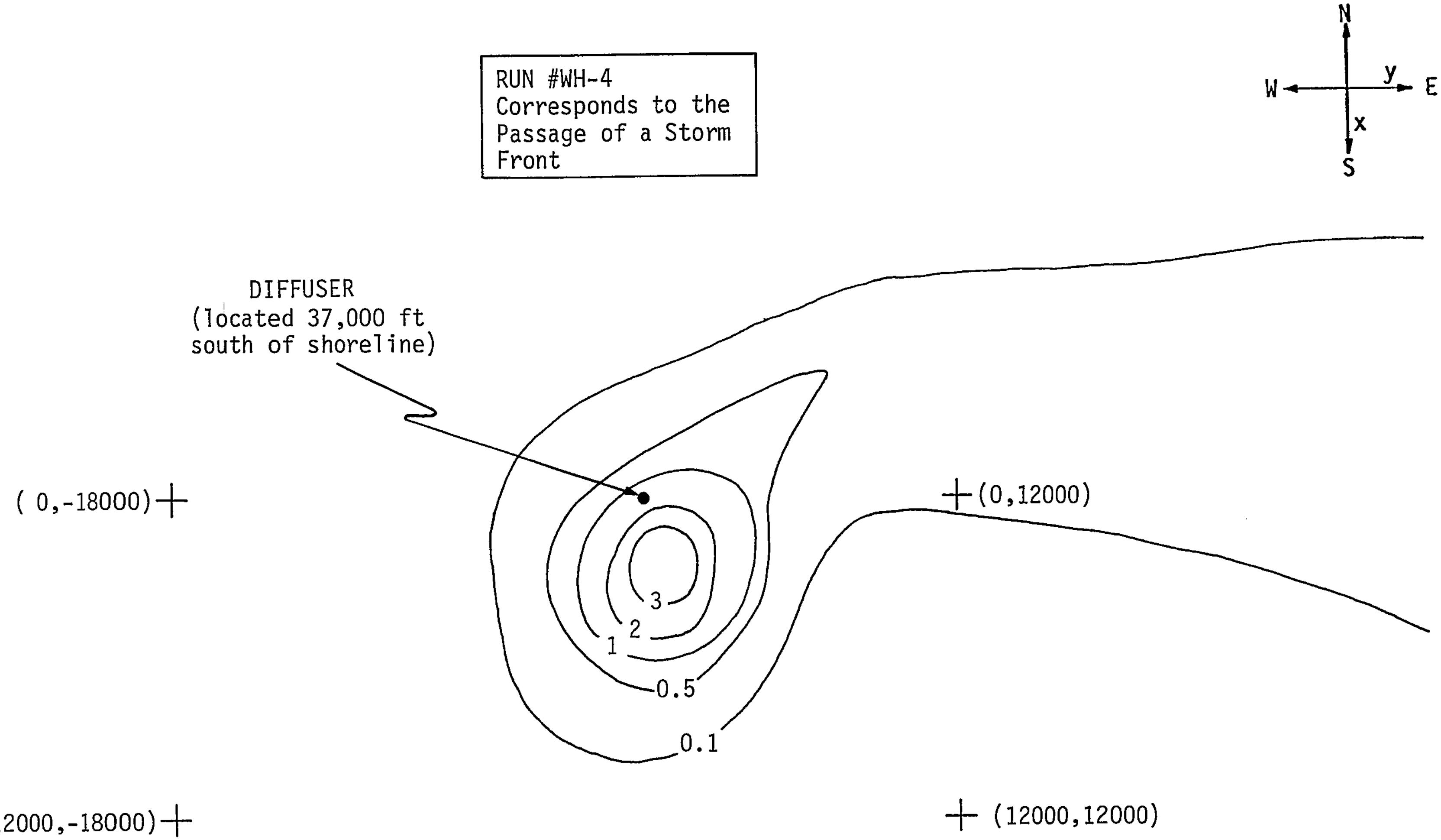


Figure 2.3-24. Contours of Excess Salinity Concentrations (ppt) for Run #WH-4 at Time = 48 Hours on the Bottom (0000, 1/27/78)

At the commencement the plume (Figure 2.3-22) is oriented to the west-southwest in the presence of a current setting to the southwest. Twenty-four hours later, due to the passage of the storm the currents have shifted to east-northeast. The salinity contours surrounding the diffuser generally follow this direction (Figure 2.3-23) but some remnants of the earlier pattern extend out to the west. After twenty-four more hours have elapsed, the currents have shifted to the southeast and the plume appears to be shifting to align itself in that direction. The 0.5 ppt contour however displays a "horn" pointing to the northeast, reflecting the earlier current in that direction.

The results of Runs #WH-3 and #WH-4 indicate that under both typical current conditions and storm conditions the plume is generally oriented parallel to the coastline. Such an orientation is consistent with the general observation that the longshore current component is larger than the offshore/onshore component.

With regard to the area enclosed by the various salinity contours, Figures 2.3-25a and 2.3-25b provide comparisons between the Base Case and Runs #WH-3 and #WH-4. Examination of Figure 2.3-25a indicates that the currents measured with the West Hackberry Replacement current meter, under typical current conditions (Run #WH-3), produced plumes which, for a given level of excess salinity, cover areas larger than but of the same magnitude as covered in the Base Case. Likewise, as shown in Figure 2.3-25b, the currents measured with the West Hackberry Replacement current meter, under conditions corresponding to the passage of a storm front (Run #WH-4), produced plumes covering slightly larger areas than those for the Base Case, but smaller than those for Run #WH-3.

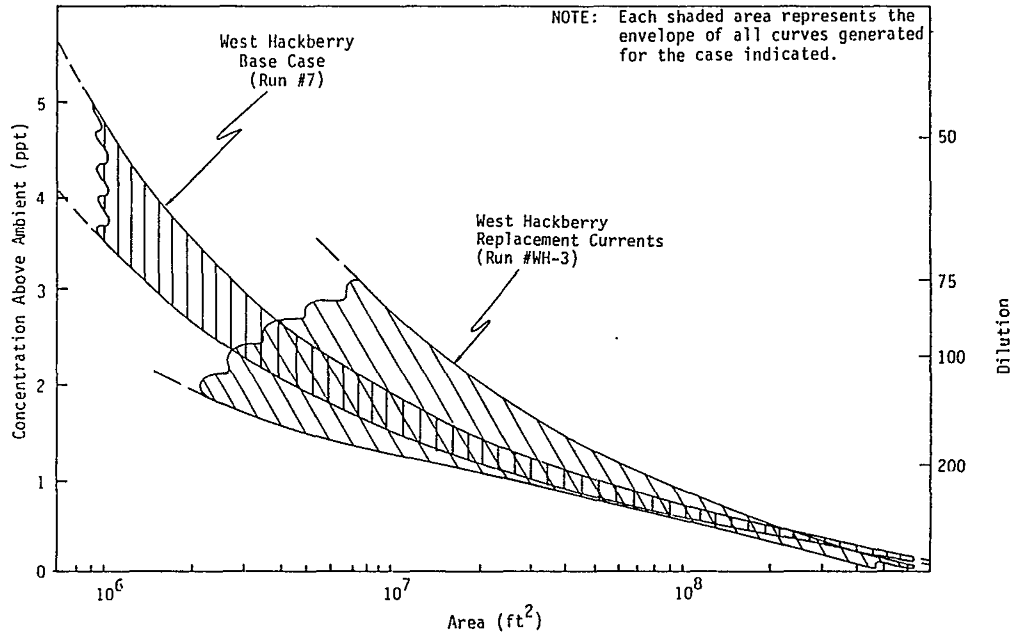


Figure 2.3-25a Excess Salinity versus Exposed Bottom Area for Run #WH-3

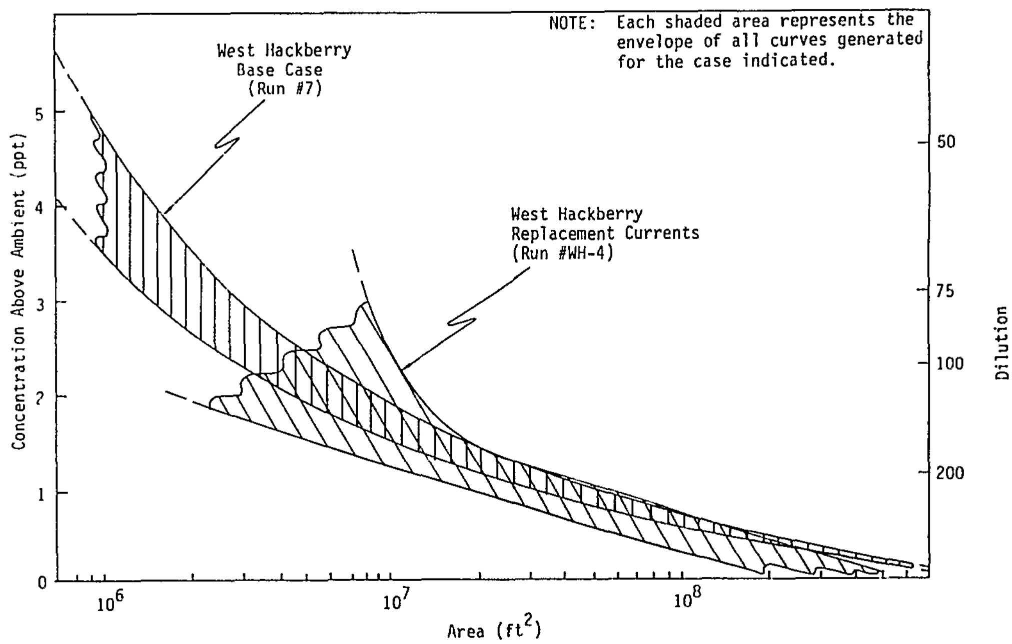


Figure 2.3-25b Excess Salinity versus Exposed Bottom Area for Run #WH-4

2.3.1.5 Conclusions

The results presented for Runs #WH-1 through #WH-4 are based on actual measured currents in the vicinity of the site for the West Hackberry brine diffuser. The measured currents for Runs #WH-1 and #WH-2 were somewhat smaller than those for Runs #WH-3 and #WH-4 but in general the measured currents for the four runs were of the same order of magnitude as the earlier estimates of the currents. The locations of the current meters corresponding to the first two runs were further removed from the diffuser site than was the location of the current meter used in the last two runs. The total time intervals for the current data, upon which the first two runs were based, were also relatively short (approximately 13 days) compared to the time interval upon which the last two runs were based (approximately 62 days).

The plumes produced in Runs #WH-1 and #WH-2 were generally oriented along the onshore-offshore axis while those produced in Runs #WH-3 and #WH-4 tended to be oriented along the longshore axis. In both types of orientation reversal in the plume direction was observed. For predicted salinities of less than 1 ppt the bottom areas covered by the #WH-1 and #WH-2 plumes were less than the corresponding areas for the earlier Base Case based on estimated currents. For predicted salinities greater than 1 ppt the bottom areas of the #WH-1 and #WH-2 plumes generally equalled or exceeded the corresponding areas of the Base Case. For all salinities predicted in the far field for the #WH-3 and #WH-4 plumes the bottom areas covered were larger than but of the same order of magnitude as the corresponding areas for the Base Case.

In general the plumes of Runs #WH-3 and #WH-4 appear most representative of the West Hackberry diffuser site. Such plumes tend to be oriented along the longshore axis, most likely drifting to the west. For excess salinities greater than 1 ppt the exposed bottom area amounts to less than 8.1×10^7 ft^2 or 1860 acres. The exposed bottom area for excess salinities above 3 ppt amounts to about 9.0×10^6 ft^2 or 207 acres.

2.3.2 Black Bayou Far-Field Modeling Section

2.3.2.1 Introduction

As described in Section C.4.1.2.1, in the case of the brine disposal problem at the Black Bayou site, the changes in salinity were assumed to be approximately equal to those which would occur at the West Hackberry site. More recently, due to the availability of current meter data taken in the vicinity of the Black Bayou disposal site, a separate analysis using the MIT Transient Plume Model has been performed by NOAA. Three test cases were carried out as follows:

Run #	Current Meter	Time Period Covered	Condition
BB-1	Black Bayou	0600, 11/5/77 to 0000, 11/8/77	Stagnation
BB-2	Black Bayou	0000, 11/18/77 to 0000, 11/22/77	Typical current
BB-3	Black Bayou	0600, 1/24/78 to 0000, 1/26/78	Storm passage

A time series consisting of approximately 103 days of current meter data was available for Runs #BB-1, #BB-2 and #BB-3. The time period covered by Run #BB-1 commenced the 16th day of the series and corresponds to a stagnation condition. For Run #BB-2 the time period commenced on the 29th day and represents a typical current condition. Run #BB-3 commenced on the 96th day and corresponds to the passage of a storm front. The subsections which follow provide a detailed description of the inputs used and the results obtained for the three test cases.

2.3.2.2 Inputs to MIT Transient Plume Model

A complete description of input variables for the original West Hackberry test cases is provided in Appendix D.25. For the three test cases at Black Bayou all inputs were the same as those used for West Hackberry Base Case (Run #7) except for the currents.

Maximum measured currents in the longshore direction indicated a magnitude of about 36 cm sec^{-1} while maximum measured currents in the offshore direction were approximately 21 cm sec^{-1}. Such values are of the same order of magnitude as the values used for the original test cases at West Hackberry. The time series representing the U and V input currents are shown in Figures 2.3-26 and 2.3-27 for Run #BB-1, in Figures 2.3-28 and 2.3-29 for Run #BB-2, and in Figures 2.3-30 and 2.3-31 for Run #BB-3.

2.3.2.3 Results of Runs #BB-1, #BB-2 and #BB-3

The time series shown in Figures 2.3-26 through 2.3-31 represent portions of a single 103-day series measured by the Black Bayou current meter from 10/20/77 to 2/1/78. The entire series, along with the other parameters previously noted, was used as input to the MIT Transient Plume Model. The first 12 days of the series were used to allow the model to reach quasi-equilibrium. Run #BB-1, representing a stagnation condition, commenced at 0600 on the 16th day and extended for 66 hours with outputs

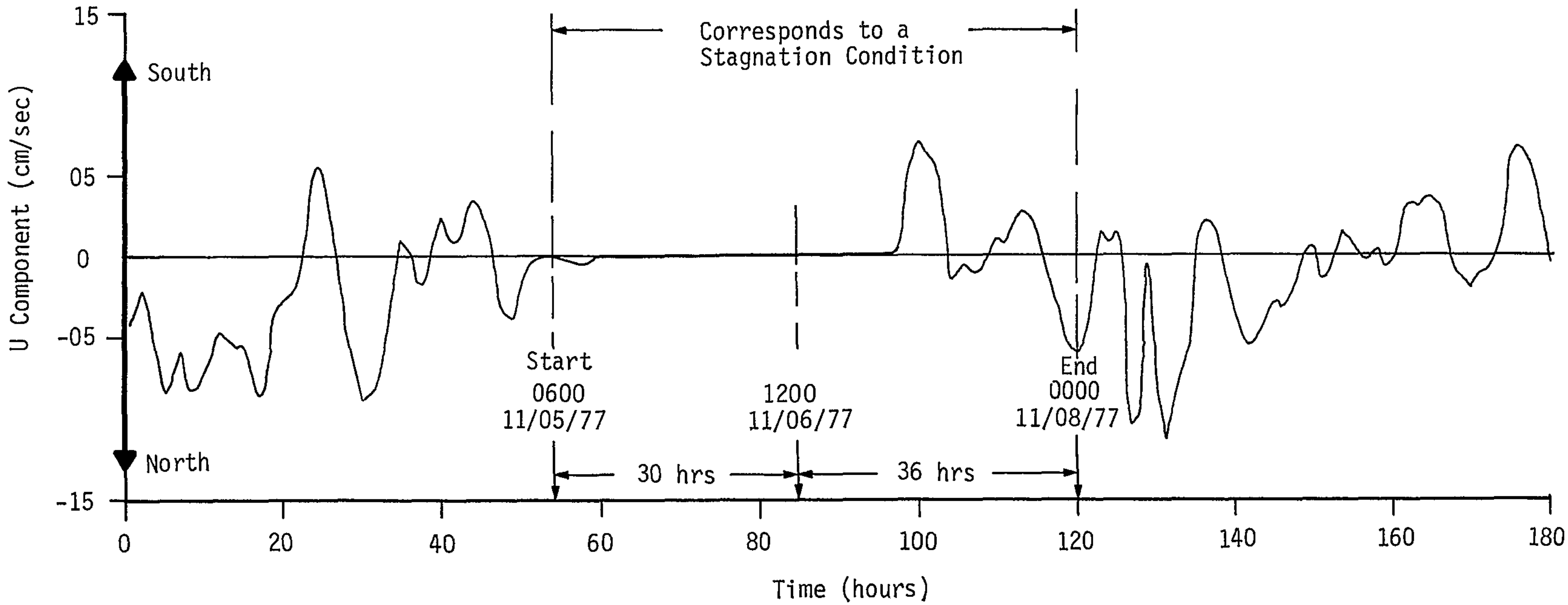


Figure 2.3-26 Time Series of Observed Offshore Current Component, U, from Black Bayou Current Meter for Run #BB-1

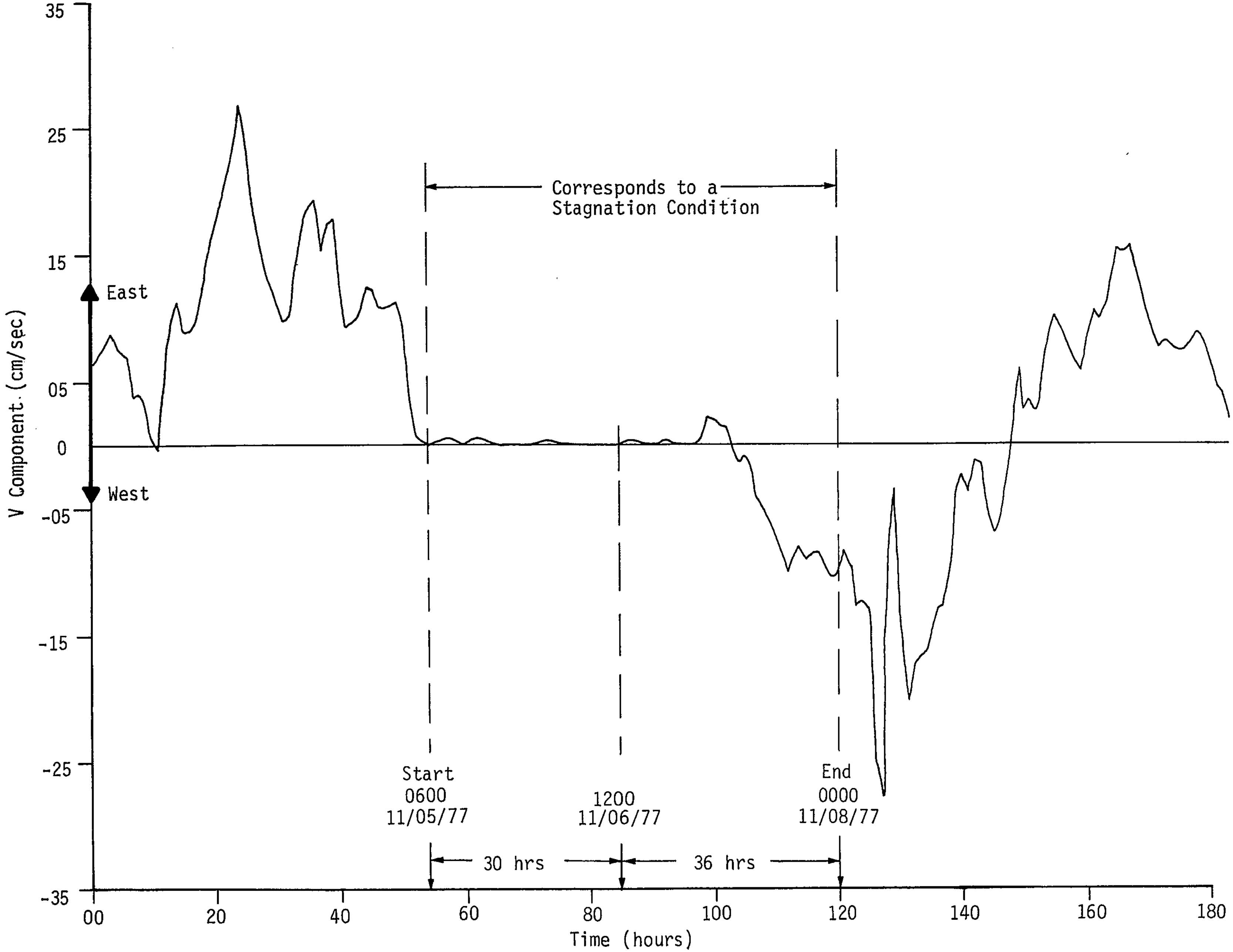


Figure 2.3-27 Time Series of Observed Longshore Current Component, V, from Black Bayou Current Meter for Run #BB-1

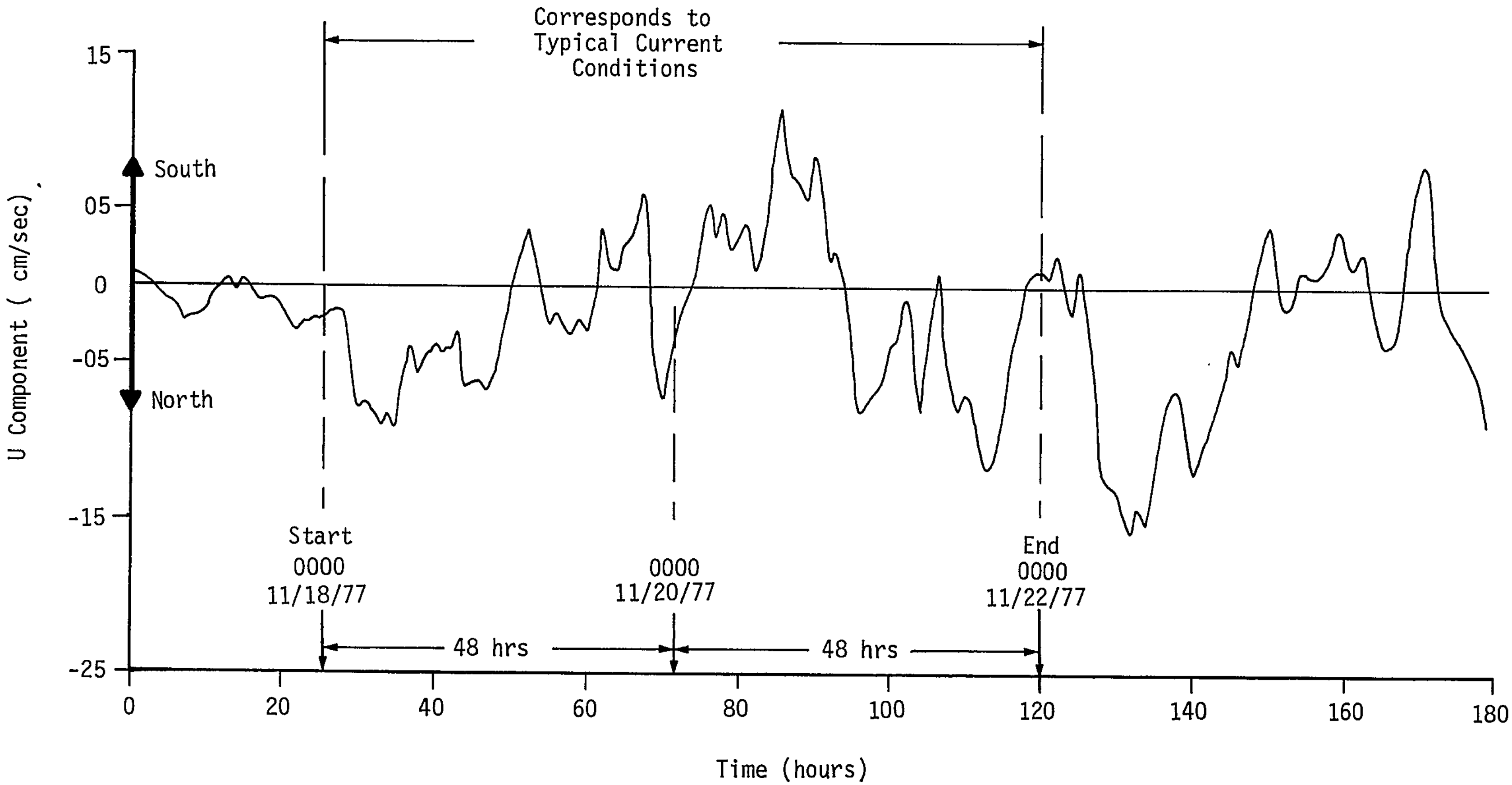


Figure 2.3-28 Time Series of Observed Offshore Current Component, U, from Black Bayou Current Meter for Run #BB-2

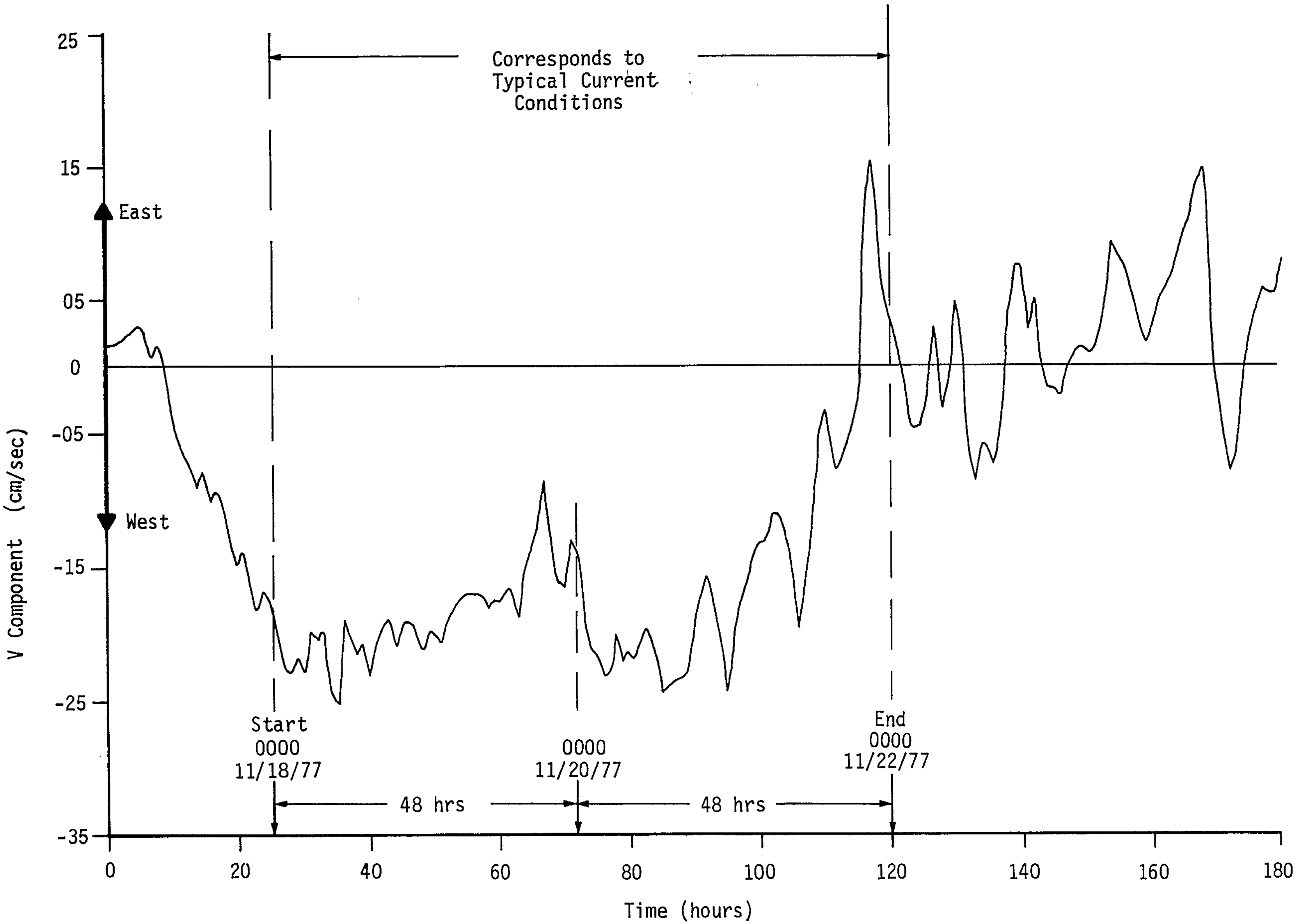


Figure 2.3-29 Time Series of Observed Longshore Current Component, V, from Black Bayou Current Meter for Run #BB-2

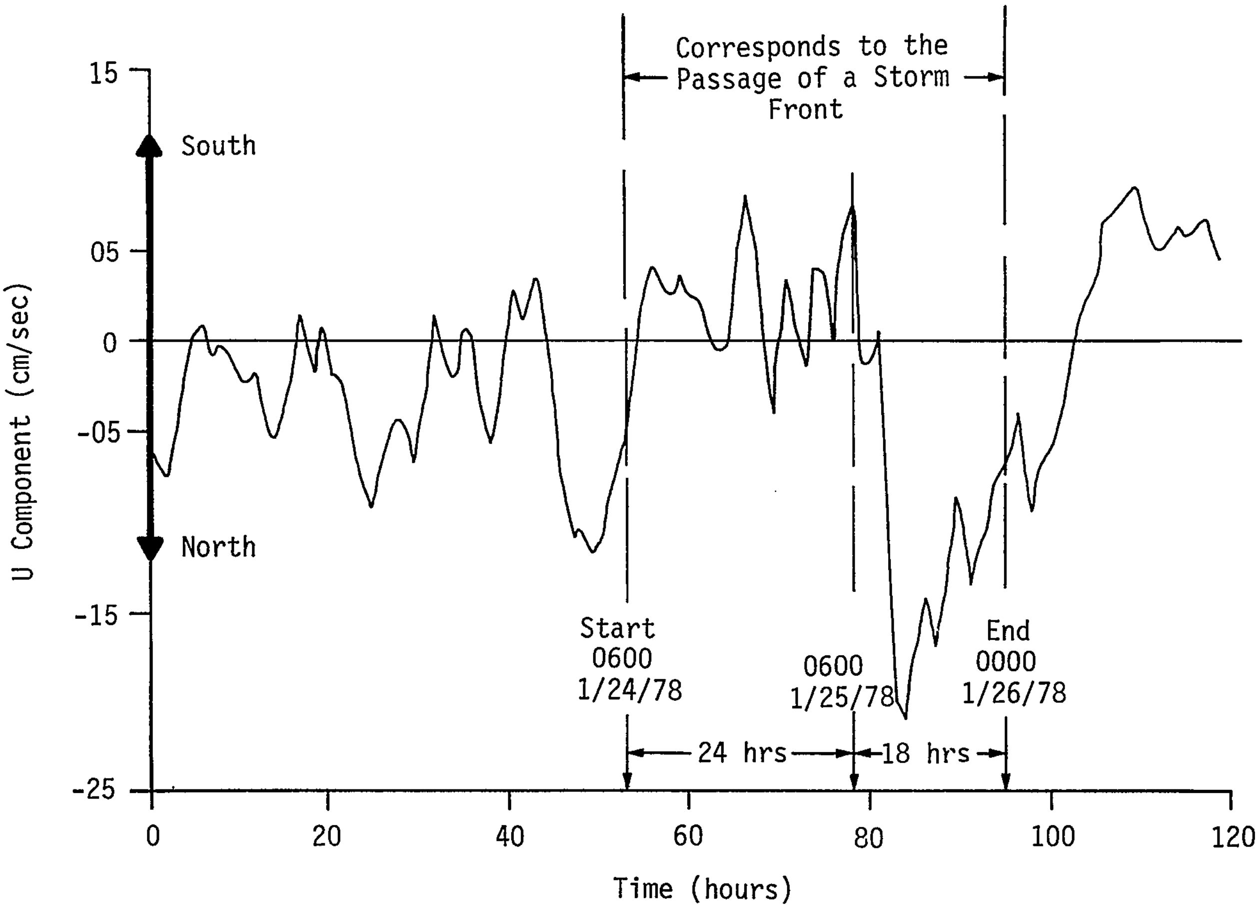


Figure 2.3-30 Time Series of Observed Offshore Current Component, U., from Black Bayou Current Meter for Run #BB-3

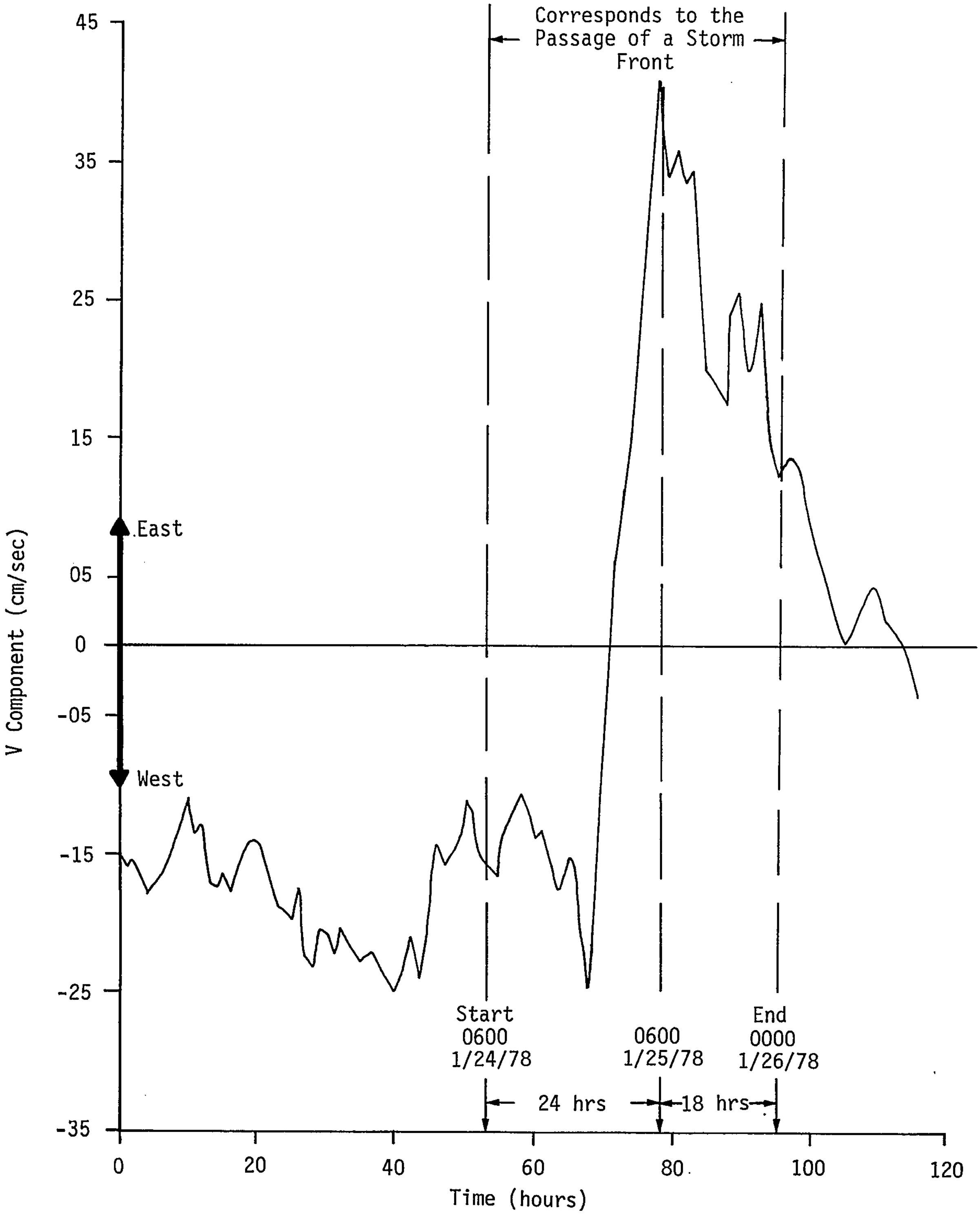


Figure 2.3-31 Time Series of Observed Longshore Current Component, V, from Black Bayou Current Meter for Run #BB-3

occurring at 0, 30, and 66 hours after commencement. Run #BB-2, representing a typical current condition, commenced at 0000 on the 29th day and continued for 96 hours with outputs at 0, 48, and 96 hours after commencement. Run #BB-3, representing the passage of a storm front, commenced at 0600 on the 96th day and covered 42 hours with outputs at 0, 24, and 42 hours following commencement.

The excess salinity contour plots resulting from stagnation conditions (Run #BB-1) are presented in Figures 2.3-32 through 2.3-34. At the commencement of the run (0 hours) as shown in Figure 2.3-32, the plume is relatively narrow and displays an eastward drift. This eastward direction reflects the eastward setting current which was present prior to stagnation. Thirty hours later, with essentially no current present the eastward orientation of the plume remains, as shown in Figure 2.3-33, but the plume is considerably broader, especially in the vicinity of the diffuser. After 66 hours the plume remains relatively broad but is oriented to the southeast as shown in Figure 2.3-34. At this time the current has recently shifted to the northwest but sufficient time has not elapsed for the plume to adjust.

For Run #BB-2, corresponding to typical current conditions, the excess salinity contours are provided in Figures 2.3-35 through 2.3-37. As shown in Figure 2.3-35, at the commencement of the run the plume covers a relatively large area and displays a general westward drift in response to the westward-setting current. After 48 hours, in response to a persistent westward-setting current with a small northward component, the plume is much narrower with west-northwest drift, as shown in Figure 2.3-36. The plume pattern after 96 hours (Figure 2.3-37) is also relatively

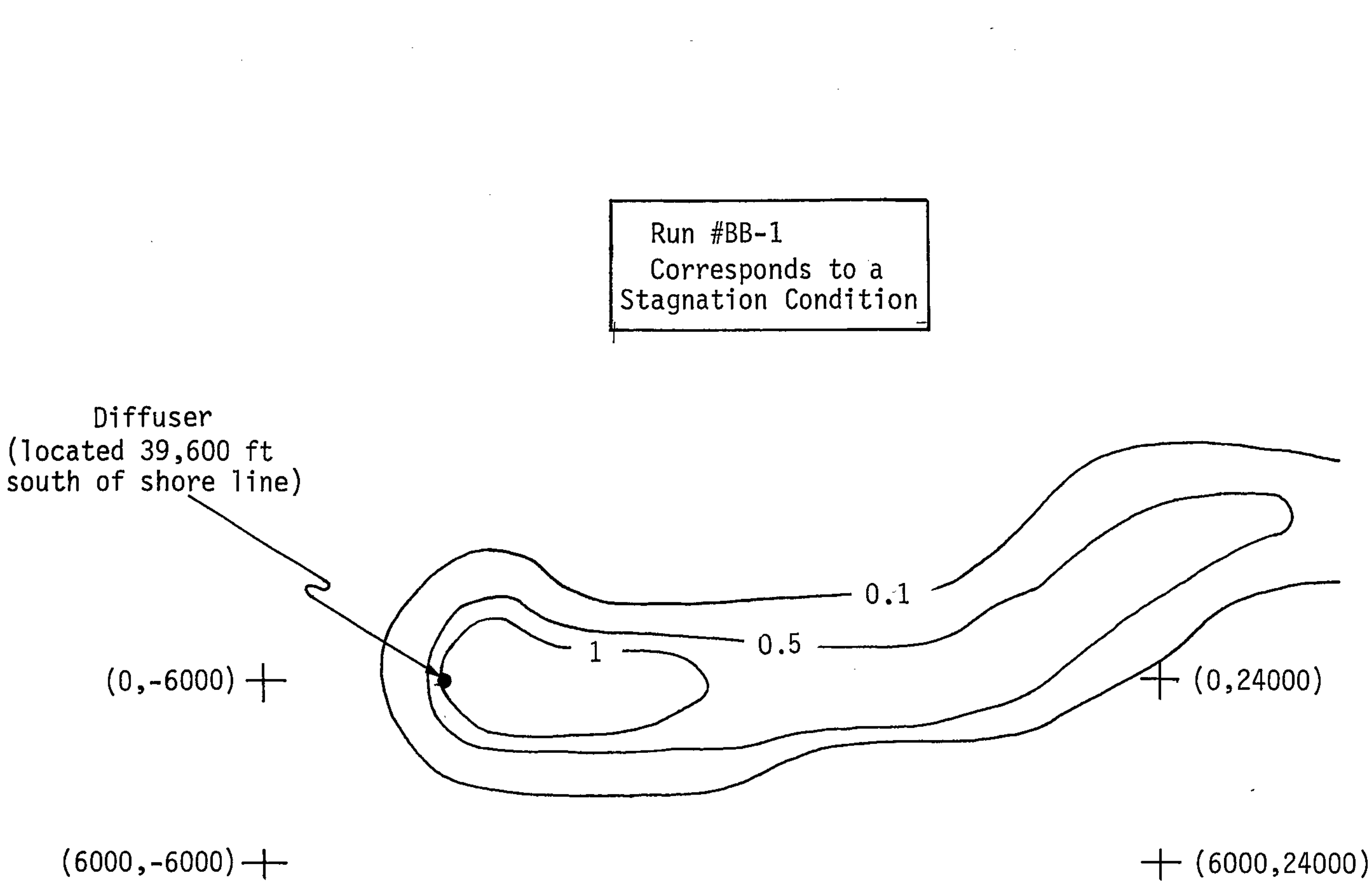


Figure 2.3-32 Contours of Excess Salinity Concentrations(ppt) for Run #BB-1 at Time = 0 Hours on the Bottom (0600, 11/05/77)

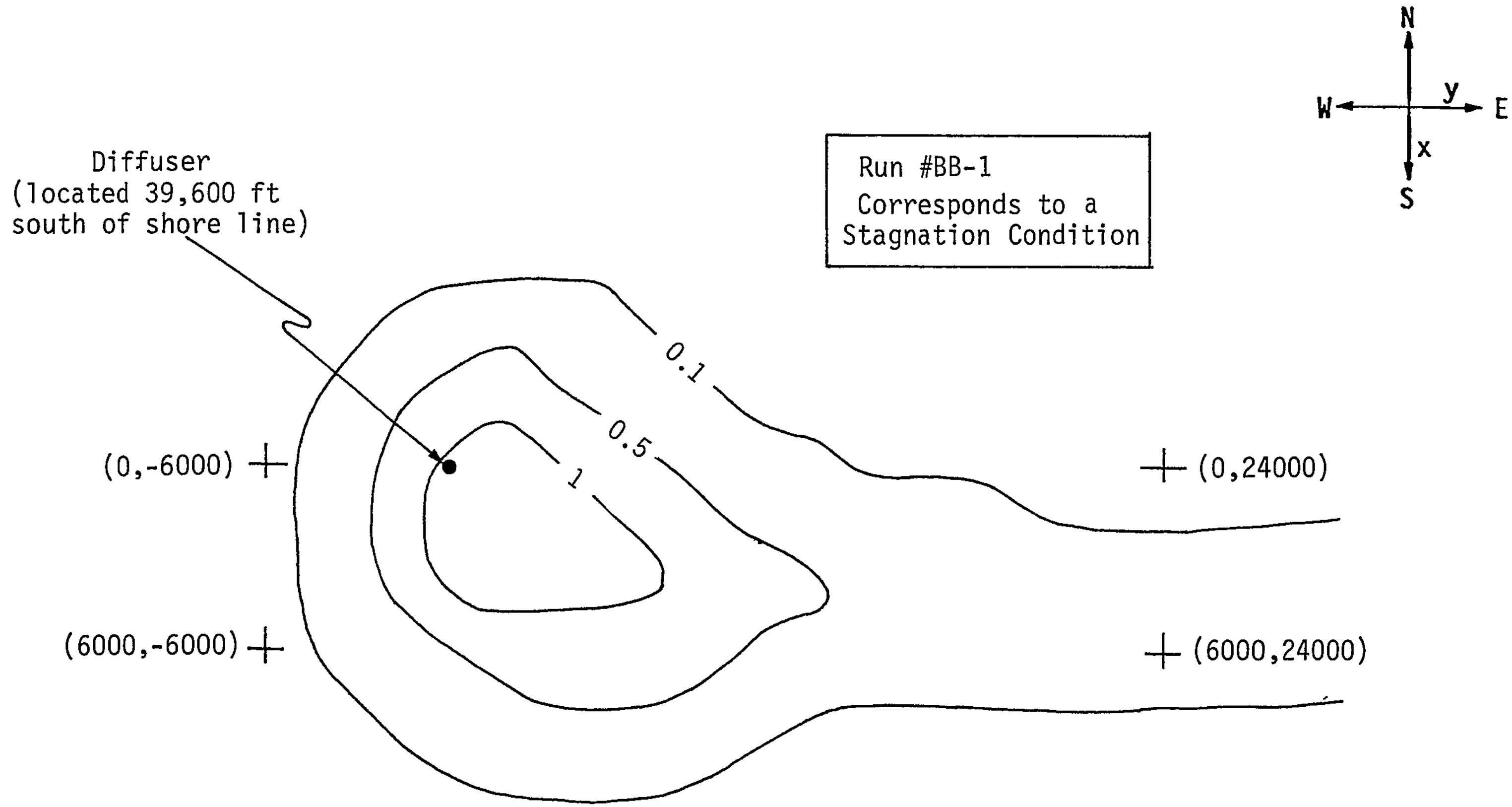


Figure 2.3-33 Contours of Excess Salinity Concentrations (ppt) for Run #BB-1 at Time = 30 Hours on the Bottom (1200, 11/06/77)

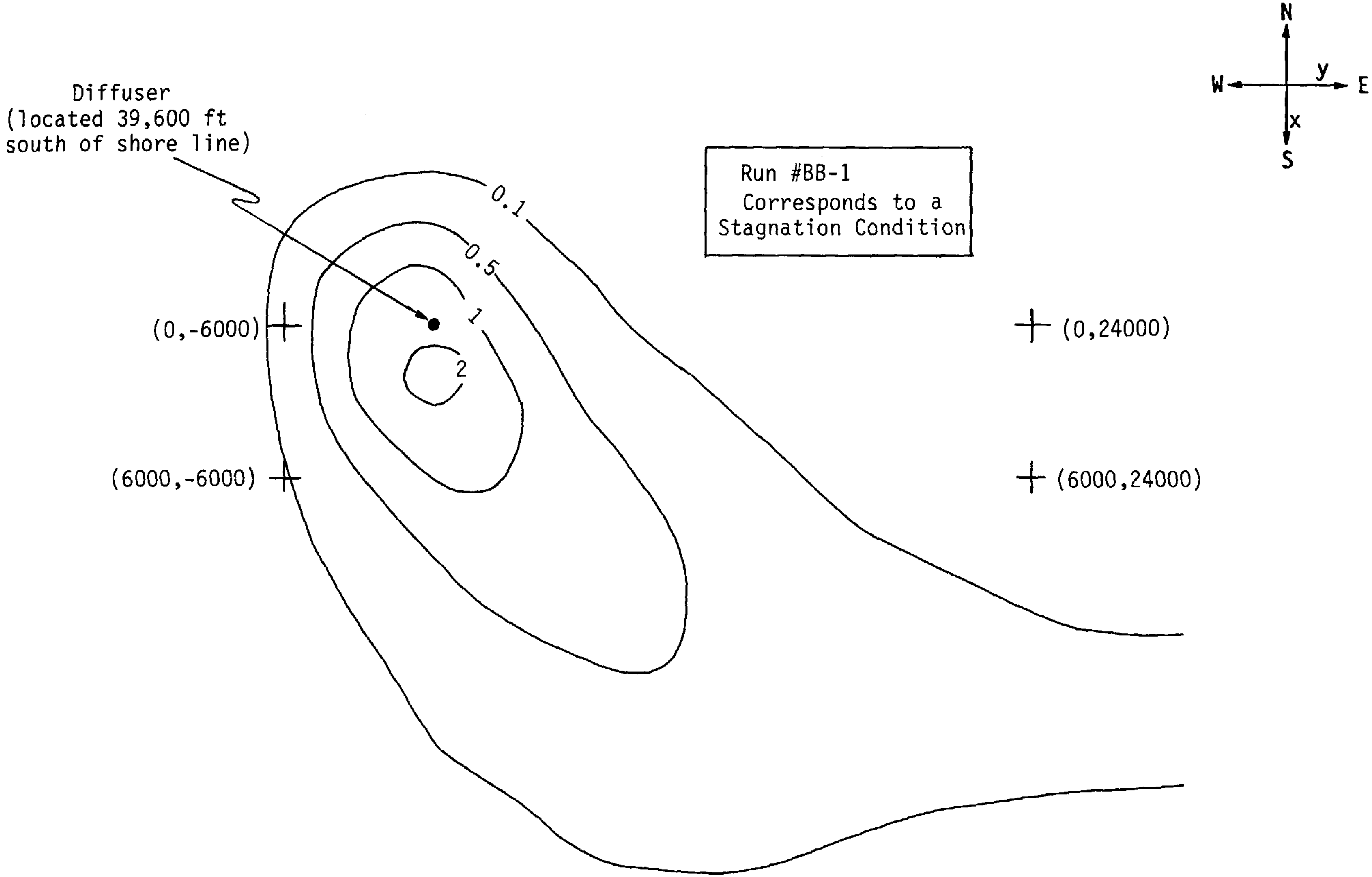


Figure 2.3-34 Contours of Excess Salinity Concentrations (ppt) for Run #BB-1 at Time = 66 Hours on the Bottom (0000, 11/08/77)

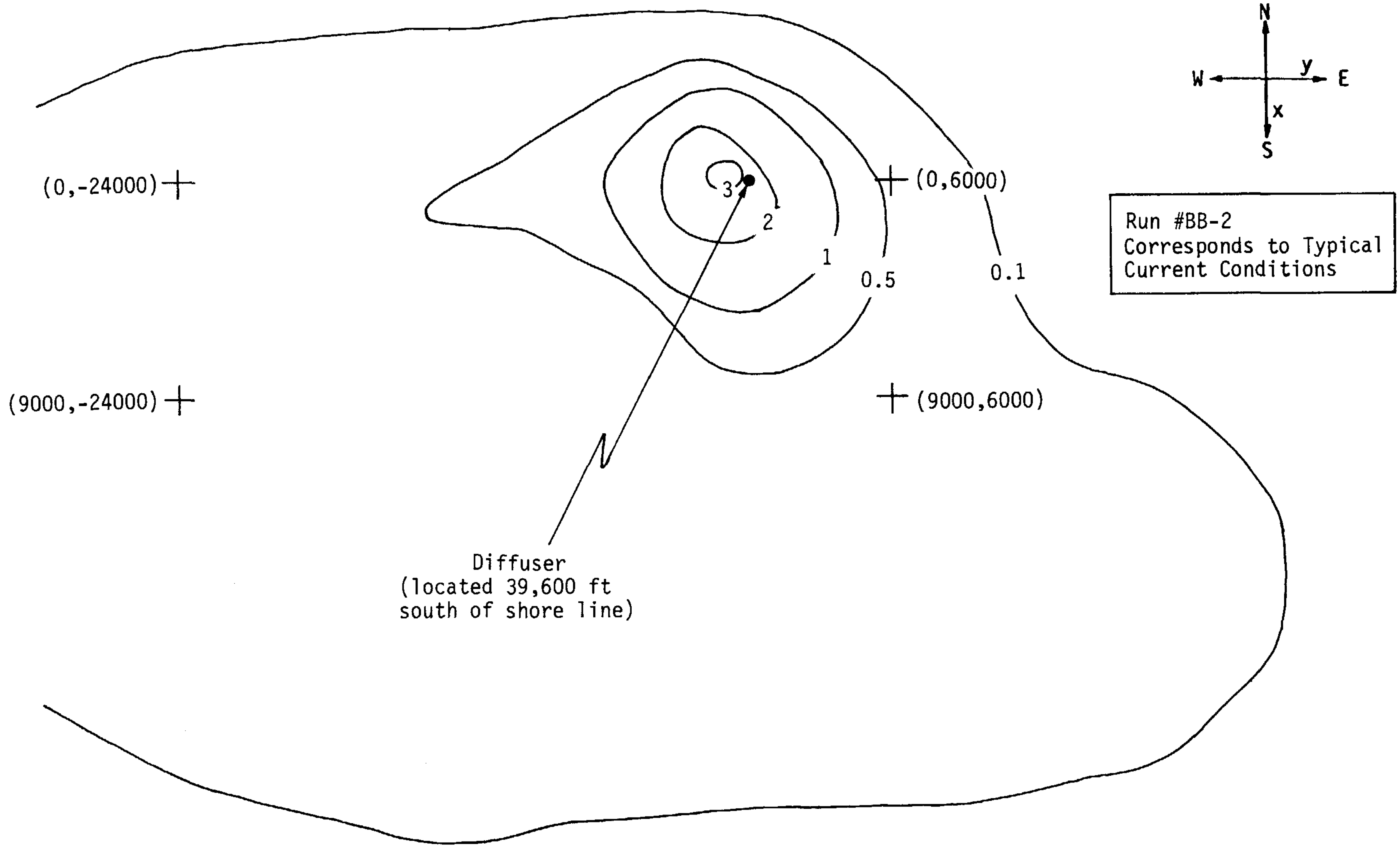


Figure 2.3-35 Contours of Excess Salinity Concentrations (ppt) for Run #BB-2 at Time = 0 Hours on the Bottom (0000, 11/18/77)

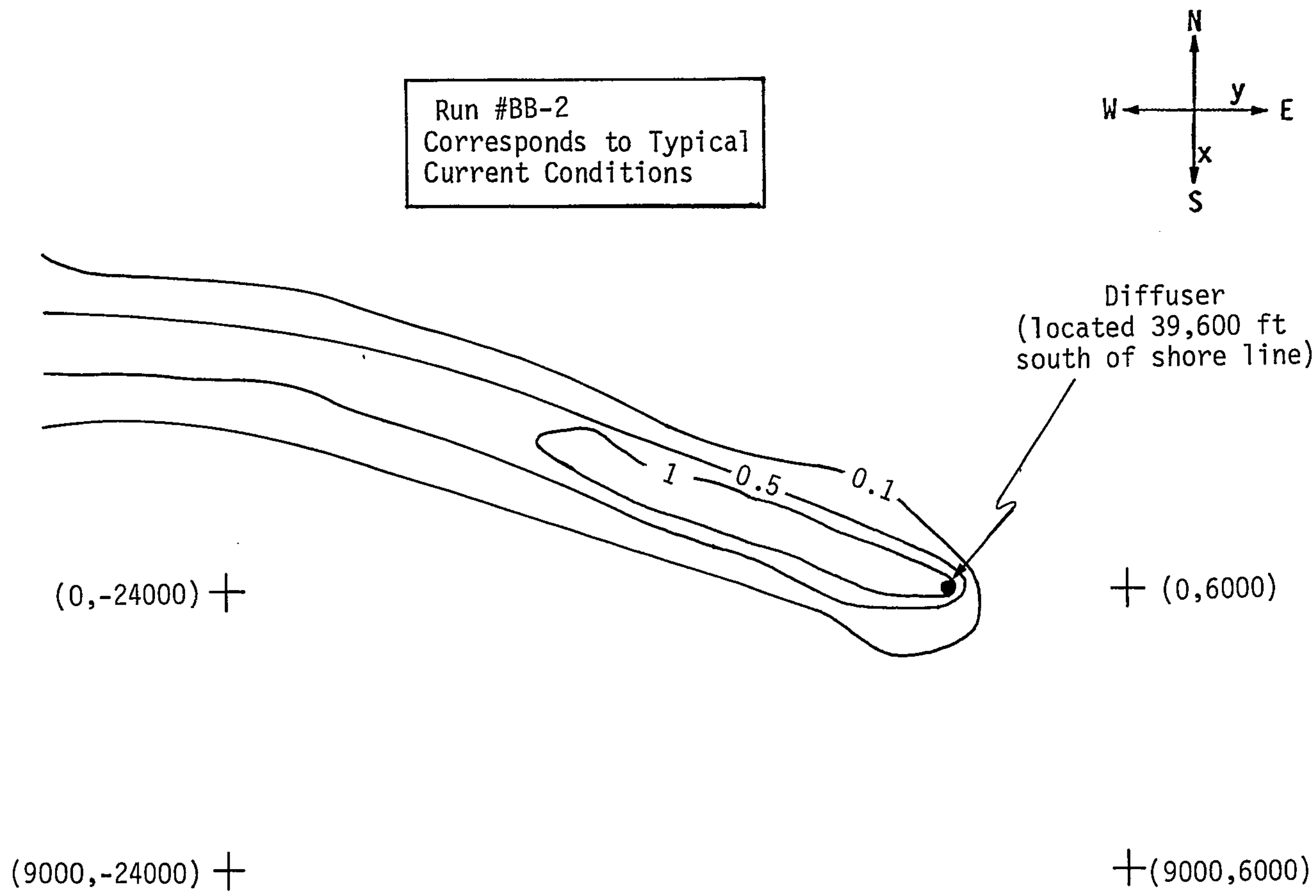


Figure 2.3-36 Contours of Excess Salinity Concentrations (ppt) for Run #BB-2 at Time = 48 Hours on the Bottom (0000, 11/20/77)

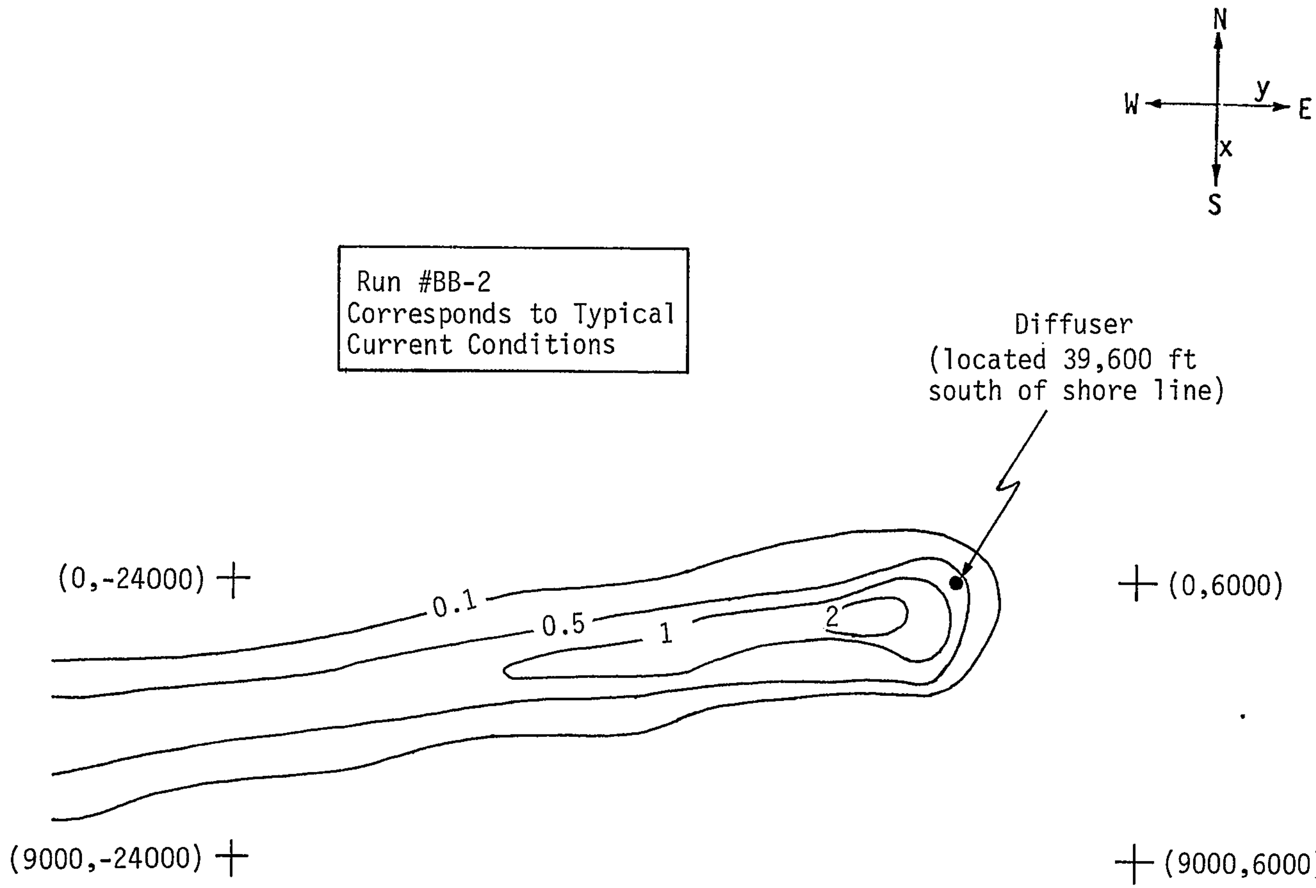


Figure 2.3-37 Contours of Excess Salinity Concentrations (ppt) for Run #BB-2 at Time = 96 Hours on the Bottom (0000, 11/22/77)

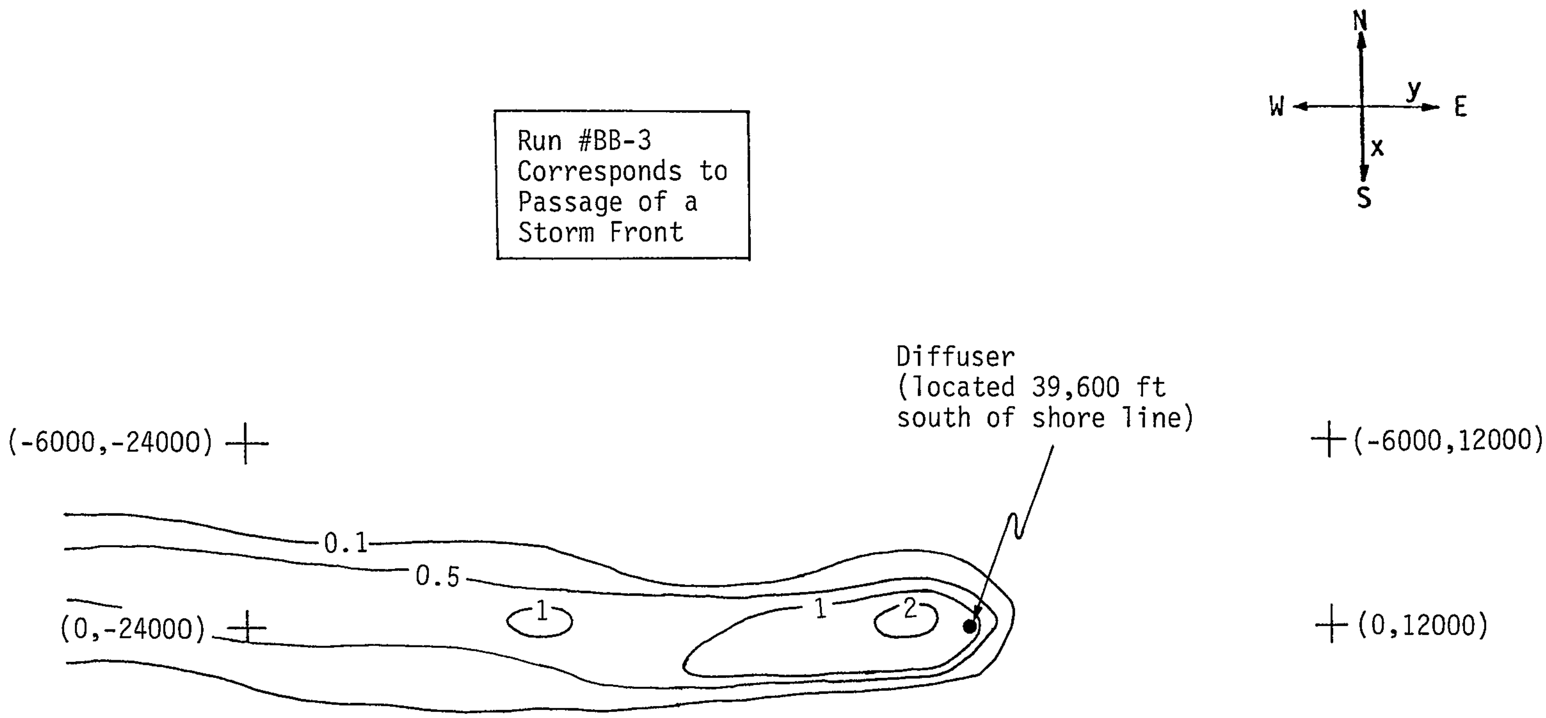


Figure 2.3-38 Contours of Excess Salinity Concentrations (ppt) for Run #BB-3 at Time = 0 Hours on the Bottom (0600, 1/24/78)

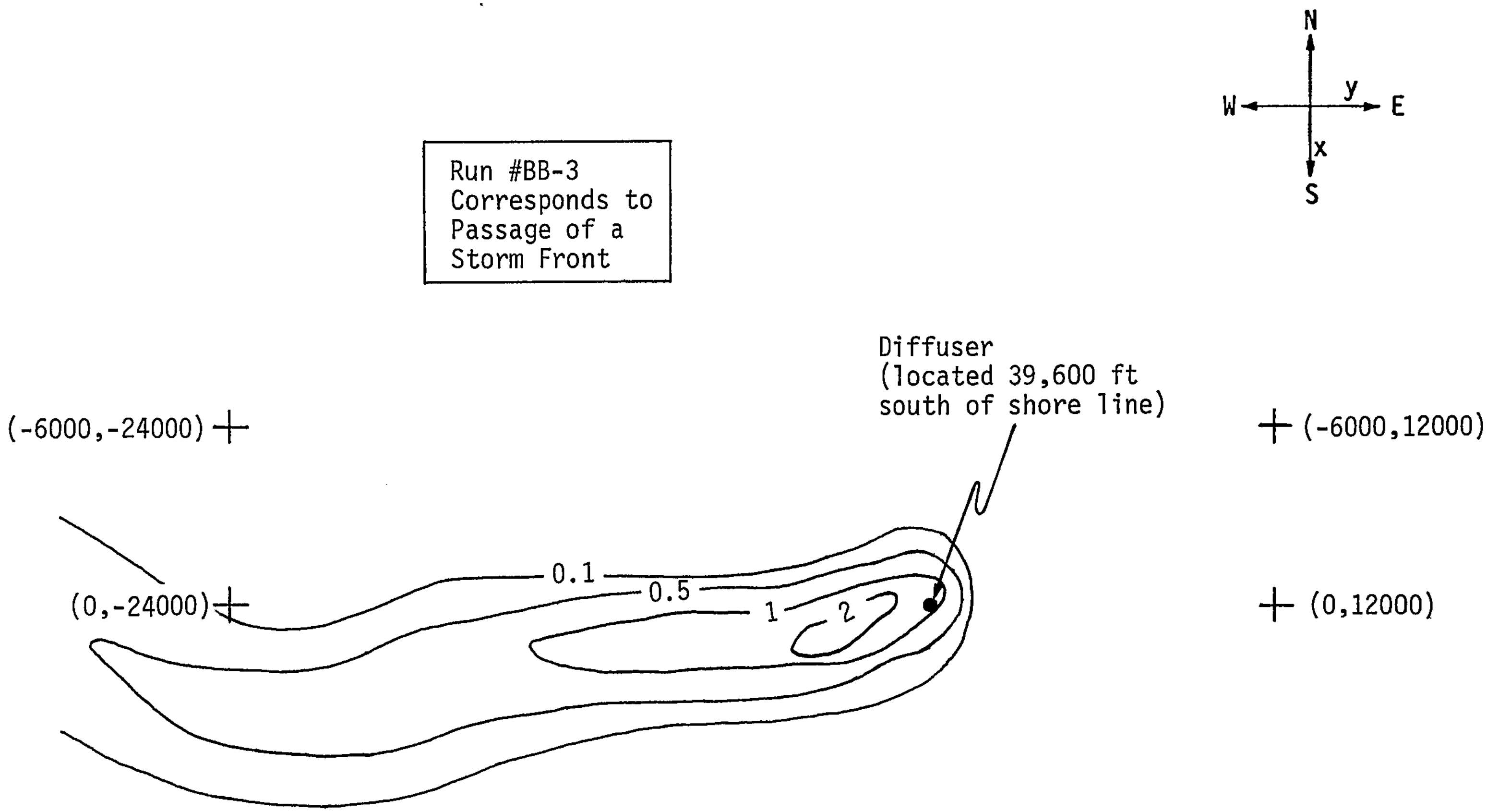


Figure 2.3-39 Contours of Excess Salinity Concentrations (ppt) for Run #BB-3 at Time = 24 Hours on the Bottom (0600, 1/25/78)

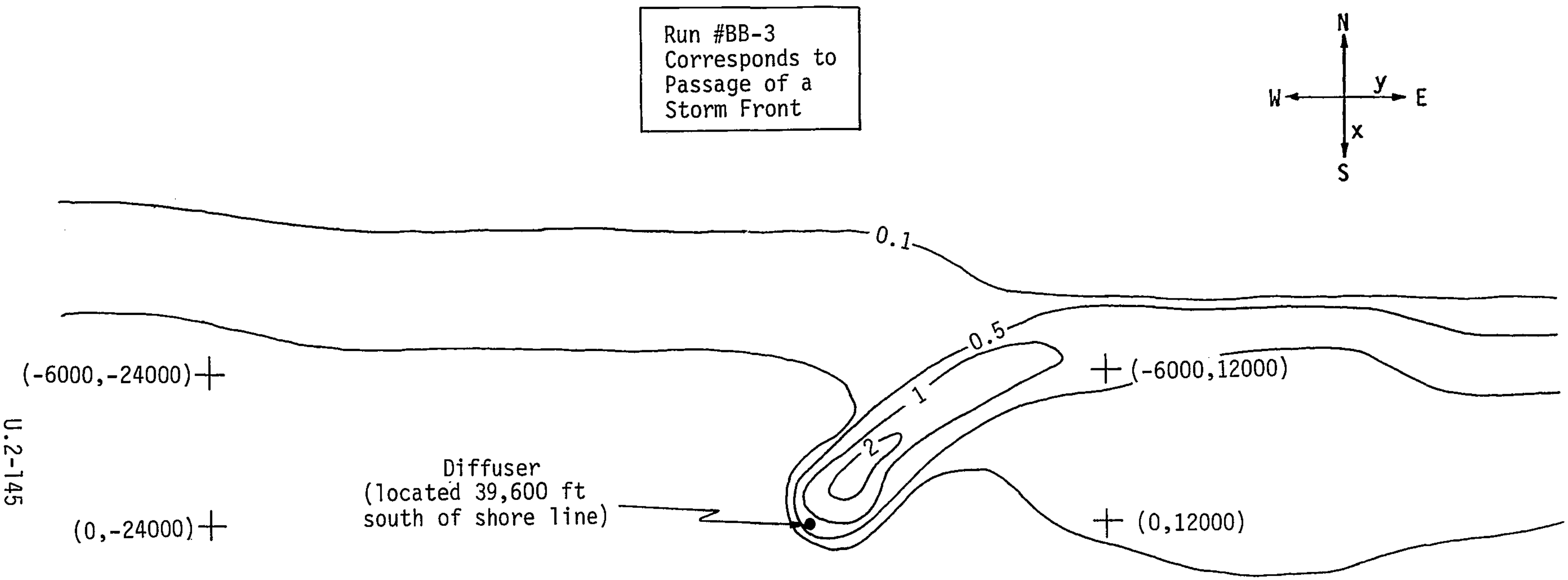


Figure 2.3-40 Contours of Excess Salinity Concentrations (ppt) for Run #BB-3 at Time = 42 Hours on the Bottom (0000, 1/26/78)

narrow, and appears to be rotating counter-clockwise in response to a current which has recently shifted from the northwest to the southeast.

For Run #BB-3, representing the passage of a storm front, the excess salinity contour plots are provided in Figures 2.3-38 through 2.3-40. At the beginning of the run (Figure 2.3-38) the plume pattern is relatively narrow with a westward drift, reflecting the westward-setting current. Twenty-four hours later the current has shifted to the southeast due to the passage of the storm front. In response to this current shift the plume, as shown in Figure 2.3-39, has broadened slightly and appears to be rotating counter-clockwise to align itself with the new current direction. After 42 hours (Figure 2.3-40) the 0.5, 1, and 2 ppt salinity contours are oriented toward the northeast, aligned with the prevailing current direction. The 0.1 ppt contour displays an east-west orientation, resulting from remnants of the westward drifting plume prior to the current reversal.

In terms of the amount of bottom area exposed to various levels of excess salinity, Figures 2.3-41a through 2.3-41c provide a comparison between the original Base Case at West Hackberry, based on estimated currents, and the results of #BB-1, #BB-2 and #BB-3, based on measured currents. Examination of these figures shows that for observed current conditions ranging from stagnation to storm-induced maximum, the predicted bottom coverage for salinities greater than 1 ppt excess and greater than 3 ppt excess are similar to, but larger than, corresponding bottom coverage areas previously predicted using estimated currents (West Hackberry Base Case). For excess salinities greater than 1 ppt, in all three cases the maximum exposed bottom area amounted to less than 8.5×10^7 ft^2 or 1960 acres, and for excess salinities greater than 3 ppt, the

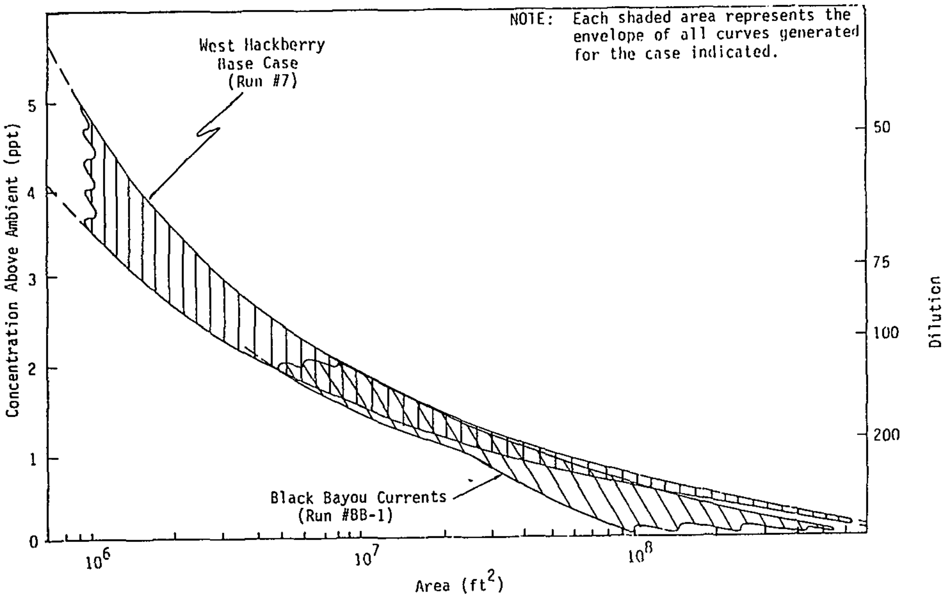


Figure 2.3-41a Excess Salinity versus Exposed Bottom Area for Run #BB-1

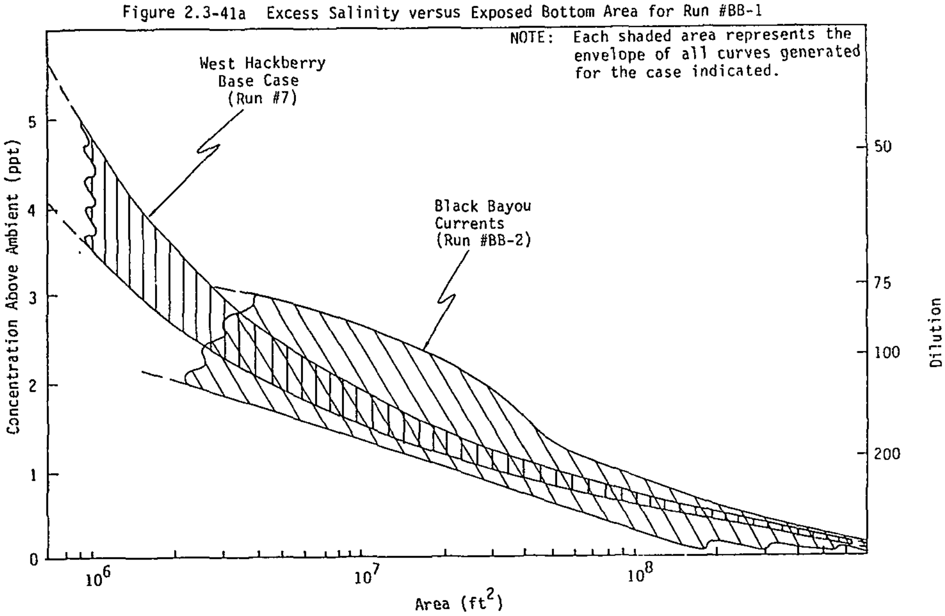


Figure 2.3-41b Excess Salinity versus Exposed Bottom Area for Run #BB-2

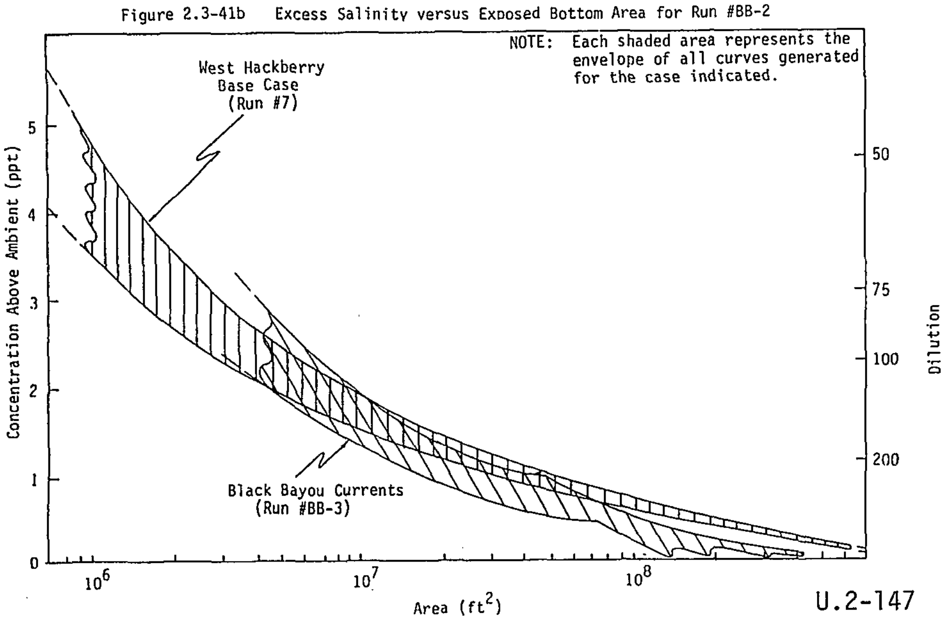


Figure 2.3-41c Excess Salinity versus Exposed Bottom Area for Run #BB-3

maximum exposed bottom area amounted to less than 4.5×10^6 ft^2 or 104 acres. For the West Hackberry Base Case, previously predicted bottom coverage ranged up to 1200 acres for excess salinities greater than 1 ppt and up to 70 acres for greater than 3 ppt. Among observed conditions at Black Bayou, the envelope of curves generated for stagnation and storm-induced currents generally fell within the envelope of curves generated for the typical event.

2.3.2.4 Conclusions

The results presented for Runs #BB-1, #BB-2 and #BB-3 are based on actual measured currents in the vicinity of the site for the Black Bayou brine diffuser. The total time interval for the current data, upon which the three runs are based, extended for 103 days.

The plumes produced in Runs #BB-1, #BB-2 and #BB-3 tended to be oriented along the longshore axis with both westward and eastward drifting plumes being observed. Reversal in the direction of the plume drift was observed under conditions corresponding to the passage of a storm front.

Comparing the Black Bayou runs (#'s BB-1, BB-2 and BB-3) with the West Hackberry base case (Run #7) some differences in areal extent of the plume were noted. Run #BB-1 (stagnation) most closely approximated the West Hackberry base case, with a smaller area coverage for the 1 ppt above ambient plume. A similar situation was seen for #BB-3 (storm passage) but here, the 3 ppt coverage was greater than for WH run #7. For #BB-2, (typical) both the 3 and 1 ppt above ambient contours encompassed larger areas than the West Hackberry base case. These Black Bayou plumes were similar to those predicted for West Hackberry for Runs #WH-3 and #WH-4 based on the measured currents. For excess salinities greater than 1 ppt the exposed bottom area amounted to less than 1960 acres. The bottom area exposed to excess salinities greater than 3 ppt amounted to less than 104 acres.

2.3.3 Big Hill Far-Field Modeling

2.3.3.1 Introduction

As described in Section C.6.1.2.1 in the case of the brine disposal at the Big Hill site, the changes in salinity were originally assumed to be similar to, but less than, those which would occur at the West Hackberry site. Subsequently a separate analysis utilizing the MIT Transient Plume Model was carried out by NOAA based on estimated values of currents and diffusion coefficients at Big Hill (NOAA, 1977). More recently due to the availability of current meter data taken in the vicinity of the Big Hill disposal site, additional analysis, using the MIT Model, has been performed by NOAA. Two test cases were carried out as follows:

Run #	Current Meter	Time Period Covered	Condition
BH-1	Big Hill Secondary	0000, 1/21/78 to 0600, 1/24/78	Typical current
BH-2	Big Hill Secondary	0000, 1/25/78 to 0600, 1/27/78	Storm passage

A time series consisting of approximately 63 days of current meter data was available for Runs BH-1 and BH-2. The time period covered by Run BH-1 commenced on the 52nd day of the series and corresponds to a typical current condition. For Run BH-2 the time period commenced on the 56th day and corresponds to the passage of a storm front. The subsections which follow provide a detailed description of the inputs and the results obtained for the two most recent test cases.

2.3.3.2 Inputs to MIT Transient Plume Model

A complete description of inputs for the original test cases for West Hackberry is provided in Appendix D.25. For the two runs at Big Hill, BH-1 and BH-2, all inputs were the same as those used for the West Hackberry Base Case (Run #7) except for the rate of discharge, the diffuser length and the currents. The rate of discharge for Big Hill was set at 43.7 cfs and the diffuser length was 3,420 feet.

Observed maximum longshore current components near the Big Hill site were about 40 cm/sec while maximum transshelf (or onshore-offshore) were about 16 cm/sec. These are of the same order of magnitude as those used in the earlier test runs (NOAA, 1977). The actual time series representing the U and V input current components for Run #BH-1 as measured by the Big Hill Secondary current meter are shown in Figures 2.3-42 and 2.3-43. The time series for Run #BH-2 are presented in Figures 2.3-44 and 2.3-45.

2.3.3.3 Results of Run #BH-1 and #BH-2

The time series shown in Figures 2.3-42 through 2.3-45 represent portions of a single 63-day series measured by the Big Hill Secondary current meter from 11/30/77 to 2/1/78. The entire series, along with the other parameters previously noted, was used as input to the MIT Transient Plume Model. The first 12 days of the series were used to allow the model to reach quasi-equilibrium. Run #BH-1, representing a typical current condition, commenced at 0000 on the 52nd day and continued for 78 hours. Run #BH-2, representing the passage of a storm front, commenced on the 56th day and continued for 54 hours. Outputs were taken for Run #BH-1

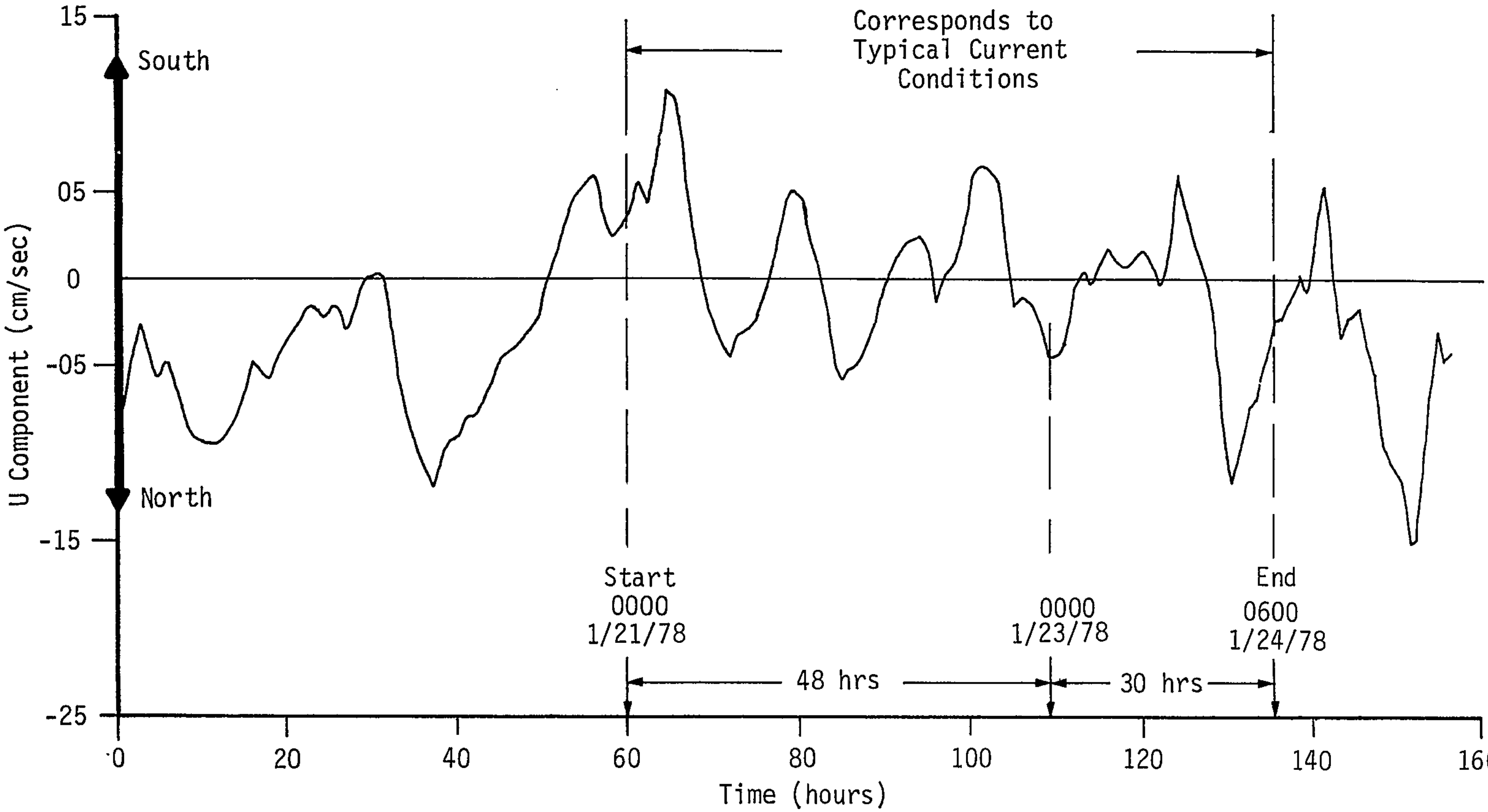


Figure 2.3-42 Time Series of Observed Offshore Current Component, U, from Big Hill Secondary Current Meter for Run #BH-1

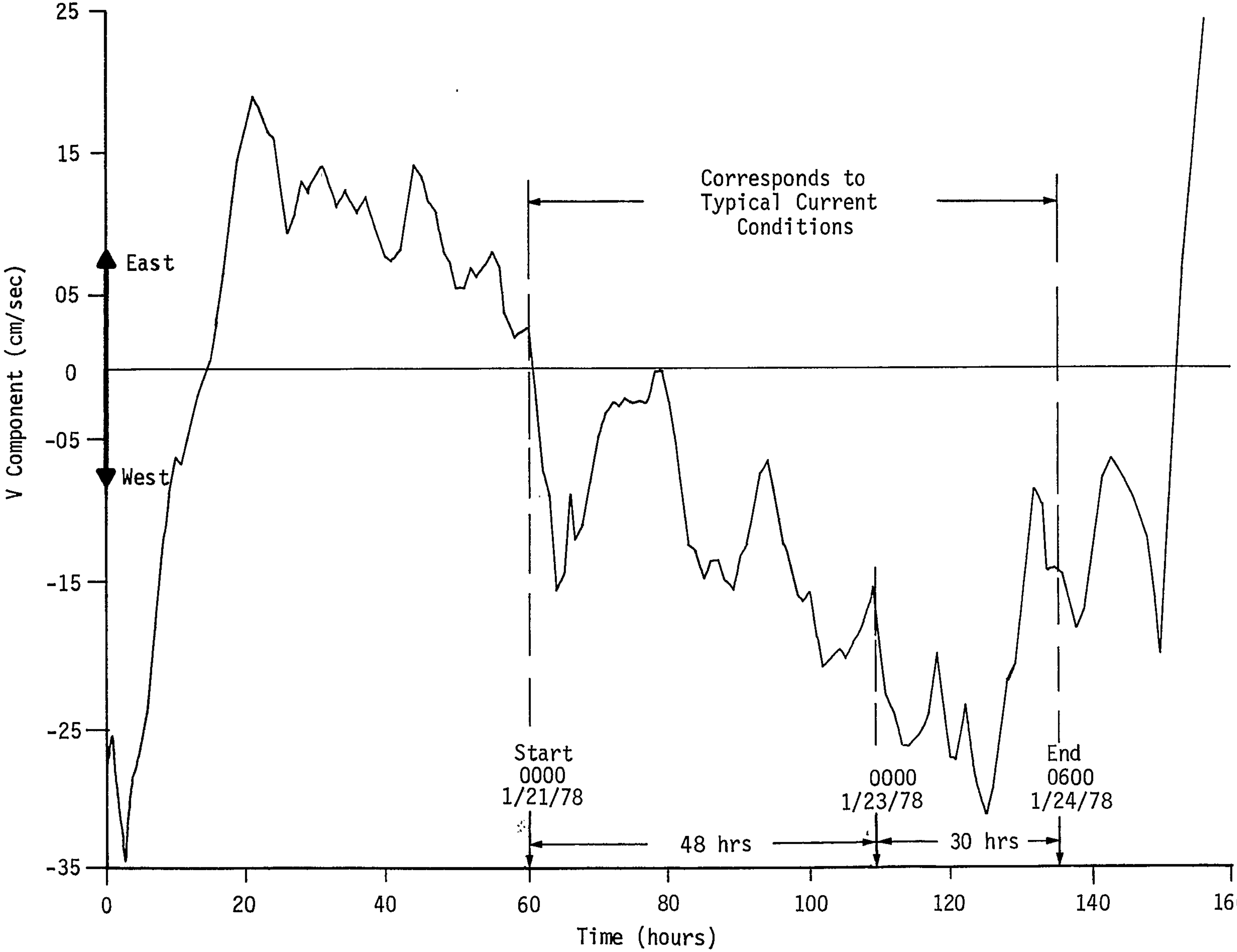


Figure 2.3-43 Time Series of Observed Longshore Current Component, V, from Big Hill Secondary Current Meter for Run #BH-1

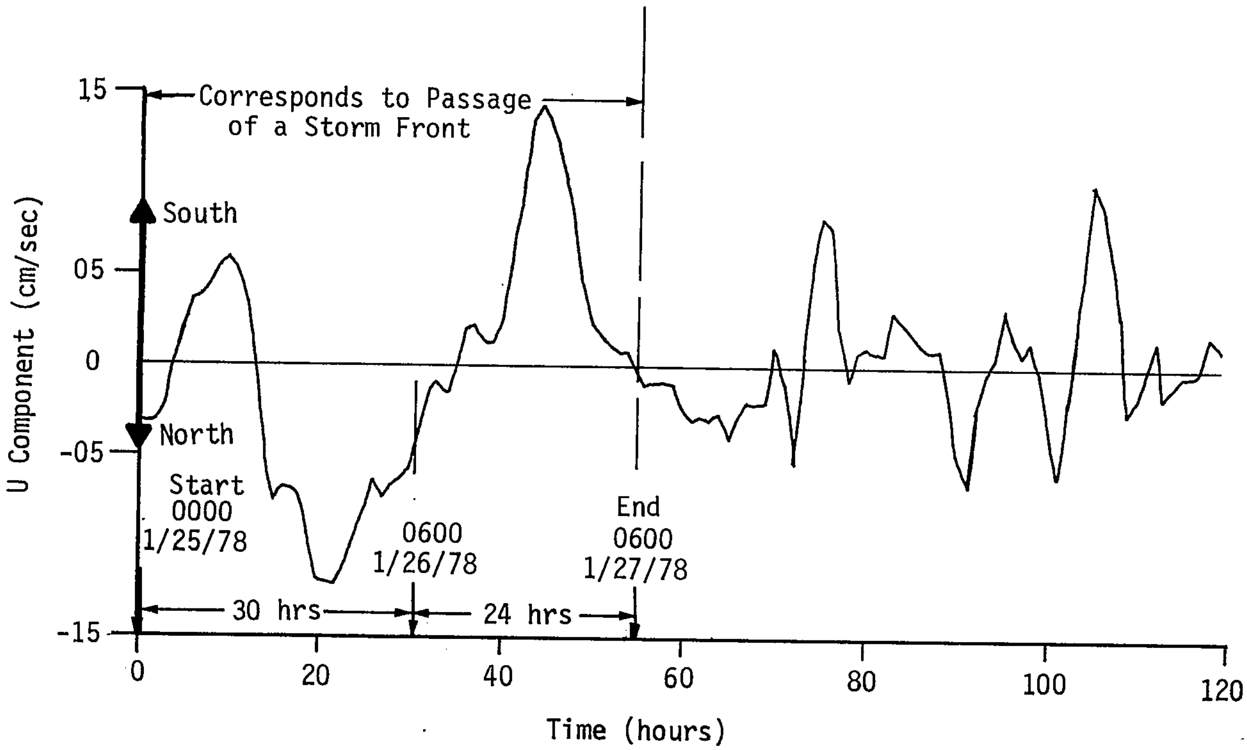


Figure 2.3-44. Time Series of Observed Offshore Current Component, V, from Big Hill Secondary Current Meter for Run #BH-2

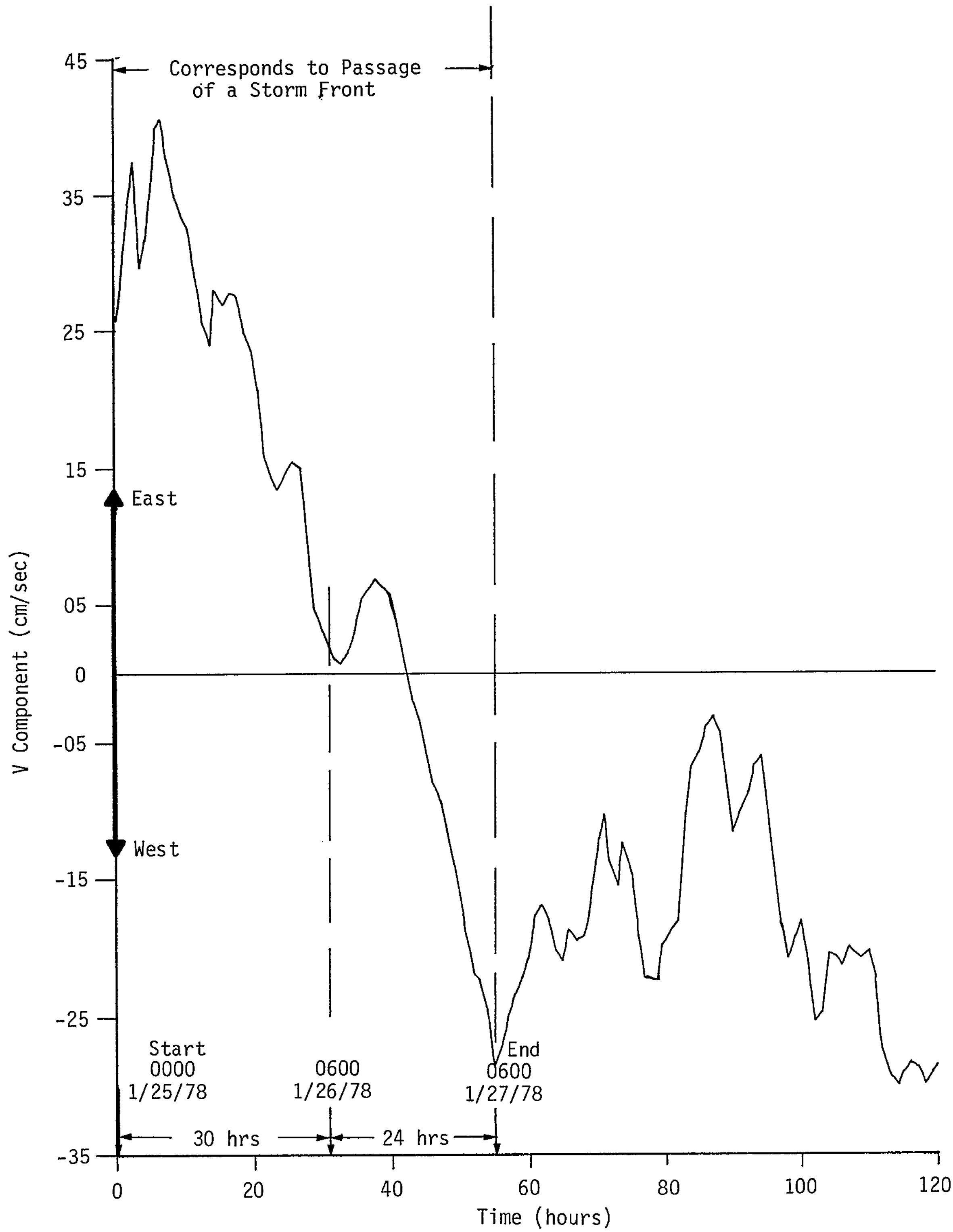


Figure 2.3-45 Time Series of Observed Longshore Current Component, V, from Big Hill Secondary Current Meter for Run #BH-2

corresponding to 0, 48 and 78 hours measured from the commencement time of the run. Likewise for Run #BH-2 outputs were obtained corresponding to 0, 30 and 54 hours measured from the commencement.

The salinity contour plots of Run #BH-1 resulting from typical current conditions are presented in Figures 2.3-46 through 2.3-48. At the commencement of the run (Figure 2.3-46) the plume displays a northeastward orientation but is rotating clockwise to align itself with southeastward-setting current. After 48 hours the set of the current has shifted from the southeast to the northwest. The plume, in response to this shift, has rotated clockwise through approximately 225° and now displays an irregular shape with a generally westward drift (Figure 2.3-47). In Figure 2.3-48, corresponding to 78 hours, a narrow, elongated, western drifting plume results from the prevailing westward-setting current.

For Run #BH-2, representing the passage of a storm front, the salinity contour plots are provided in Figures 2.3-49 through 2.3-51. At the beginning of the run (Figure 2.3-49) the plume displays a northwestward orientation but is in the process of rotating clockwise in response to the current which recently shifted from west to east. After thirty hours have elapsed the plume has rotated clockwise essentially 180° and is aligned with the prevailing current to the northeast. Twenty-four hours later the current has shifted to the west and the plume is undergoing a clockwise rotation to align itself with the new current.

Based on the results of Run #BH-1 and #BH-2, the possibility of the plume reversing direction from east to west within a period of 50 hours appears quite reasonable. Because westward currents are most likely, westward-oriented plumes are more likely to be encountered, but eastward orientations as well as north or south are also possible.

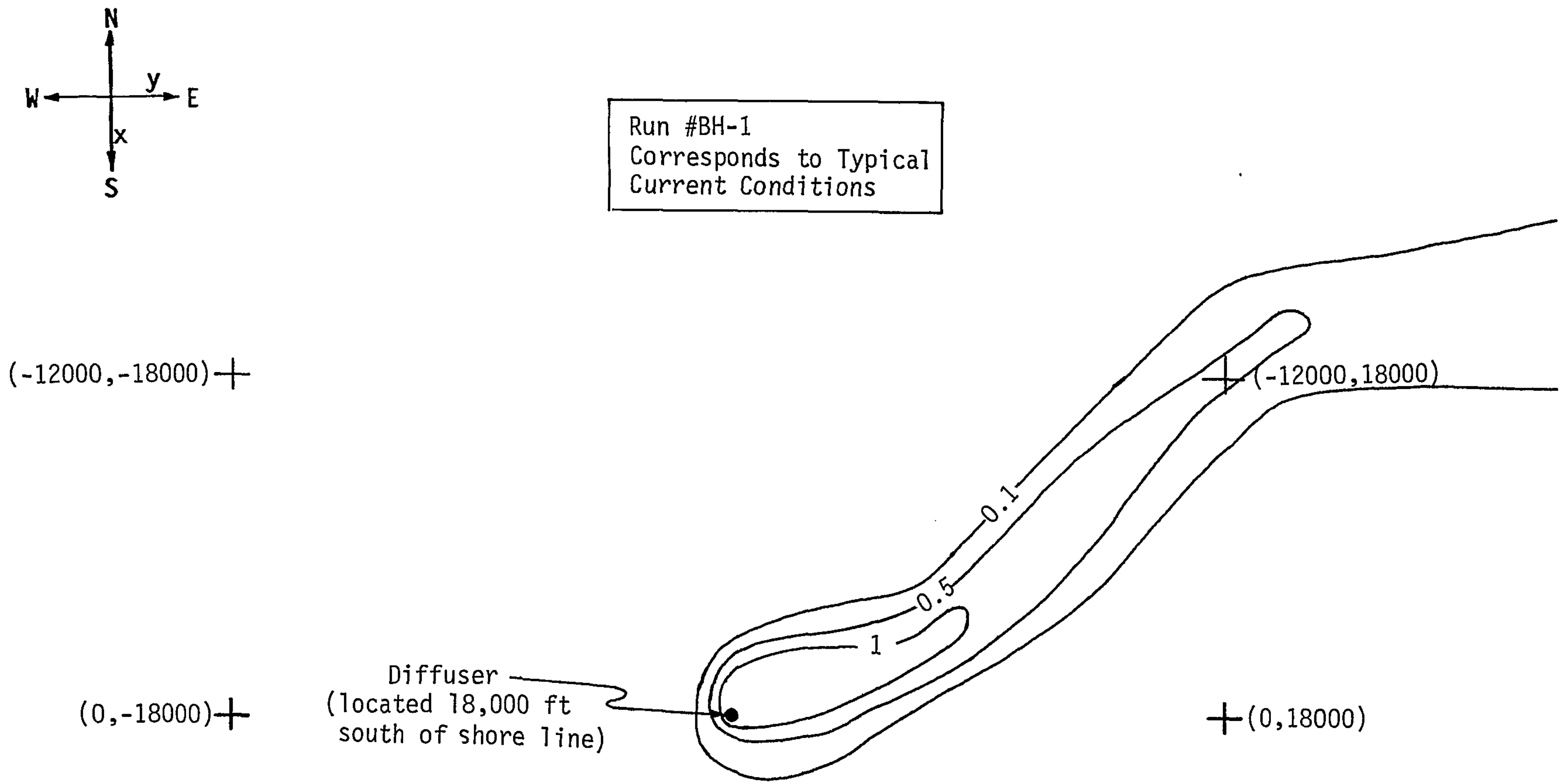


Figure 2.3-46 Contours of Excess Salinity Concentrations (ppt) for Run #BH-1 at Time = 0 Hours on the Bottom (0000, 1/21/78)

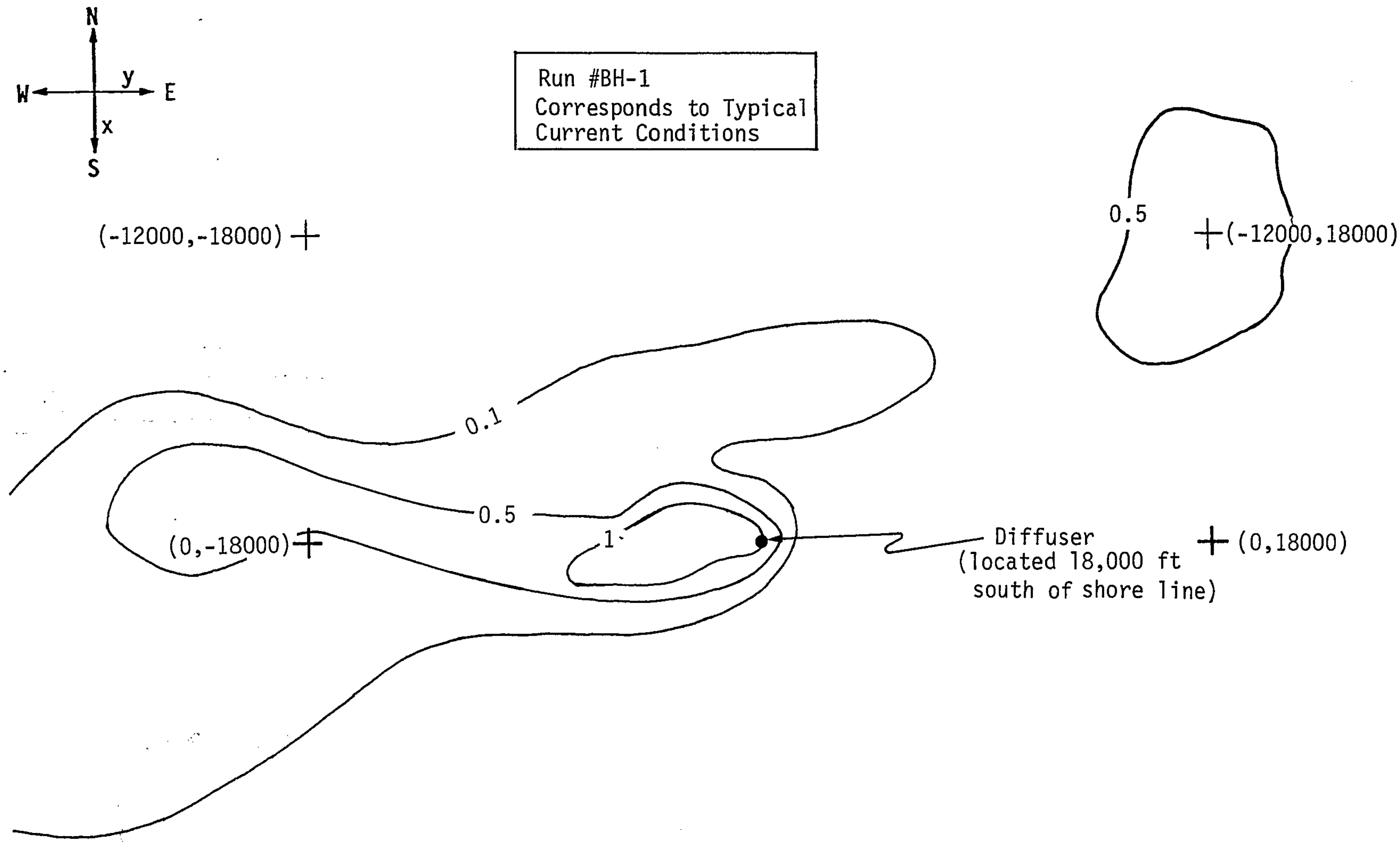


Figure 2.3-47 Contours of Excess Salinity Concentrations (ppt) for Run #BH-1 at Time = 48 Hours on the Bottom (0000, 1/23/78)

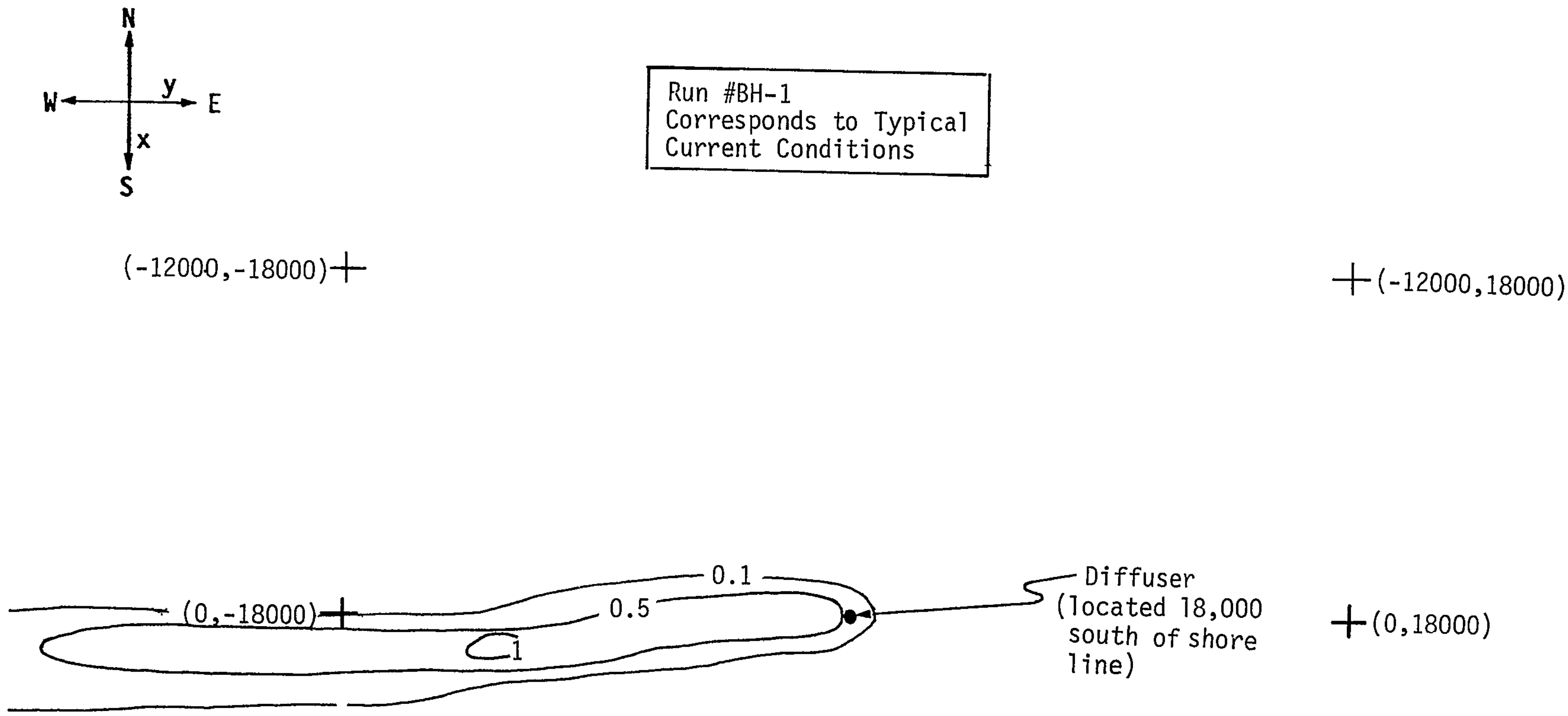


Figure 2.3-48 Contours of Excess Salinity Concentrations (ppt) for Run #BH-1 at Time = 78 Hours on the Bottom (0600, 1/24/78)

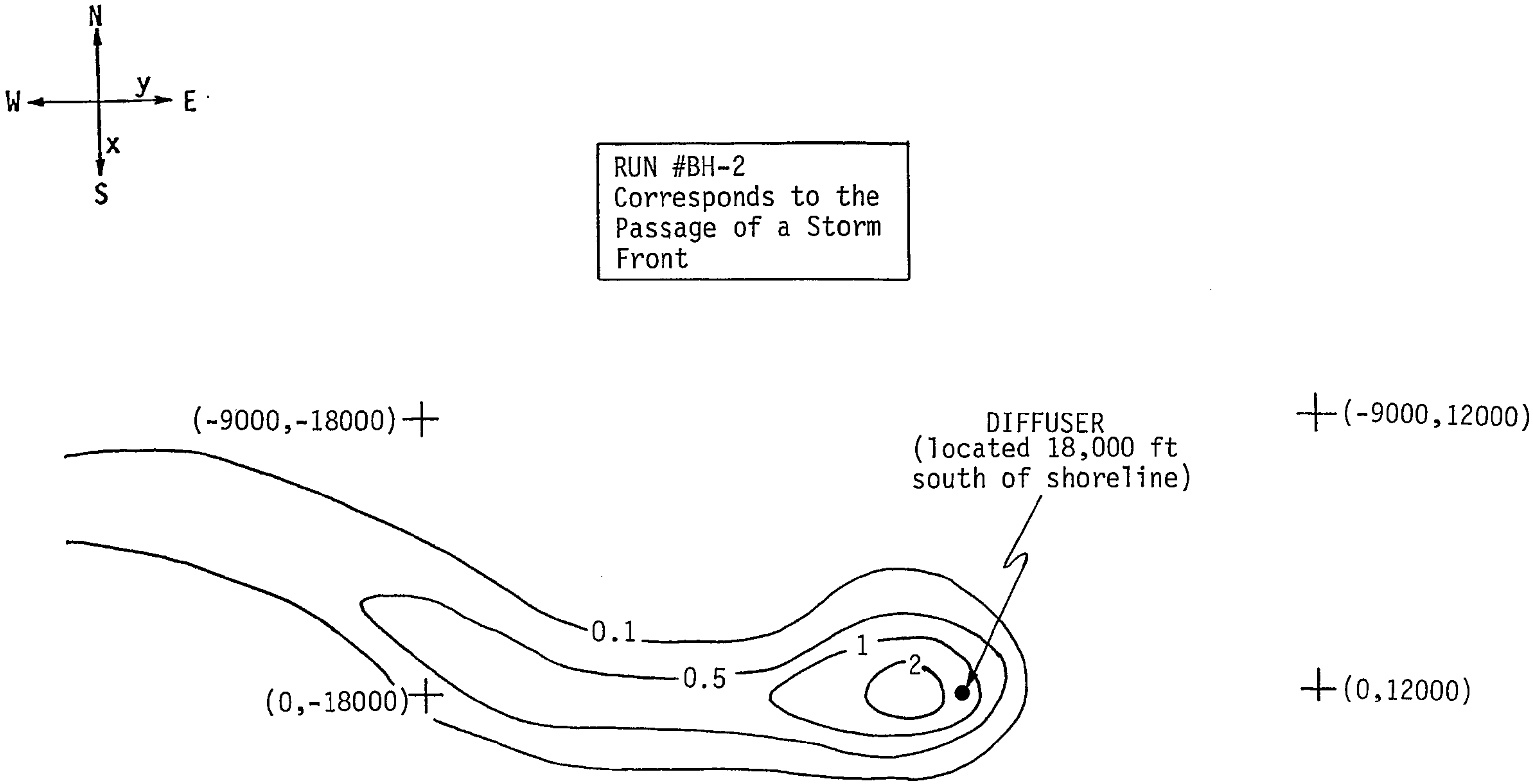


Figure 2.3-49 Contours of Excess Salinity Concentrations (ppt) for Run #BH-2 at Time = 0 Hours on the Bottom (0000, 1/25/78)

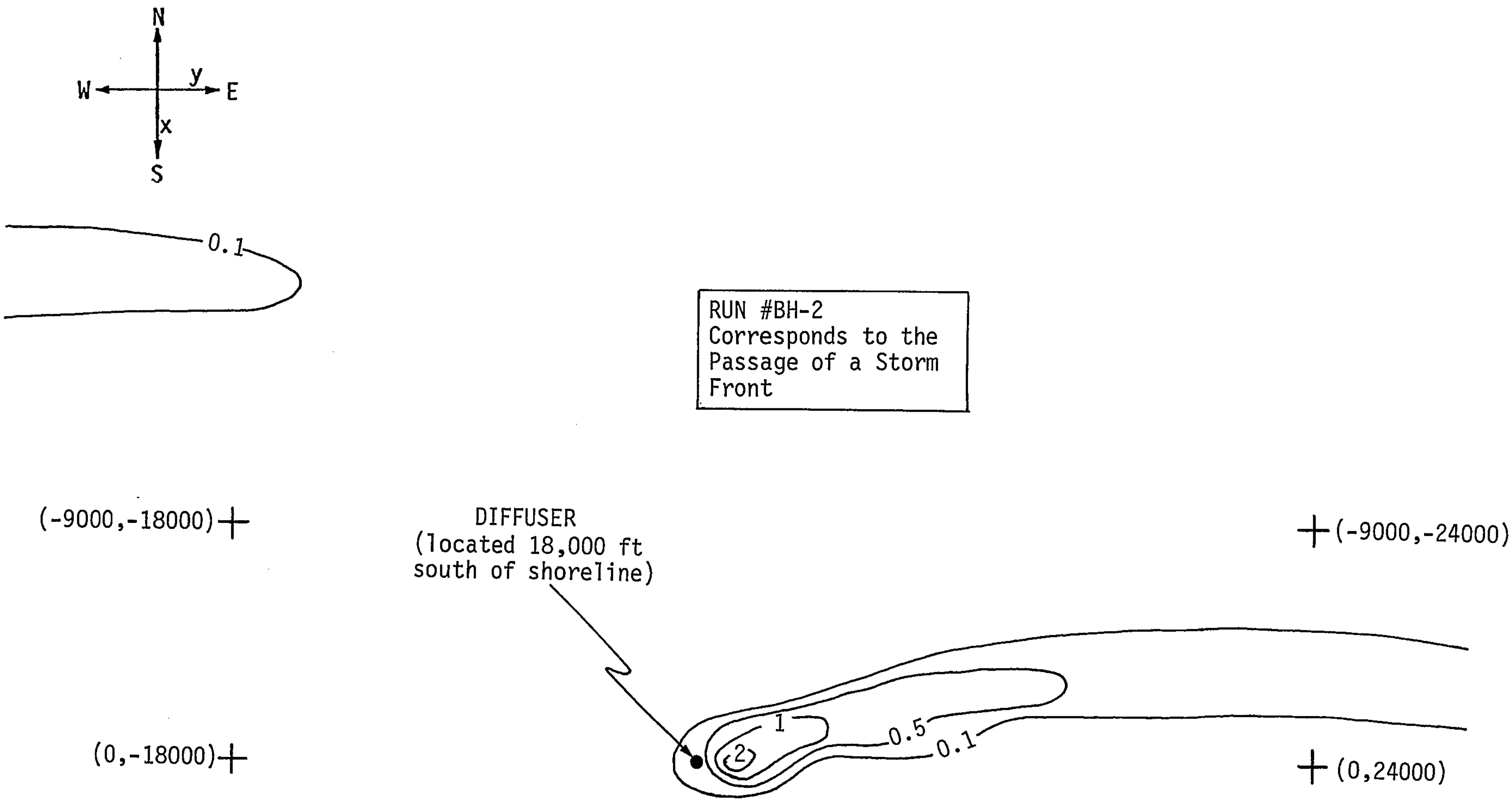


Figure 2.3-50 Contours of Excess Salinity Concentrations (ppt) for Run #BH-2 at Time = 30 Hours on the Bottom (0600, 1/26/78)

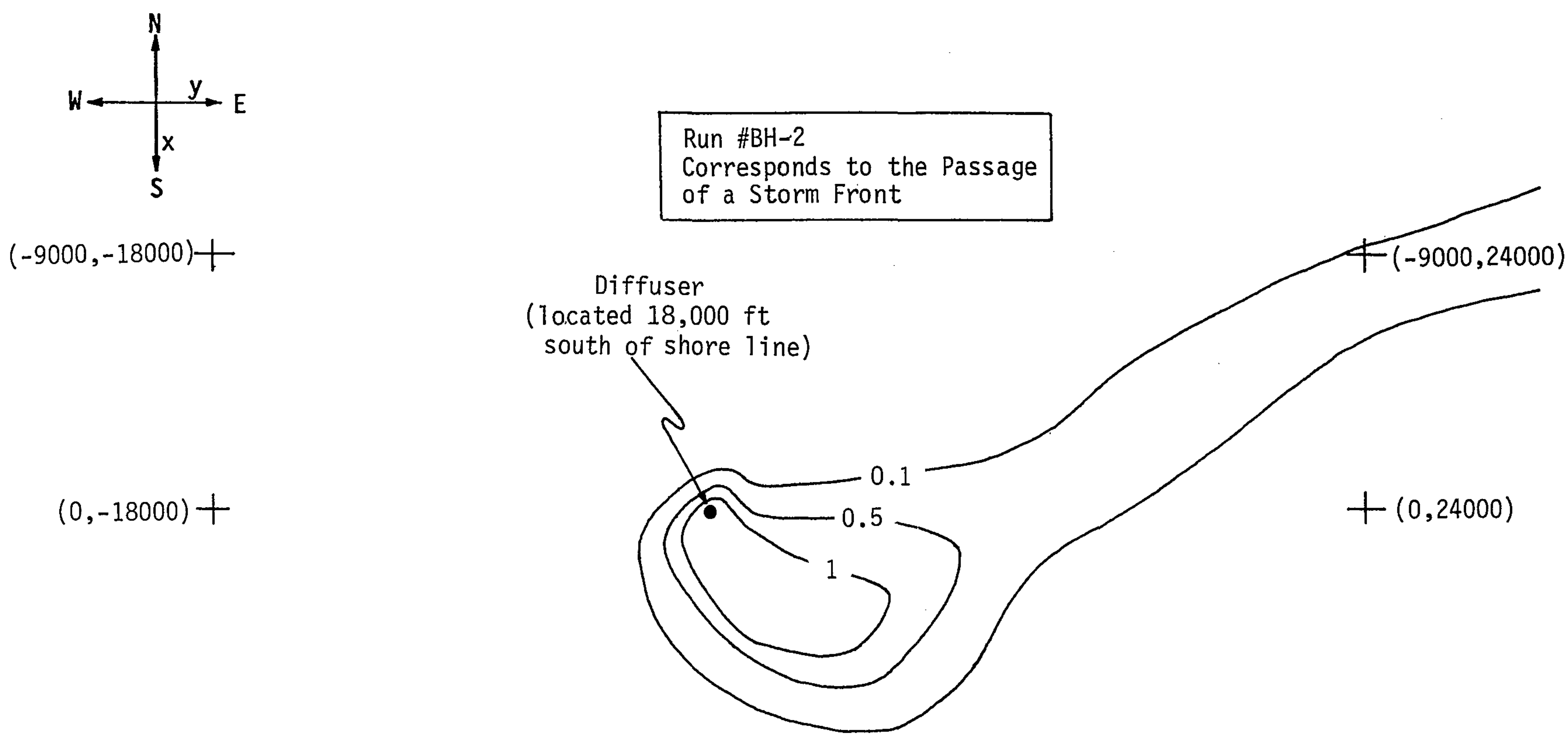


Figure 2.3-51 Contours of Excess Salinity Concentrations (ppt) for Run #BH-2 at Time = 54 Hours on the Bottom (0600, 1/27/78)

With respect to the amount of bottom area exposed to various levels of excess salinity, Figures 2.3-52a and 2.3-52b provide a comparison between an earlier Big Hill analysis based on estimated currents (NOAA, 1977) and the results of Runs #BH-1 and #BH-2 based on measured currents. Examination of Figure 2.3-52a indicates that the currents measured with the Big Hill Secondary current meter, under typical current conditions (#BH-1), produced plumes which, for a given level of excess salinity, cover smaller areas than covered by the plumes in the earlier analysis. The currents measured with the Big Hill Secondary current meter, under conditions corresponding to the passage of a storm front (Run #BH-2) produced plumes covering areas slightly greater than those produced in Run #BH-1 but still generally less than the plumes based on the earlier analysis. For excess salinities greater than 1 ppt in either case the exposed bottom area amounted to less than 3.15×10^6 ft^2 or 724 acres. For excess salinities greater than 3 ppt the maximum exposed bottom area amounted to less than 2.25×10^6 ft^2 or 52 acres. For both runs involving measured currents the exposed bottom areas were generally significantly less than those predicted using estimated currents.
currents.

2.3.3.4 Conclusions

The results presented for Runs #BH-1 and #BH-2 are based on actual measured currents in the vicinity of the site for the Big Hill brine diffuser. The total time interval for the current data, upon which the two runs were based, extended for 63 days.

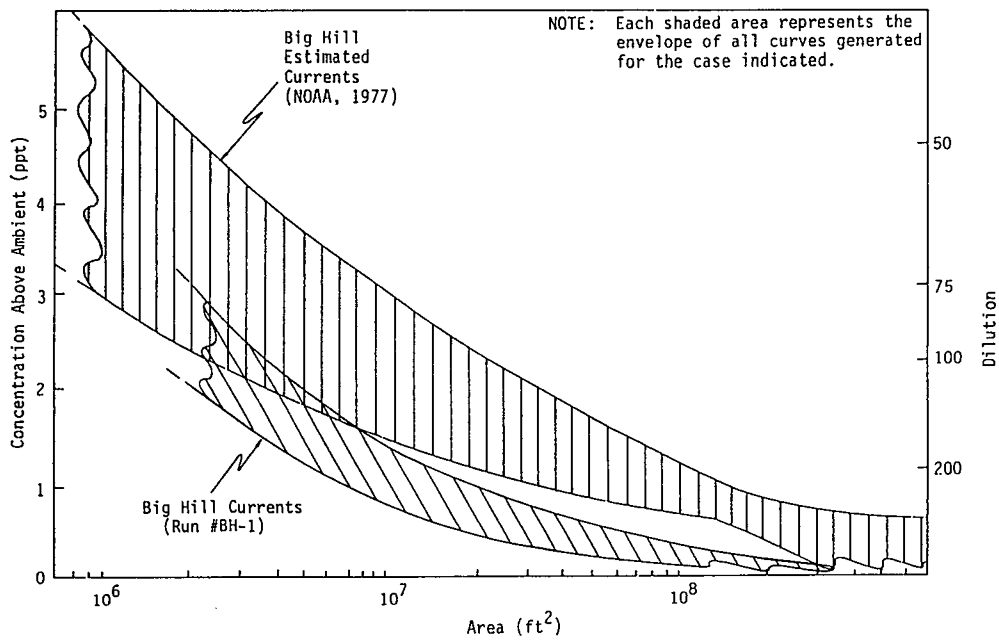


Figure 2.3-52a Excess Salinity versus Exposed Bottom Area for Run #BH-1

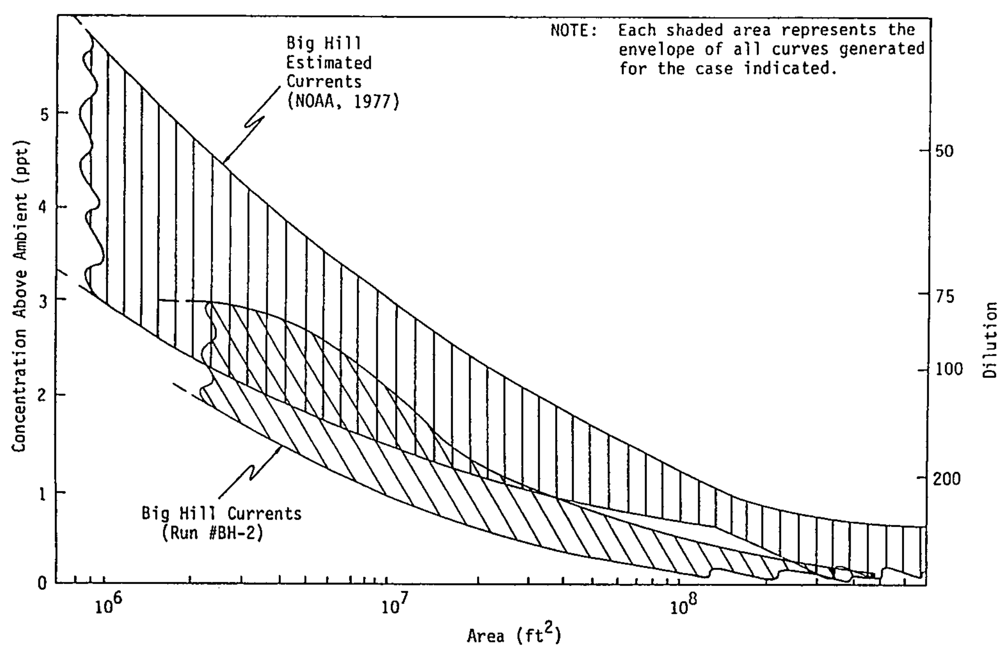


Figure 2.3-52b Excess Salinity versus Exposed Bottom Area for Run #BH-2

The plumes produced in Runs #BH-1 and #BH-2 tended to be oriented along the longshore axis. Reversal in the direction of plume drift was observed in both runs, with both eastward and westward drifting plumes being present. In addition to their primary longshore orientation the plumes to a lesser degree showed a tendency to drift along the onshore-offshore axis.

For all predicted excess salinities the #BH-1 and #BH-2 plumes covered less bottom area than covered by the plumes generated in the earlier Big Hill Analysis (NOAA, 1977). The bottom area exposed to excess salinities greater than 1 ppt amounted to less than 724 acres. The bottom area exposed to excess salinities greater than 3 ppt amounted to less than 52 acres.

In general the plumes of Runs #BH-1 and #BH-2 appear representative of the Big Hill diffuser site. The plumes are smaller than those at West Hackberry due primarily to the lower brine discharge rate.

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Section 3.0

Chemical Oceanography

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FOREWORD

The results contained in this report represent a chemical/geochemical study based on four sampling periods conducted from September 1977 through December 1977. The coastal area under study is an extremely dynamic regime in which all components are subject to major temporal alterations as the result of natural variations in environmental factors. Since the goal of any baseline study is to establish limits of natural variability for identified environmental parameters, it must be pointed out that at least one complete annual cycle should be sampled before the data base initiated here can hope to be a comprenehsive and reliable representation of the range of ambient, pre-brine-disposal conditions.

Many of the sampling and analytical techniques utilized in this study conform directly to those developed and specified by the Bureau of Land Management (U. S. Department of Interior) Outer Continental Shelf Environment Baseline Studies (BLM, 1976). The rationale behind utilizing these methods is that they were developed over a period of time with much effort by several of the most respected members of this country's marine chemistry community, and over the last four years the vast majority of the systematic collections and analyses made in U. S. coastal waters have been made using these techniques.

All data contained herein will in the near future be submitted on magnetic tape to the Environmental Data Service (EDS) of NOAA. It is critical, in the instance of baseline data gathering and reporting, to make the raw data, as well as reductions of that data, available to the scientific public for future comparisons during post-activity monitoring.

3.1. INTRODUCTION

Environmental impact assessment has two major functions. First, the most important requirement is to provide sufficient information for someone to decide whether a proposed activity should occur as planned. Of as great importance, however, is the need to sufficiently describe the environmental character of the system(s) which might be impacted should the program be undertaken. In many instances the environmental impacts of proposed activities are not predictable enough to allow them to proceed without monitoring safeguards. This is especially true for programs such as the Strategic Petroleum Reserve (SPR) offshore brine disposal program, being planned by the Department of Energy (DOE).

The contents of this report describe the study designed to provide chemical baseline data prior to the dispersion of brine fluid in the open, coastal waters of the Gulf of Mexico, off the West Louisiana and East Texas coasts (Figure 3.1-1). At the time of this study, the initial implementation of the SPR brine disposal program is virtually assured, and the chief objective of field studies such as this is to wisely and systematically gather descriptive data of high enough quality to allow their use as references or benchmarks in monitoring efforts.

Offshore disposal of the saturated brine resulting after cavitation of the onshore salt domes is currently thought to be the least detrimental of the disposal alternatives. However, it is recognized that doing so has its own set of potential impacts, several of which may be significant. Among the potential impacts are the disturbance of the ionic balance of the marine system and the imparting of toxic substances, such as heavy metals and petroleum-related hydrocarbons, to the system. Some of the effects of brine disposal are relatively obvious while others are less so. The potential haloclinic perturbation just from increasing the total dissolved ionic solids is expected to be severe for some members of the ecosystem. Associated with this effect, however, is the possibility of altering several geochemical flux cycles. As an example, brine disposal has the potential of mobilizing materials (e.g., some metals) which are already present in the system but which normally might be unavailable to the living portion.

The chemical field and analysis study was designed to describe spatial variations in water column and sediment chemical quality, recognizing that this is the necessary first step in delineating the overall composition of the system. In order to assess the potential effects of a brine discharge, with its accompanying osmotic effects, ionic imbalance, and contributions/redistributions of toxic elements, it is mandatory that the distributions of important chemical species in the dissolved and particulate phases of both the water column and

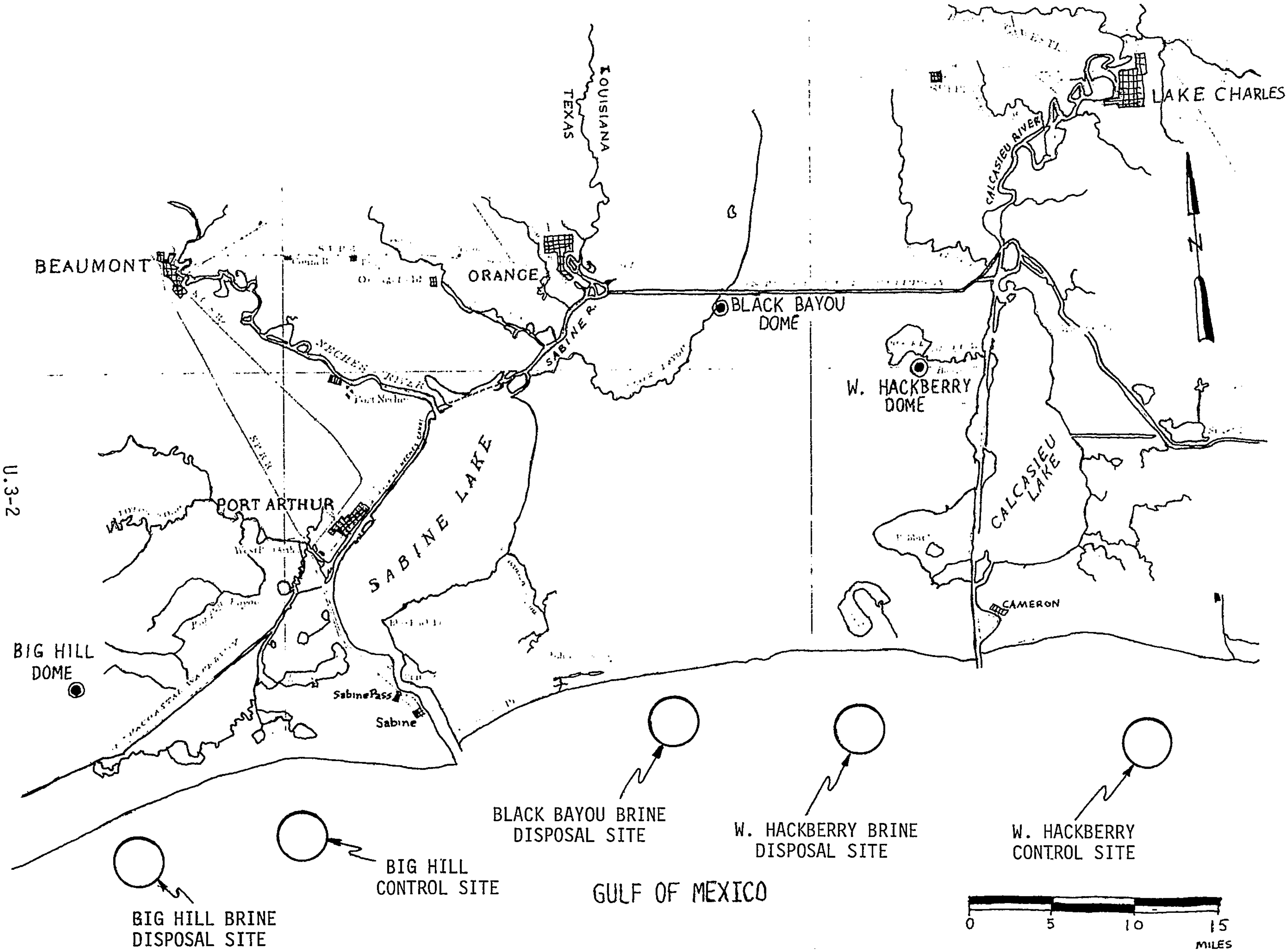


Figure 3.1-1. Sampling Sites for Collection of Baseline Data for the SPR Brine Disposal Program.

the associated sediments be elucidated. The initial parameters chosen for observation and documentation include (1) heavy metals in sediments, sediment pore water, selected biota, dissolved in the water column, and associated with suspended particulate matter; (2) high molecular weight (petroleum-related) hydrocarbons in sediments, selected biota, and dissolved in the water column; (3) peripheral geochemical parameters such as total organic carbon (TOC), per cent calcium carbonate, grain size distribution, and ATP (biomass) in sediments, and dissolved organic carbon (DOC), particulate organic carbon (POC), total suspended matter (TSM), nutrients, and major ionic species in the water column.

In looking for far-reaching conclusions in the set of chemical data contained in this report, it should be kept in mind that marine chemists have had very little experience in working with brine solutions, and as a result many conclusions that might be derived from this chemical data may not be immediately available. The baseline information documented at this time will have more and more usefulness as additional related information from laboratory "effects" and "bioassay" experiments and dispersion modeling as well as chemical/geochemical equilibrium modeling is acquired.

3.2. METHODOLOGIES

3.2.1 SAMPLE COLLECTION AND ON-BOARD PROCESSING

Figures 3.2-1 to 3.2-5 give locations of the West Hackberry, West Hackberry Control, Black Bayou, Big Hill and Big Hill Control sampling sites. The figures show orientation to bottom topography and the numbered sampling sites. In addition, Figures 3.2-1 to 3.2-5 show the positions of trawl transects covered in the collection of epifaunal organisms for biological and chemical analyses.

Dissolved and Particulate Trace Metals, Major Ions, Nutrients, POC, DOC, and TSM in Seawater Samples

Water samples were collected in 5-ℓ Go-Flo Niskin bottles which had been acid-cleaned and rinsed. Initially, 200 ml of water were drawn into glass stoppered reagent bottles for POC-DOC analysis. Triplicate 50-ml aliquots were then filtered through pre-combusted, 25-mm glass fiber filters. The filters were folded and placed into pre-combusted ampoules which were then frozen. The DOC filtrates were collected in 60-ml, pre-combusted glass bottles and also frozen.

To collect suspended matter samples, approximately 1ℓ of water from each station was pressure filtered with N_2 through acid-washed 47-mm diameter, 0.4-μm Nuclepore filter pads. Each filter pad had been pre-weighed on a 6-place Mettler balance, and loaded into in-line polypropylene filter heads. The filtrates for major ion and trace metal analysis were collected in 1-2ℓ , acid-washed polyethylene bottles and preserved with 5 ml of concentrated Ultrex HNO_3. This water was kept under refrigeration until analysis. The Nuclepore pads with particulate matter were rinsed twice with deionized water, and stored in acid-cleaned polyethylene vials. Nutrient water samples were collected in "Whirl-Pack" bags and frozen.

Dissolved High Molecular Weight Hydrocarbons (HMWHCs)

Samples for analysis of dissolved HMWHCs were collected by pumping seawater with a Teflon diaphram pump through kiln-fired, 293-mm, 1.4-m glass fiber filters. The filtrates were collected in pre-cleaned, 20-ℓ glass carboys and poisoned with 150 ml of chloroform. The carboys were capped with corks lined with kiln-fired foil and then enclosed in polyethylene bags.

Trace Metals in Surficial Sediments and Pore Water

The upper 5 cm of surficial sediment were collected in polyethylene capped plastic core liners by divers. Immediately after collection, each core was put into individual polyethylene bags and refrigerated. Each sediment sample was tested for the presence of ambient anaerobic (chemically reducing) conditions by visual inspection and by punch-in

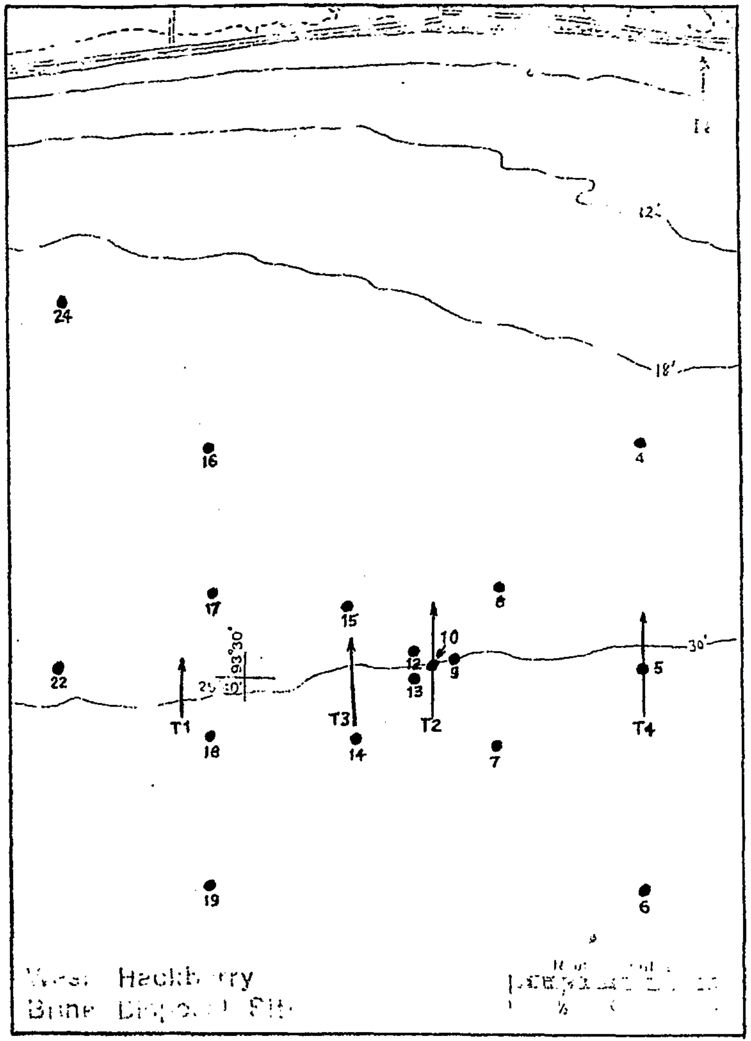


Figure 3.2-1. Locations of Sampling Stations and Trawl Transects for the West Hackberry Disposal Site.

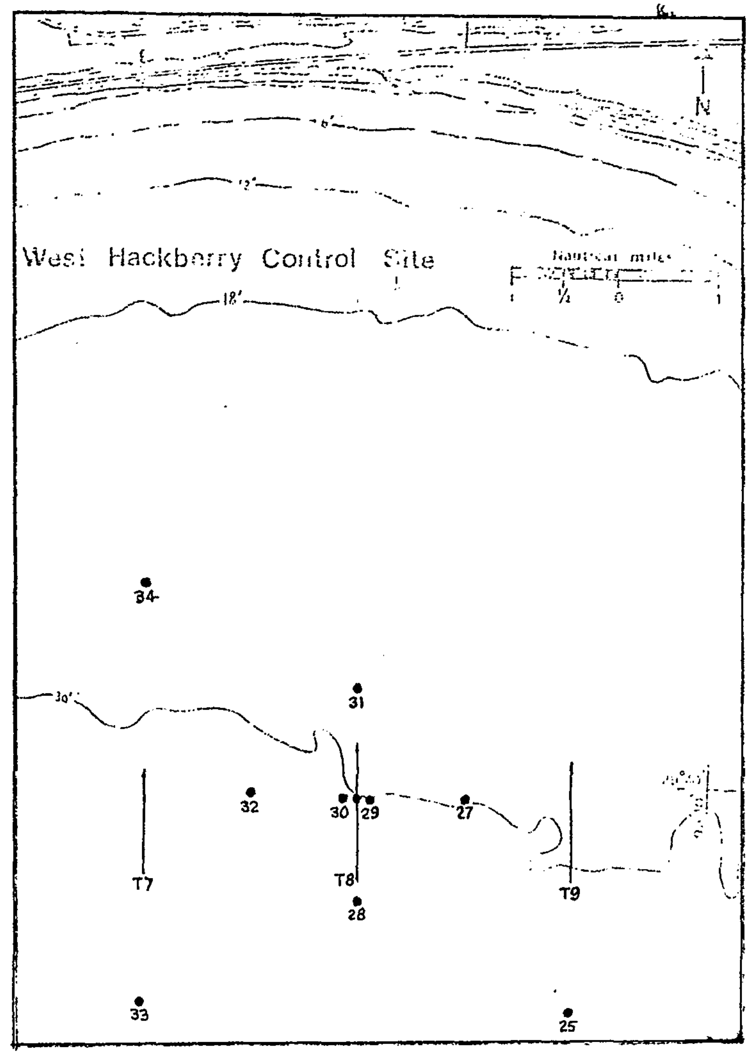


Figure 3.2-2. Locations of Sampling Stations and Trawl Transects for the West Hackberry Control Site.

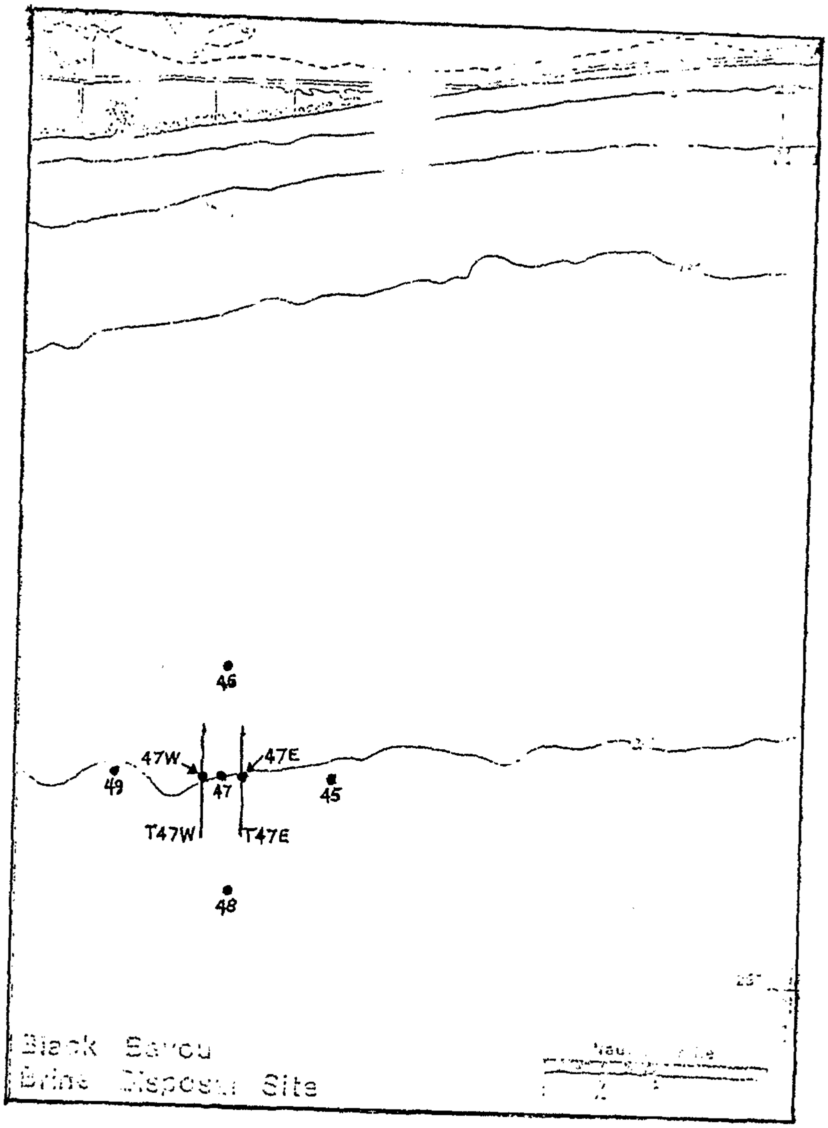


Figure 3.2-3. Locations of Sampling Stations and Trawl Transects for the Black Bayou Disposal Site.

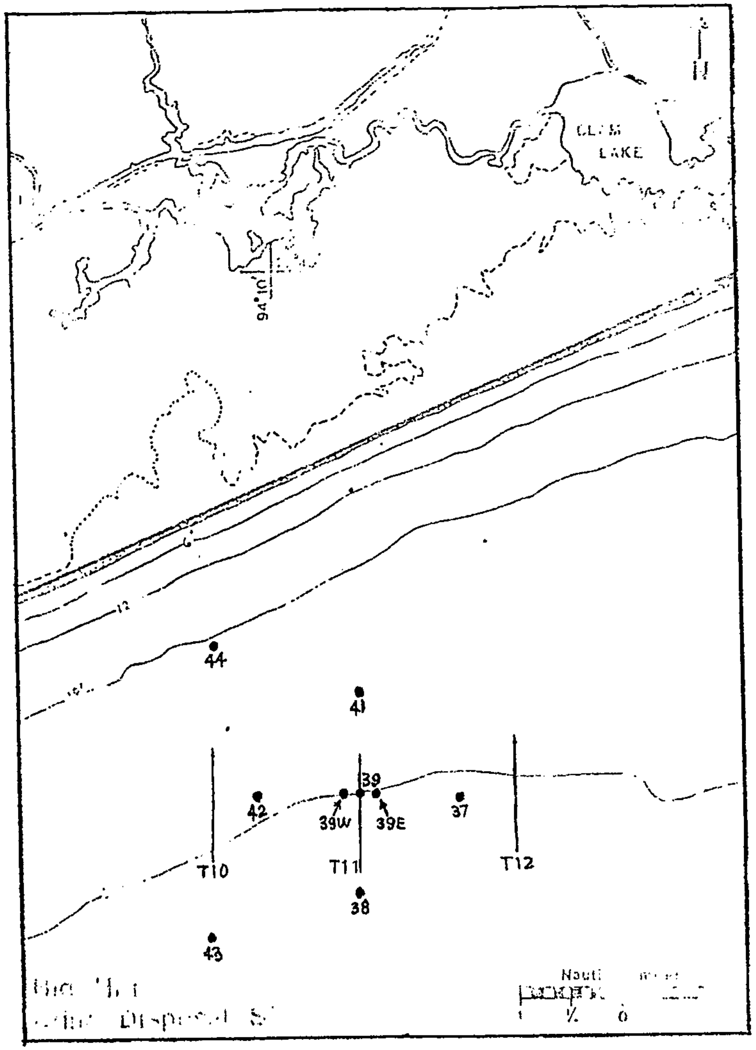


Figure 3.2-4. Locations of Sampling Stations and Trawl Transects for the Big Hill Disposal Site.

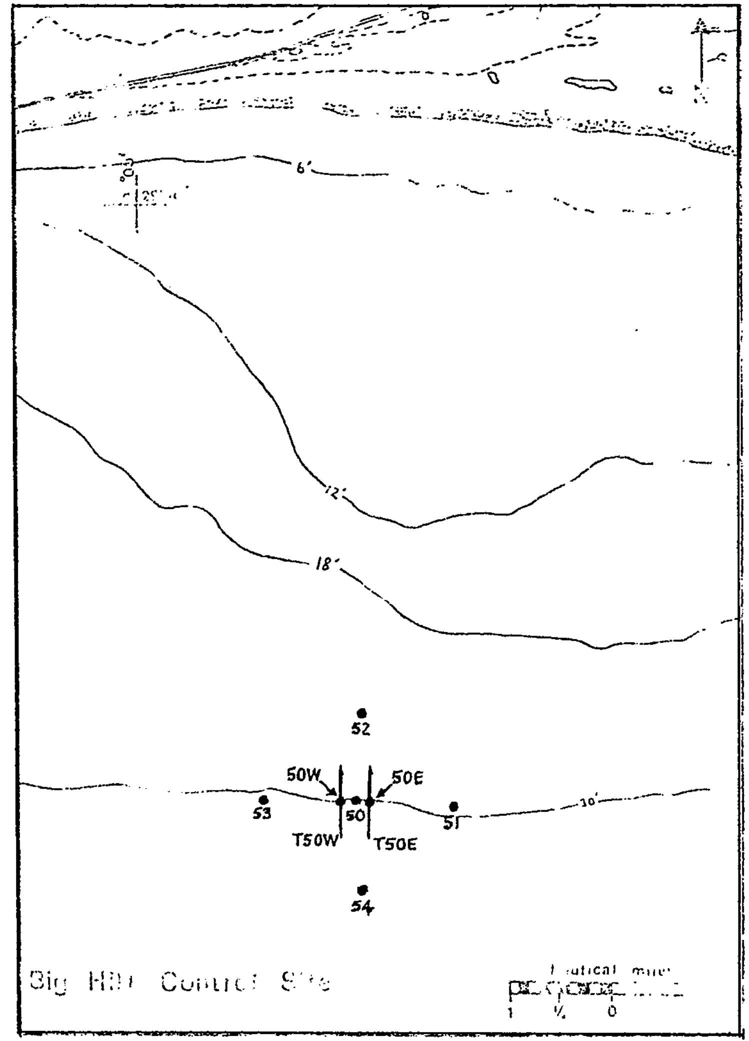


Figure 3.2-5. Locations of Sampling Stations and Trawl Transects for the Big Hill Control Sites.

electrode Eh measurement. In no instances were reducing (negative Eh) conditions encountered. This fact allowed the storage of sediment samples as described for subsequent pore water collection to approximate in situ conditions and to not cause significant alterations in the pore water chemistry of these samples

HMWHCs, Sediment Texture and TOC in Surficial Sediments

Sediment for analysis of HMWHCs was collected with an aluminum Van Veen type grab sampler. The upper 5 cm of surficial sediment were removed using a stainless steel spoon, placed in a pre-cleaned, foil-capped glass jar and frozen. Sub-samples were collected for TOC and sediment texture from the same grab sample. TOC samples were frozen in glass jars and sediment texture samples were kept at ambient temperatures.

ATP in Surficial Sediments

Sediment subsamples for analysis of ATP were taken from the Van Veen grab at each sediment station. Triplicate 2-cm^3 surficial sediment samples were taken at each station using disposable Stylex syringes with trimmed barrels. Each sample was injected into a scintillation vial containing 10 ml of 0.6 N H_2SO_4. After thorough shaking, 0.1 ml of TRIS buffer was added to two of the vials and 0.1 of ATP Internal Standard was added to the third. Each sample was placed on ice and was shaken occasionally. After 15 minutes the samples were vacuum filtered at 10-psi vacuum using Millipore filter beds. A Millipore HA filter pad (47.0 mm; 0.45 μm) was used underneath a Whatman GF/C glass microfibric pad (42.5 mm). Three filter head units were used (to allow simultaneous separation times for all three aliquots), and filter pads were changed between sample filtrations. From the filtrates collected in clean vials, 8 ml were kept for each sample and 2 ml of EDTA plus 5 ml of TRIS buffer were added to each. After mixing, the pH was adjusted to approximately 7.7 with 1 N KOH and 10 drops of phenolphthaline indicator. The KOH was added by pipet until the sample turned pink and then a few drops of 0.6 N H_2SO_4 were added to back-titrate the sample (until the solution was light pink in color). The sample volumes were brought to 25 ml with TRIS and shaken well after which 10 ml were transferred to a clean vial and frozen (Holm-Hansen and Booth, 1966).

HMWHCs and Trace Metals in Biota

Macroepifauna and demersal fishes were collected using a well-weathered (i.e., non-contaminating) otter trawl and 10-20 minute tows. The samples chosen for trace metals and HMWHC analyses were *Penaeus setiferus* (white shrimp, a commercially important crustacean), *Micropogon undulatus* (croaker, a dominant demersal fish at the sampling sites), *Loligo brevis* (squid), *Anchova mitchilli* (anchovy).

Specimens for HMWHC analysis were removed from the trawl, put in foil-capped glass jars, labeled, and frozen. Specimens for trace metals analysis were rinsed with deionized water, put in polyethylene bags, labeled, and frozen.

Zooplankton samples were collected using a trace metal free, 0.5-m net (202 μm). The collection net had been acid-soaked and rinsed with deionized water. Rinsings were checked as blanks for the contribution of any metals by the net. After each tow, the PVC cod-end was removed, and the plankton sample rinsed with deionized water through an acid washed 202-μm, mesh nylon screen. The samples were transferred to wide-mouth, 250-ml acid-cleaned linear polyethylene bottles, labeled, and stored frozen.

3.2.2 LABORATORY ANALYSES

Dissolved Trace Metals, Major Ions and Nutrients in Seawater and Pore Water

To collect pore water, sediment was transferred from polyethylene bags to nylon mud squeezers containing Whatman No. 50 filter paper. The squeezers were assembled, and under N_2 pressure, 50 ml of water were filtered and collected in polyethylene syringes. The water was further filtered through a 0.4 μm Nuclepore filter pad housed in a Millipore Swinnex polypropylene filter holder. Pore water samples were stored frozen in 100-ml acid-cleaned conventional polyethylene bottles, and .5 ml of concentrated Ultrex HNO_3 was added to each sample to reduce the pH to ≤ 2 to ensure dissolution of any precipitated constituents. Seawater and pore water samples were then analyzed for major ions (Cl^-, SO_4^{++}, K^+, Mg^{++}, Na^+), nutrients (PO_4, Si, NO_3) and trace metals (Hg, Cd, Cu, Fe, Pb, Mn, Zn). The analysis of Hg and NO_3 in pore waters were precluded because of sample size and the addition of HNO_3, respectively.

Chloride

Chloride analyses were performed on the sea water and pore water samples using method 408A (Argentometric Method) prescribed in ASTM Standard Methods, 14th ed. The sea water samples were volumetrically diluted (1:10) and titrated with standard silver nitrate.

Since the method of analysis required a volumetric titration, only calibrated volumetric glassware was used in critical steps. The end point was verified by titrating known standards. Analysis of 8 replicates of a single sample gave a precision of 0.3% (coefficient of variation).

Sulfate

The analysis was done gravimetrically with drying of residue by a modified version of method 427B in ASTM Standard Methods, 14th ed. Barium sulfate was precipitated from ten ml of each sea water and pore water sample by adding a saturated solution of barium chloride. Additional deionized water was added to prevent barium chloride precipitation. The solution was filtered, dried, and weighed as prescribed. Analysis of 6 replicates of a single sample gave a precision of 4.0% (coefficient of variation).

Calcium

Calcium concentrations in the sea water and pore water samples were determined using the EDTA tritrimetric method, 306C, contained in ASTM Standard Methods, 14th ed. Calcium was determined directly, using standard EDTA titrant, on the volumetrically diluted sea water samples. Analysis of 5 replicates of a single sample gave a precision of 0.8% (coefficient of variation).

Potassium

Potassium was analyzed directly by AAS after a 1:400 dilution of the sea water and pore water samples. Each sample was analyzed by the method of standard additions since matrix effects from other major sea water constituents depressed the signal from potassium. Analysis of 5 replicates of a single sample gave a precision of 4.0% (coefficient of variation).

Magnesium

Magnesium was analyzed by making a 1:10 dilution followed by direct AAS (flame) aspiration. Standard instrument conditions were used for analysis. An artificial sea water stock of 1,300 mg/l magnesium was used in various dilutions as standard. Analysis of 5 replicates of a single sample gave a precision of 3.5% (coefficient of variation).

Sodium

Sodium was analyzed directly by flame AAS after a 1:200 dilution of the water samples. The recommended instrument conditions were used for the analyses. Duplicate analysis of 2 samples gave a precision of 1% (coefficient of variation).

Phosphate

Sea water and pore water samples were analyzed for phosphate using a stannous chloride reduction method (Method 425E, ASTM Standard Methods, 14th ed.). Molybdophosphoric acid was formed and reduced to the intensity colored complex, molybdenum blue, by stannous chloride.

Silica

Reactive silica was analyzed using the Molybdosilicate Method (Method 426B) as described in ASTM Standard Methods, 14th ed. The silica reacts with molybdate to give a colored complex which can be detected with a visible absorption spectrophotometer.

Nitrate

Nitrite was allowed to oxidize to nitrate with time. No preservative was added to prevent oxidation from occurring. The samples were analyzed for total nitrate to the Brucine Method (Method 419D) as specified in ASTM Standard Methods, 14th ed. The reaction between nitrate and Brucine produces a yellow color that is used for colorimetric determination of the nitrate.

Mercury

The sea water samples only (100-ml aliquotes) were analyzed for Hg using standard cold vapor AAS. Stannous chloride was used to reduce the mercury in solution to mercury vapor which was purged through a 259 nm wavelength beam and the energy absorption measured.

Interstitial sea water samples (10-ml aliquotes) were chelated/extracted with 1 ml of a 1% APDC/DDC solution into 1 ml of MIBK at a pH of 3.6. The combined MIBK from three repeated extractions on each sample was evaporated to dryness. The dry metal complexes were then redissolved with 1 ml of 1 N HNO_3. This modification to the sea water technique was required due to the small amount of sample available for analysis. The aqueous solutions were then analyzed directly for Hg by AAS using a carbon rod analyzer. Any molecular absorption background was successfully removed by the instrument's H_2 lamp.

Cadmium, Copper, Iron, Lead, Manganese, Zinc

Ten-ml sea water and pore water sample aliquotes were chelated/extracted with 1 ml of a 1% APDC/DDC solution into 1 ml of MIBK at a pH of 3.6. The combined MIBK from three repeated extractions of each sample was evaporated to dryness and the dry metal complexes then redissolved with 1 ml of 1 N HNO_3. The 1 N HNO_3 solutions were then analyzed by direct injection into the carbon rod analyzer of the AAS.

Seawater Particulate Trace Metals

Suspended particulate samples were rinsed twice with deionized water, desiccated for three days in polyethylene vials and weighed on a Mettler balance.

Weak Acid Soluble Leach (WAS). After weighing, the sample pads were folded and placed into polypropylene funnels with Teflon stopcocks. The pads were opened and the funnels were filled with 4 ml of 25% acetic acid (BLM, 1976). After two hours the funnels were drained into 25-ml polypropylene volumetric flasks containing 1.5 ml of concentrated Ultrex HNO_3. The pads were rinsed several times and the flasks were brought to volume. Reagent blanks and standard solutions were also prepared with this matrix.

Refractory Digestion. Following the WAS leach, the samples were placed in Teflon bombs aand 750 μl of concentrated Ultrex HCl were added to each (BLM, 1976). The bombs were heated to 80^oC for 30 minutes. After cooling, 25 μl of concentrated Ultrex HNO_3 were added to each and the bombs were heated for an additional 30 minutes. The bombs were once again cooled, 25 μl of concentrated Ultrex HF were added to each and the bombs were heated again for 60 minutes. After a final cooling, the contents of the bombs were transferred into 50-ml volumetric flasks. Reagent blanks, standard solutions and NBS plastic clays were processed in a similar manner. All metals analyzed for sediments were also analyzed for suspended particulates with the exception that Ca and Cu were analyzed only in the WAS fraction and Al was analyzed in the refractory fraction only.

Seawater Dissolved HMWHCs

Figure 3.2-6 presents a schematic diagram of the analytical procedure for seawater HMWHC analysis. Each water sample was extracted three times, the first extraction with 150 ml of chloroform followed by two 100-ml extractions with methylene chloride. (all solvents were previously checked for purity by analysis as blanks). Thorough mixing during each extraction was accomplished with a high speed stainless steel stirring rod. The three extracts were combined and reduced in volume on a rotary evaporator in preparation for liquid chromatography.

Column chromatography was conducted using 1.0 x 20.0-cm columns packed in hexane with a 1:2 ratio of alumina over silica. Both substrates were of Activity I. Two fractions were collected: First the aliphatic fraction was eluted with two bed volumes of hexane. The aromatic fraction was then eluted with two bed volumes of benzene (Payne et al., 1977a, 1977b, 1977c; Parker et al., 1976). Both fractions were reduced in volume on a rotary evaporator, transferred to clean vials, and reduced to near dryness under a stream of pre-purified nitrogen. To each vial, 100 μl of hexane was added and an aliquot (5-7 μl) was weighed on a Cahn electrobalance. This weight was then used to determine the proper loading of the GC column.

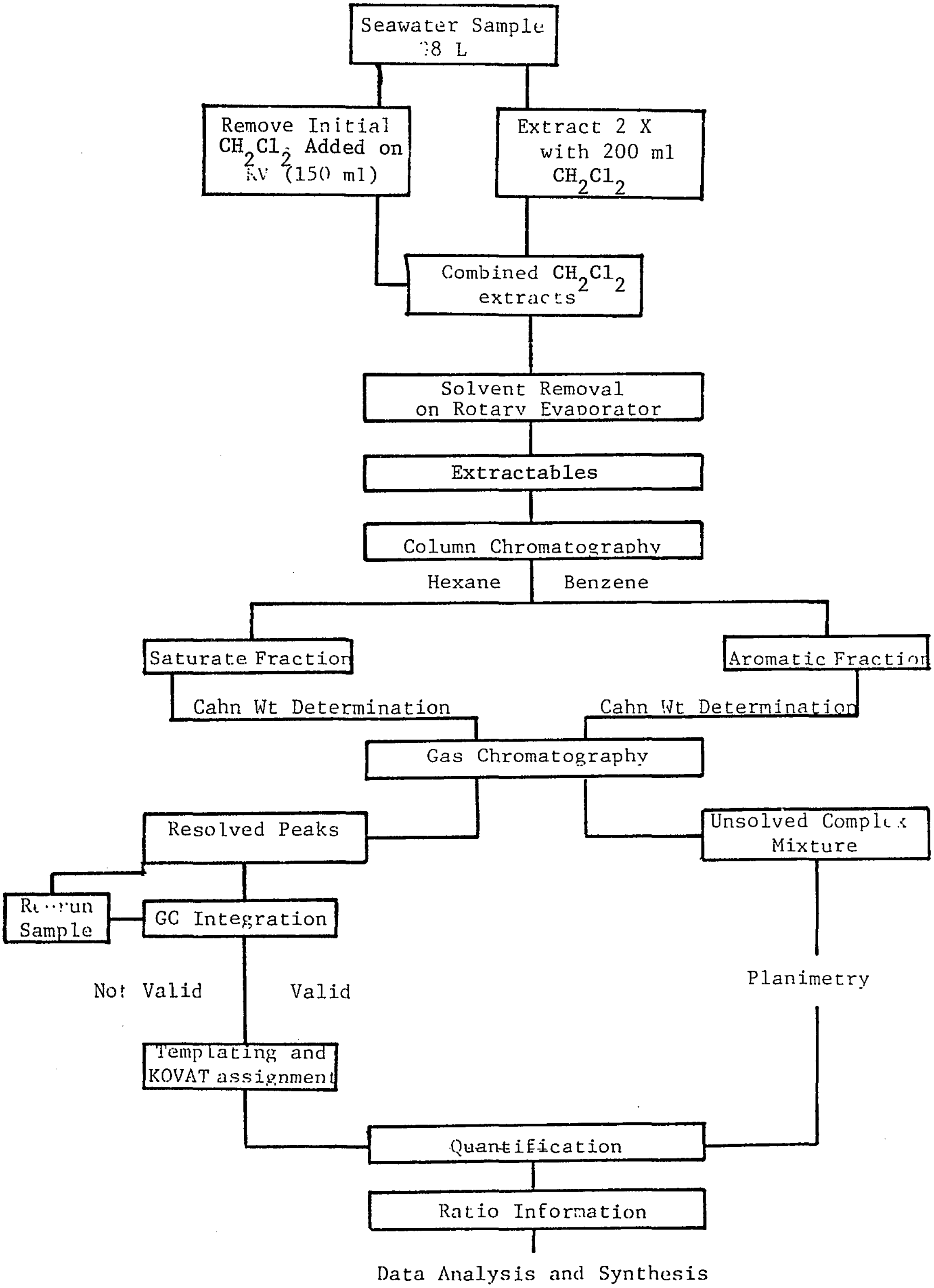


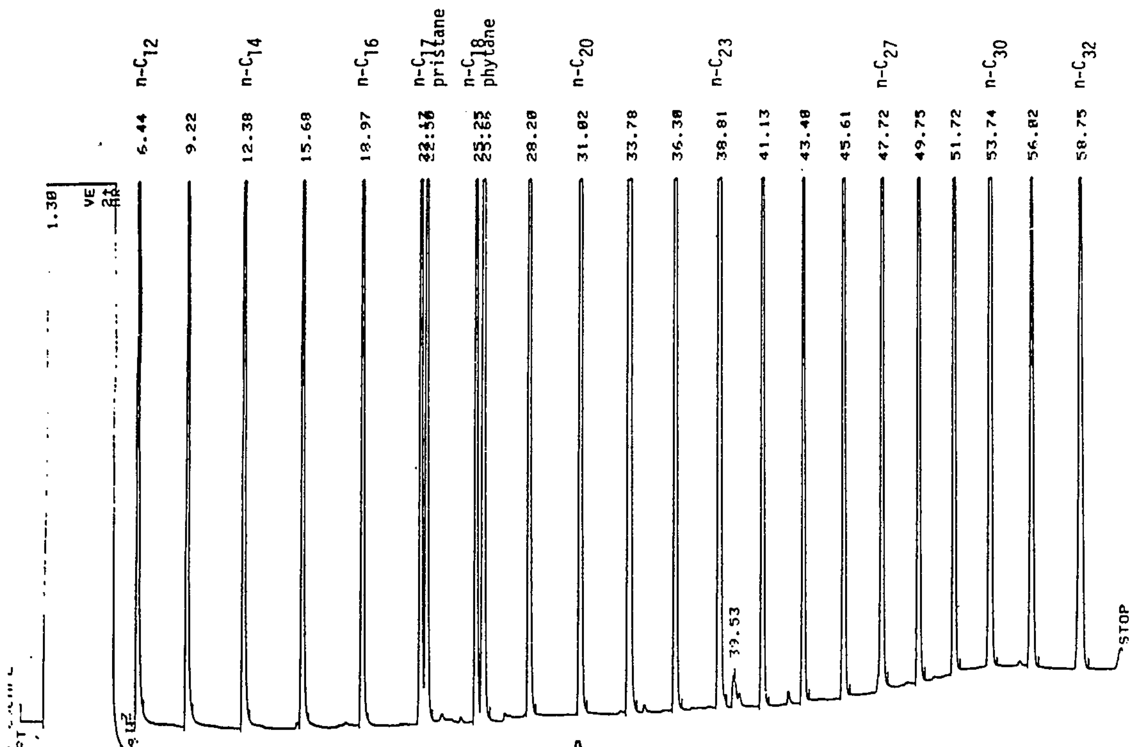
Figure 3.2-6. Seawater Hydrocarbon Analysis Scheme.

Gas chromatography was done using a Hewlett Packard 5840A gas chromatograph equipped with a 30-m glass WCOT capillary column. The liquid phase used was SP2100, and the carrier gas was nitrogen at a flow rate of about 1.0 ml/min. Peak detection was accomplished using a hydrogen flame ionization detector. Program conditions included injector and detector temperatures of 275^{o} and 325^{o}C. After injection, the oven was held at 45^{o}C for 1.0 min., after which the excess solvent was purged and the oven temperature was rapidly increased to 110^{o}C. The oven was then linearly temperature programmed at 4^{o}C/min to 270^{o}C where it was held for 30 minutes. Retention data were compared to known n-alkane standards and KOVAT indices were assigned to each of the resolved peaks. Retention time reproducibility was maintained at better than 0.05 minutes up to 60 minutes after injection (Figure 3.2-7). The unresolved complex mixture (UCM) of each was quantified by planimetry, and characteristic peak ratios then computed. Assignment of KOVAT indices to branched or cyclic compounds eluting between n-alkanes was done by interpolation. Assignment of KOVAT indices to peaks in the benzene (aromatic) fraction was made by direct correlation of unknown peaks with retention times from the n-alkanes standard run completed prior to sample injection (Payne et al., 1977c).

Quantification of all samples was completed using response factors determined from even and odd n-alkanes in the n-C_{12} to n-C_{32} range; the gas chromatograph was recalibrated at least every 10 injections (5 samples). For quantification of compounds eluting between n-alkanes, the weighted average of the response factors from adjacent n-alkanes was used. Unresolved complex mixtures (UCMs) were measured in triplicate by planimetry; the planimeter area was converted to the gas chromatograph's standard area units at a given attenuation and quantitated using the average response factors (μg/integrator counts) of all the n-alkanes occurring within the range of the UCM (Payne et al., 1977c).

The Hewlett-Packard 5840A gas chromatograph used in this program is directly interfaced with a dedicated data storage system and DEC-10 in-house computer. This allows retention time and peak area data for all resolved peaks in samples and standards to be stored following each run. Thus, in addition to recording the total concentration of unknowns in the unresolved complex mixture, it was possible (and feasible) to calculate a KOVAT index and concentration (in μg/g dry weight of sample) for every resolved peak (compound) in a sample. Examples of the gas chromatographic raw data output and DEC-10 computer reduced data output are shown for a moderately contaminated sediment sample in Figures 3.2-8 and 3.2-9, respectively.

As a minimum, the following additional diagnostic information was also obtained:



A

HP RUN # 4 MAY/30/78 TIME 08:28:22
ID:274-05-30-78 BOTTLE 21
ESTD

RT	EXP RT	AREA	CAL #	AMT
6.44	6.43	26590	2	0.041
9.22	9.22	26710	3	0.042
12.38	12.39	28660	4	0.045
15.68	15.68	25860	5	0.042
18.97	18.97	28060	24	0.044
22.17	22.17	26460	6	0.044
22.50	22.50	26730	7	0.044
25.25	25.25	27280	8	0.041
25.66	25.67	42370	9	0.064
28.20	28.21	38360	10	0.056
31.02	31.03	45040	11	0.062
33.78	33.79	121700	12	0.167
36.30	36.31	47070	13	0.062
38.81	38.92	89400	14	0.122
41.13	41.15	32770	15	0.042
43.40	43.42	24200	16	0.039
45.61	45.62	33170	17	0.043
47.72	47.73	30660	18	0.039
49.75	49.77	29760	19	0.040
51.72	51.74	30610	20	0.043
53.74	53.75	40350	21	0.060
56.02	56.04	21630	22	0.035
58.75	58.78	27310	23	0.045

DIL FACTOR: 1.0000 E+ 0

B

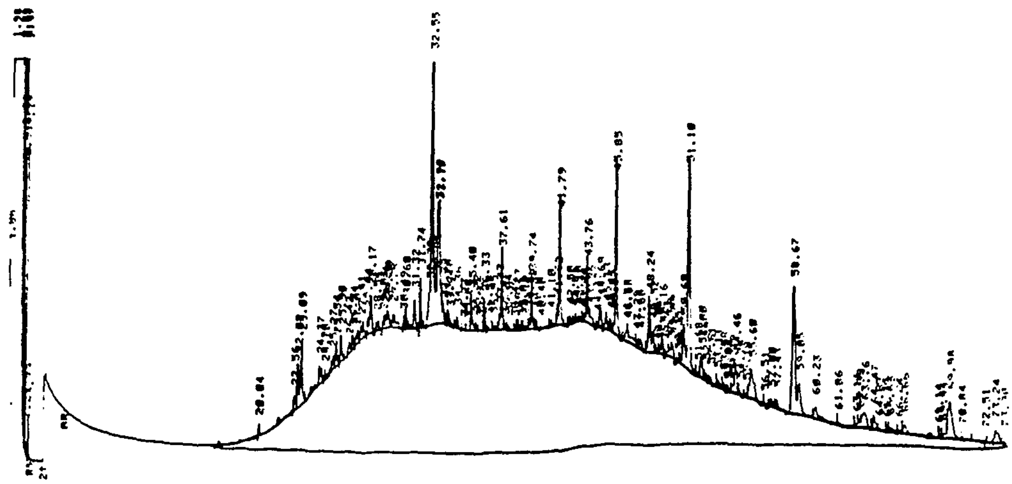
ESTD
% RTW: 5.00 CALIB RUNS 1

CAL #	RT	AMT	AMT/AREA
(R) 1	100.00	4.3800 E- 2	1.5682 E- 6
2	6.43	3.9400 E- 2	1.5242 E- 6
3	9.22	4.0800 E- 2	1.5567 E- 6
4	12.39	4.4300 E- 2	1.5670 E- 6
5	15.68	4.1800 E- 2	1.6246 E- 6
6	22.17	4.3900 E- 2	1.6441 E- 6
7	22.50	4.3600 E- 2	1.6299 E- 6
8	25.25	4.1400 E- 2	1.5132 E- 6
9	25.67	6.4600 E- 2	1.5122 E- 6
10	28.21	5.6700 E- 2	1.4610 E- 6
11	31.03	6.2900 E- 2	1.3731 E- 6
12	33.79	1.7000 E- 1	1.3710 E- 6
13	36.31	6.3400 E- 2	1.3165 E- 6
14	38.82	1.2400 E- 1	1.3608 E- 6
15	41.15	4.3200 E- 2	1.2969 E- 6
16	43.42	3.9900 E- 2	1.6089 E- 6
17	45.62	4.3500 E- 2	1.2958 E- 6
18	47.73	4.0600 E- 2	1.2848 E- 6
19	49.77	3.9600 E- 2	1.3320 E- 6
20	51.74	4.1900 E- 2	1.3925 E- 6
21	53.75	5.8300 E- 2	1.4353 E- 6
22	56.04	3.3000 E- 2	1.5973 E- 6
23	58.78	4.3000 E- 2	1.6580 E- 6
24	18.97	4.3900 E- 2	1.5682 E- 6

DIL FACTOR: 1.0000 E+ 0

C

Figure 3.2-7. Temperature programmed glass capillary FID gas chromatogram of SAI's laboratory n-alkane standard (A); data output of expected and actual compound retention times in minutes and amounts in µg (B); and expected individual compound amounts and calculated response factors from previous calibration runs (C).



HP RUN # 139 JAN/14/78 TIME 15:00:12
ID:854-1
ESTD

RT	EXP RT	AREA	CAL #	AMT
22.82	22.80	1650	6	0.014
23.09	23.09	3204	7	0.026
25.54	25.54	1094	8	0.009
25.90	25.91	1781	9	0.014
28.17	28.17	2406	10	0.019
30.68	30.69	1038	11	0.008
32.99	33.14	1825	12	0.015
35.40	35.42	2215	13	0.025
37.61	37.64	3225	14	0.042
39.74	39.74	2041	15	0.027
41.79	41.77	2000	16	0.049
43.76	43.74	2579	17	0.037
45.85	45.80	8606	18	0.125
48.24	48.14	3965	19	0.061
51.10	50.90	17920	20	0.227
54.46	54.21	2450	21	0.040
58.67	58.23	16150	22	0.276
63.76	63.15	2229	23	0.039

DIL FACTOR: 1.0000 E+ 0

ESTD
% RTW: 5.00 CALIB RUNS 1

CAL #	RT	AMT	AMT/AREA
(R) 1	100.00	1.2900 E- 1	6.8363 E- 6
2	9.22	1.3800 E- 1	9.8654 E- 6
3	11.59	1.4300 E- 1	9.6864 E- 6
4	14.28	1.5500 E- 1	9.1204 E- 6
5	17.11	1.4600 E- 1	8.9297 E- 6
6	22.80	1.5300 E- 1	8.3974 E- 6
7	23.09	1.5300 E- 1	8.1950 E- 6
8	25.54	1.4500 E- 1	8.0155 E- 6
9	25.91	2.2600 E- 1	7.9522 E- 6
10	28.17	1.9900 E- 1	8.0993 E- 6
11	30.69	2.2000 E- 1	8.2459 E- 6
12	33.14	5.9600 E- 1	9.6393 E- 6
13	35.42	2.2200 E- 1	1.1269 E- 5
14	37.64	4.3200 E- 1	1.2876 E- 5
15	39.74	1.5100 E- 1	1.3339 E- 5
16	41.77	1.4000 E- 1	1.7522 E- 5
17	43.74	1.5200 E- 1	1.4206 E- 5
18	45.80	1.4200 E- 1	1.4579 E- 5
19	48.14	1.3900 E- 1	1.5261 E- 5
20	50.90	1.4700 E- 1	1.6041 E- 5
21	54.21	2.0400 E- 1	1.6372 E- 5
22	58.23	1.1500 E- 1	1.7096 E- 5
23	63.15	1.5800 E- 1	1.7389 E- 5
24	19.98	1.5300 E- 1	6.8363 E- 6

DIL FACTOR: 1.0000 E+ 0

HP RUN # 139 JAN/14/78 TIME 15:00:12
ID:854-1
AREA %

RT	AREA	AREA %
22.56	311	0.207
22.82	1650	1.099
23.09	3204	2.133
24.37	679	0.452
25.27	265	0.176
25.54	1094	0.728
25.90	1781	1.186
26.42	235	0.156
26.74	572	0.381
27.03	235	0.156
27.41	484	0.322
27.94	414	0.276
28.17	2406	1.602
28.54	346	0.230
29.03	246	0.164
29.21	203	0.135
29.39	255	0.170
30.68	1038	0.691
31.32	1680	1.119
31.74	2821	1.878
32.55	19560	13.023
32.99	1825	1.215
33.70	543	0.362
34.36	1328	0.884
35.40	2215	1.475
36.33	2003	1.334
36.59	256	0.170
36.95	310	0.206
37.43	283	0.188
37.61	3225	2.147
38.04	514	0.342
38.73	567	0.378
39.19	327	0.218
39.56	311	0.207
39.74	2041	1.359
40.85	500	0.333
41.10	686	0.457
41.62	668	0.445
41.79	2800	1.864
42.50	807	0.537
43.10	495	0.330
43.76	2579	1.717
43.96	341	0.227
44.47	265	0.176
44.69	1867	1.240
45.13	1511	1.006
45.43	339	0.226
45.67	269	0.179
45.85	8606	5.730
47.60	881	0.587
48.24	3965	2.640
48.52	1056	0.704
49.16	1381	0.919
49.89	650	0.437
50.66	3189	2.123
51.10	17920	11.931
52.00	1931	1.286
52.29	460	0.306
52.61	475	0.316
53.58	397	0.264
54.46	2450	1.631
54.74	232	0.154
55.60	5807	3.866

~~~ETC.~~~

Figure 3.2-8. Typical FID gas chromatogram and raw data report from the hexane fraction of a moderately polluted benthic sediment extract.
~~~

```
1,251 854.1 BLM SAMPLE NUMBER.HEPTANE FRACTION
      1 FILE NUMBER OF SAMPLE 854.1
 110  478  1  0  0.2 SAI SAMPLE NUMBER
4,249 2 TYPE OF SAMPLE: BENTHIC SEDIMENT
STATION NO: 110
1,253 4.04 MONTH.DAY
1,254 1978 YEAR
1,255 1 REPLICATE NUMBER
2,254 90 WET WEIGHT SEDIMENT
      90 DRY WEIGHT SEDIMENT
2,249 0.2 TIDE HEIGHT . SAMPLE DEPTH
2,255 1 WEIGHT NSL RECOVERED
2,256 100 PERCENT NSL ON LC COLUMN
1,250 359.982 WT. OF ALIQUOT FOR CAHN
      5714. TOTAL HYDROCARBON RECOVERED BY WEIGHT
      0.5714 WT.OF FRACTION AS % OF NSL
3,251 6.3 VOLUME OF ALIQUOT FOR CAHN
3,252 100 INITIAL VOLUME FOR CAHN
3,253 182 PIV
1,249 2 INJECTION VOLUME
3,254 5 SAMPLE GC ATTENUATION: LOG BASE 2
3,255 737 UNRESOLVED ENVELOPE AREA
4,251 16.32 SMALLEST.LARGEST N-ALKANE FOR DETERMINING
           AVERAGE RESPONSE FACTOR FOR UCM
4,253 0 FILE NUMBER FOR CALIBRATION ID:




TOTAL RESOLVED HYDROCARBON = 2.27461
TOTAL UNRESOLVED HYDROCARBON = 26.6038
RESPONSE FACTOR AV. FOR C - 1600 TO 3200 FOR UCM =  12.658
RATIO: RESOLVED/UNRESOLVED = 8.54994E-2

SUM OF THE N-ALKANES = 1.17398
SUM OF THE EVEN N-ALKANES = 0.267864
SUM OF THE ODD N-ALKANES = 0.906118

RATIO: (PRISTANE+PHYTANE)/(N-ALKANES) = 3.75610E-2
RATIO: ODD/EVEN  N-ALKANES = 3.38275
RATIO: PRISTANE/C-17 = 1.89502
RATIO: PHYTANE/C-18 = 1.61511
RATIO: PRISTANE/PHYTANE = 1.85392
RATIO: (N-ALKANES)/(BRANCHED HYDROCARBONS) = 1.06665
```

LAB = BLM-854.1	FRAC HEX	RETENTION KOVAT DAMOYR 40478.		CONCENTRATION
RETENTION TIME	KOVAT INDEX	CONCENTRATION UG/GM	WT%	ASSIGNMENT
22.56	1691	0.0028	0.12	
22.82	1700	0.01512	0.66	NC 17
23.09	1710	0.02864	1.26	PRISTANE
24.37	1757	6.06000E-3	0.27	
25.27	1790	2.33000E-3	0.1	
25.54	1800	9.57000E-3	0.42	NC 18
25.9	1815	1.54500E-2	0.68	PHYTANE
26.42	1833	0.00206	0.09	
26.74	1846	5.03000E-3	0.22	
27.03	1857	0.00207	0.09	
27.41	1871	0.00426	0.19	
27.94	1891	3.65000E-3	0.16	
28.17	1900	2.12600E-2	0.93	NC 19
28.54	1915	0.00307	0.13	
29.03	1934	0.00219	0.1	
29.21	1941	1.81000E-3	0.08	
29.39	1949	2.27000E-3	0.1	
30.68	2000	9.34000E-3	0.41	NC 20
31.32	2028	0.01582	0.7	
31.74	2046	0.02735	1.2	
32.55	2081	0.20003	8.79	
32.99	2100	1.91900E-2	0.84	NC 21
33.7	2129	5.99000E-3	0.26	
34.36	2157	0.01531	0.67	
35.4	2200	0.02723	1.2	NC 22
36.33	2242	2.61000E-2	1.15	
36.59	2254	0.00339	0.15	
36.95	2270	0.00419	0.18	
37.43	2292	0.00392	0.17	
37.61	2300	4.53000E-2	1.99	NC 23
38.04	2320	0.00727	0.32	
38.73	2353	0.00812	0.36	
39.19	2374	4.72000E-3	0.21	

ETC.

Figure 3.2-9. SAI's DEC-10 computer reduced output on the sediment sample extract presented in Figure 3.2-8.

Volume or wet weight of sample extraced.

Dry weight of sample extracted (for sediments and tissues).

Percent dry weight of wet weight (for sediments and tissues).

Total resolved hydrocarbons recovered by GC ($\mu g/l$ or $\mu g/g$ dry weight of sample).

Total unresolved "hydrocarbons" recovered by GC ($\mu g/l$ or $\mu g/g$ dry weight of sample).

Sum of the n-alkanes ($\mu g/l$ or $\mu g/g$ dry weight).

Sum of the even n-alkanes ($\mu g/l$ or $\mu g/g$ dry weight).

Ratio: Unresolved hydrocarbons/resolved hydrocarbons.

Ratio: (Pristane + phytane) /n-alkanes

Ratio: Odd n-alkanes/even n-alkanes.

Ratio: Pristane/n-C_{17}.

Ratio: Phytane/n-C_{18}.

Ratio: Pristane/phytane.

Ratio: n-alkanes/branched hydrocarbons.

DOC and POC in Seawater

DOC and POC samples were analyzed by infrared spectroscopy using an Oceanography International Corporation Total Carbon Analyzer after persulfate oxidation (Fredericks and Sackett, 1970).

Trace Metals in Surficial Sediments

Each sample was freeze-dryed in a Virtis Unitrap II freeze dryer, ground with an alumina ceramic mortar and pestle, and transferred to polyethylene bottles for storage. Three grams of each were removed and weighed into a polypropylene Erlenmyer flask containing 45 ml of 1 N HNO_3. All glass and plastic ware and utensils were soaked in 3 N HNO_3 for 24 hours and rinsed at least four times with deionized water. Samples were mechanically shaken for two hours. The mixtures were transferred to polypropylene tubes, centrifuged for 20-25 minutes, decanted into 50-ml polypropylene volumetric flasks and brought to volume with 1 N HNO_3. These solutions were transferred in the same manner as the samples. Working standards were prepared by appropriate dilution of 1000 ppm certified standard solutions (Fisher Scientific Co.) with 1 N HNO_3.

Nine trace metals (Cd, Cr, Cu, Pb, Ni, Zn, Fe, Al and Mn) were analyzed by using a Perkin Elmer 603 atomic absorption spectrophotometer. For flameless requirements, an HGA 2200 graphite/furnace and an AS-1 Autosampling system were utilized. Standard conditions were those published by Perkin Elmer. The precision of each type analysis was determined for each element by quintuplication of several samples as well as NBS standards (plastic clay, bovine liver): Al, 7%; Cd, 15%, Cr, 10%; Cu, 2%; Fe, 3%; Pb, 10%; Mn, 2%; Ni, 3%; Zn, 3%.

HMWHCs in Surficial Sediments

Figure 3.2-10 summarizes the HMWHC analysis procedures for sediments. Each sample was thawed and transferred to a tared glass jar. Nanograde methanol was added and the samples were placed on a shaker table for 30 minutes. After shaking, the samples were centrifuged (1500 rpm, 15 minutes, 20°C) and the supernate (methanol and water) decanted into a separatory funnel. The procedure was repeated, the supernates combined and back extracted in triplicate with hexane.

After methanol drying, 300 ml of a 9:1 (v/v) mixture of methylene chloride/methanol was added to the sample and extraction was continued on a shaker table for four hours. The sample was centrifuged and the solvent phase retained. The extraction was repeated with the shaking time extended to 24 hours. The methylene chloride methanol extracts were combined with the hexane extracts (from the drying procedure) and reduced in volume on a rotary evaporator at 40°C.

Each extract was transferred to a pre-tared vial and reduced to near dryness under a stream of pre-purified nitrogen and weighed. If the extract appeared to contain large amounts of clay, it was cleaned on a short bed of silica gel and eluted with methylene chloride, taken to near dryness, weighed and dissolved in 1-2 ml of hexane. The sediment extract was then tested for the presence of elemental sulfur with copper (Zaferious et al., 1972), and if necessary elemental sulfur was removed by treating the sediment extract with activated copper (prepared by washing in sequence with hydrocloric acid, methanol and hexane before sample exposure). Of the 20 samples collected, two were lost due to contamination. Column and gas chromatographic analysis were performed as described for seawater dissolved HMWHCs.

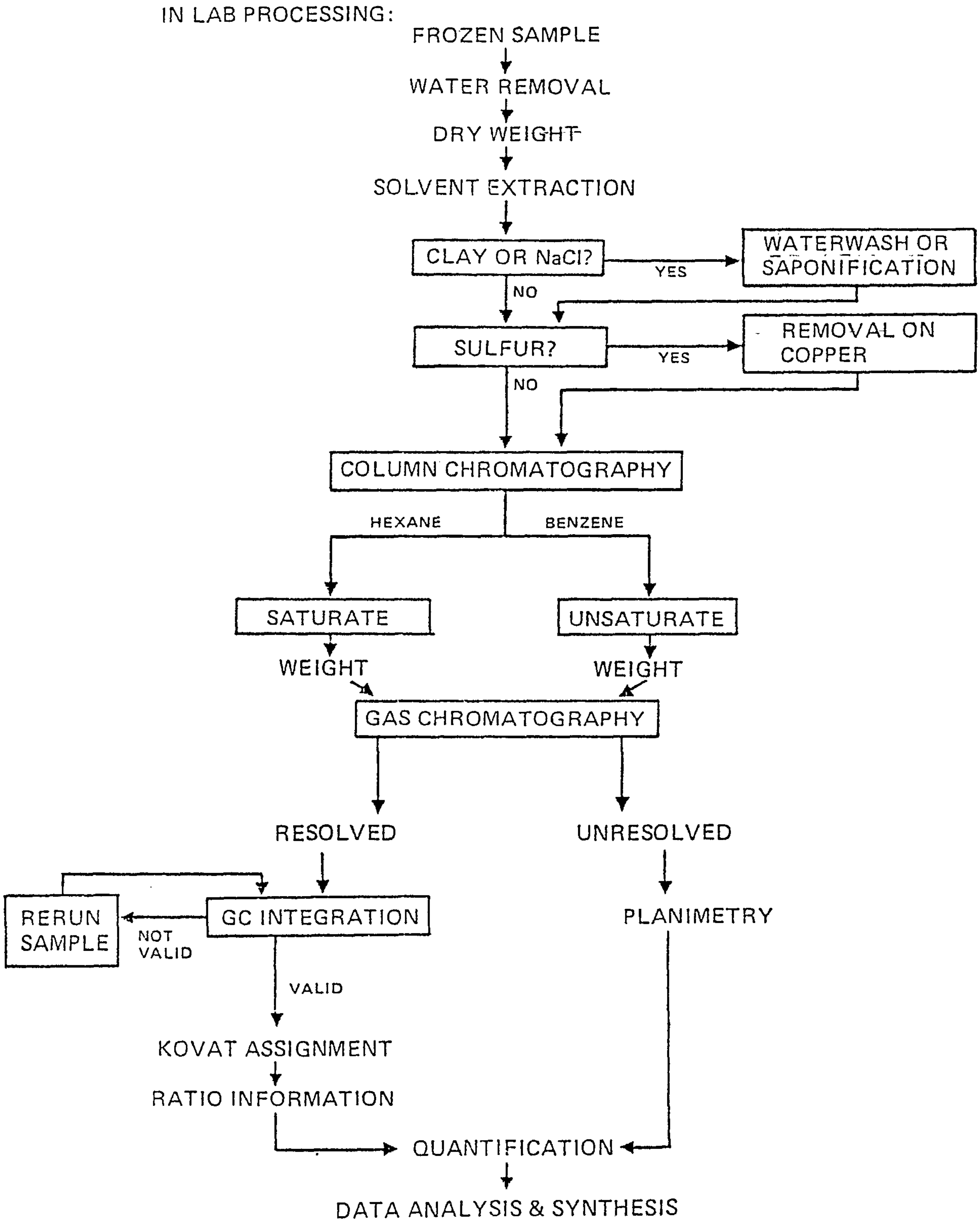


Figure 3.2-10. Flowchart of sediment analyses of HMWHC

ATP in Surficial Sediments

One-ml aliquots of luciferan-luciferase (firefly) enzyme solution were pipetted into small glass scintillation vials which were then placed one-at-a-time into the cell of an SAI ATP photometer. A specially-fitted automatic pipette was loaded with a 0.2 ml of a thawed sample and placed on top of the sample holder of the photometer. Prior to each assay the background light was recorded for a few seconds.

Each sample was then injected automatically into the enzyme preparation and the peak height of the emitted light recorded. ATP standards (Sigma brand), assayed in the same manner, were used to convert peak height to absolute concentration of ATP.

TOC and % $CaCO_3$ in Surficial Sediments

Samples were analyzed by combustion in a LECO induction furnace equipped with an infrared carbon analyzer. Percent $CaCO_3$ was calculated as the difference of total carbon and total organic carbon, each having been measured in separate assays with the LECO instrument.

Sediment Texture of Surficial Sediments

Grain size analyses were determined by the pipette method of Folk (1968), complete with seiving. Per cent clay, silt, sand and gravel fractions calculated.

HMWHCs in Biota

Figure 3.2-11 outlines the HMWHC analysis procedures for macrobiota. Faunal specimens were thawed and diced into homogenates. An aliquot of each was removed, weighed, and dried in an oven at 60°C to determine dry weight. The remainder of each sample was weighed, placed in a 1:1 mixture (methanol: 1.0 N KOH in water), and refluxed overnight at 80°C. The digested samples were transferred to separatory funnels and back extracted in triplicate with hexane. The hexane extracts were then reduced in volume on a rotary evaporator.

In most cases a hexane-soluble gelatinous matrix was contained in the extract. This matrix was removed prior to column chromatography by elution with methylene chloride over a small bed (1-2 cm) of silica gel. Column and gas chromatography and data reduction were identical to those previously described for the seawater dissolved HMWHCs.

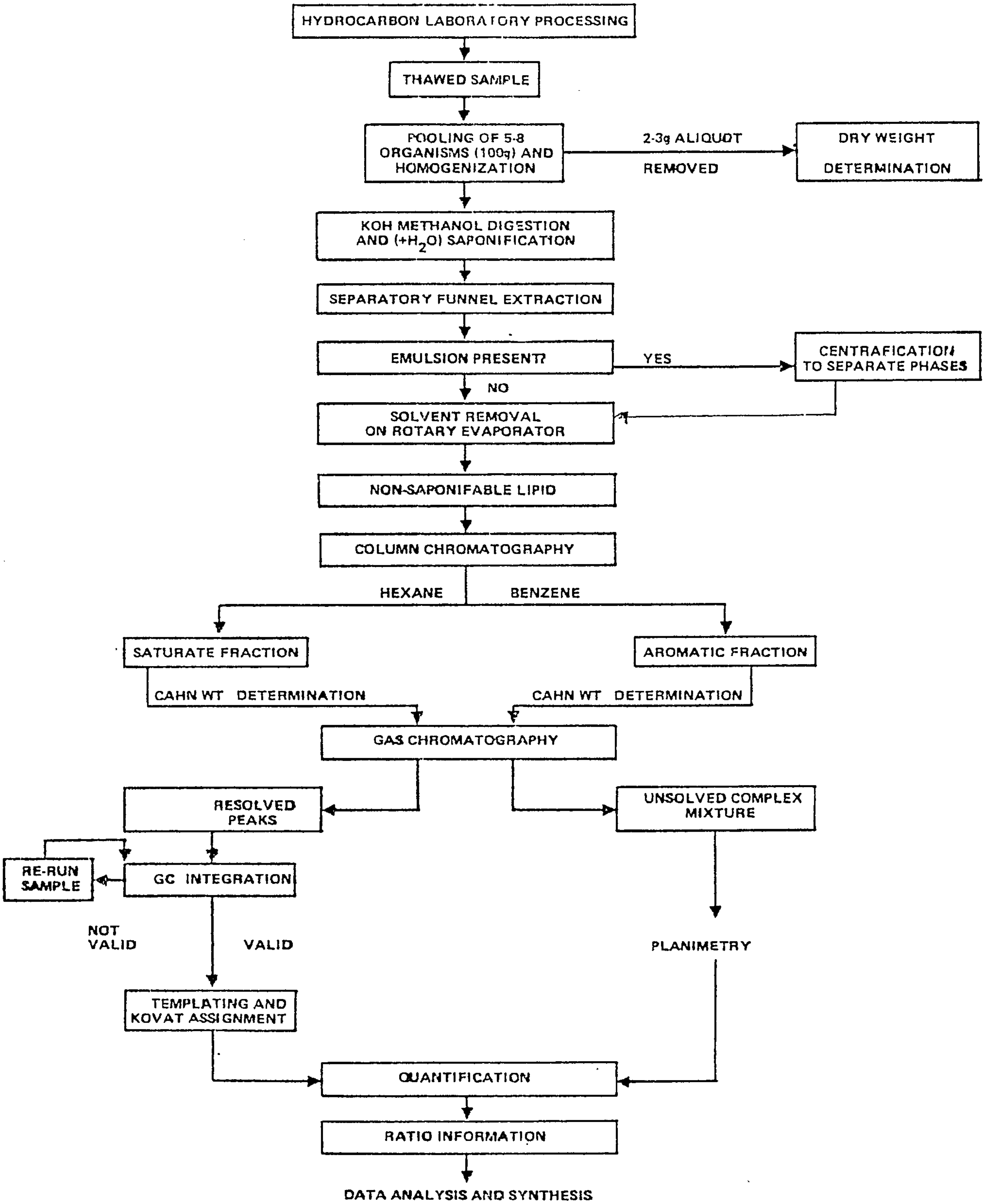


Figure 3.2-11. Procedures flow chart for HMWHC analyses of macrocrustacea and demersal fin-fish samples.

Trace Metals in Biota

Faunal samples to be analyzed for heavy metal contents were thawed and processed according to specimen type. Shrimp were de-headed and their exoskeletons were removed, leaving only the body flesh to be analyzed. Fish specimens were fileted and the outer skin and scales removed. Zooplankton were treated as whole samples.

After preparation the tissues were freeze-dried and powdered for homogenization with an agate mortar and pestle. Approximately 1.0 g of the dried tissue powder of each was weighed into a 200-ml tall form Pyrex beaker. Ten ml of redistilled HNO_3 were added to each and the samples were allowed to sit overnight at room temperature with watchglass covers. The samples were then placed on a hot plate and slowly heated until NO_2 fuming ceased. The temperature was then increased to 200-300^oC until dryness and then charring was achieved.

After charring, the residues were brought into solution with the addition of 5.0 ml concentrated HNO_3. Once the temperature was increased, 2.0 ml of Ultrex H_2O_2 were added slowly until oxidative frothing ceased. Then the solutions were transferred to 50-ml polypropylene flasks and brought to volume with deionized, Milli-Q water.

Sample blanks were prepared similarly and atomic absorption spectrophotometry was performed as described in the sediment analysis section.

3.3 RESULTS

3.3.1 WEST HACKBERRY DISPOSAL SITE AND CONTROL SITE

3.3.1.1 Heavy Metals Chemistry

In obtaining trace heavy metal concentrations in the suite of samples (sediment, biota, water, particulates) collected from the West Hackberry Disposal and Control Sites, several goals were in mind. The foremost goal was the collection of reliable baseline information for comparison against future conditions when attempting to determine adverse effects by the proposed brine discharge during its operation. Another goal was to obtain accurate concentrations of several recognized "environmentally significant" heavy metals for all sample types and relate those values to historical data from the near vicinity (when possible). Finally, the correlation of heavy metal concentrations with ancillary geochemical data can be used to explain the levels and distributions found. In taking this approach, the result has been the compilation of reliable chemical data useful for baseline reference points and for predictive modelling (to the extent that the science is capable).

Sediments

The approach taken for metal analyses of deposited surficial sediments was to approximate "biologically available" metal content by utilizing a relatively weak acid (1 $\underline{N}$ HNO_3) leach rather than total mineral dissolution. A variation of this technique is recognized by ASTM and, although there are few comparable data available from the vicinity of the study sites, the results have provided very interesting information for this particular study because they approximate loosely sorbed metal contents subject to perturbation in the event of altered ionic strength and other effects of brine intrusion.

The sediment trace metal data presented in Table 3.3-1 are best correlated with the sedimentary parameters of total organic carbon (TOC) and grain size distribution (especially the proportion of fine-grained material). Figures 3.3-1 through 3.3-4 plot per cent fines (weight fraction $<63\ \mu m$) and per cent total organic carbon over the areal dimensions of the two sampling stations. As indicated in Table 3.3-2, there is considerable difference in the composition of the sediments at the West Hackberry disposal site and West Hackberry control site. The per cent fines in the sediments at the West Hackberry site is much higher than at the control site. This reflects the sediment input into the area from Calcasieu River and, possibly from past offshore dredge spoil disposal. Also an inverse relationship exists between total organic carbon (TOC) and grain size. The finer-grained West Hackberry disposal site sediments also have higher TOC concentrations.

Table 3.3-1. Heavy Metal Distributions in Sediments from around the West Hackberry Brine Diffuser Site and also a Control Site. See Figures 3.2-1 through 3.2-5 for Station Locations (from 1N HNO_3 leach; concentrations as dry weight of sediment). Included for each metal are its concentration (*) as well as its metal/iron ratio (**). Exponents for metal/iron ratios are of ten.

Site	Station	TOC (%)	$CaCO_3$ (%)	Fines (%)	Fe (%)	Mn (ppm)	Zn (ppm)	Pb (ppm)	Ni (ppm)	Cr (ppm)	Cu (ppm)	Cd (ppm)	Al (%)
W. Hack-berry	7	.57	2.6	83.5	.3841	302. *	20.3	13.2	4.36	2.34	5.34	0.061	.135
						7.86^{-2} **	5.30^{-3}	3.44^{-3}	1.13^{-3}	6.09^{-4}	1.40^{-3}	1.59^{-5}	3.51^{-1}
	8	.97	2.1	99.2	.5593	443.3	26.63	18.04	5.61	3.36	5.02	0.0693	.1889
						7.92^{-2}	4.76^{-3}	3.22^{-3}	1.00^{-3}	6.00^{-4}	8.97^{-4}	1.24^{-5}	3.37^{-1}
	9	.69	2.7	90.8	.4383	390.5	21.81	16.31	4.98	2.66	7.81	0.0742	.1471
						8.91^{-2}	4.97^{-3}	3.72^{-3}	1.13^{-3}	6.07^{-4}	1.78^{-3}	1.70^{-5}	3.35^{-1}
	10	.54	6.8	81.0	.3874	301.3	20.17	14.61	4.58	2.25	6.48	0.0738	.1222
						7.77^{-2}	5.20^{-3}	3.77^{-3}	1.18^{-3}	5.81^{-4}	1.67^{-3}	1.90^{-5}	3.154^{-1}
	12	.64	3.7	74.2	.4105	366.8	20.93	14.88	4.37	2.35	7.09	0.0683	.1347
						8.93^{-2}	5.10^{-3}	3.62^{-3}	1.06^{-3}	5.72^{-4}	1.72^{-3}	1.66^{-5}	3.28^{-1}
	13	.72	3.1	92.6	.4535	395.6	21.93	16.08	4.67	2.53	8.53	0.0760	.1438
						8.72^{-2}	4.83^{-3}	3.54^{-3}	1.03^{-3}	5.58^{-4}	1.88^{-3}	1.67^{-5}	3.17^{-1}
	14	.57	2.7	66.5	.3885	301.5	20.51	13.29	4.13	2.27	7.26	0.0624	.1319
						7.76^{-2}	5.28^{-3}	3.42^{-3}	1.06^{-3}	5.84^{-4}	1.87^{-3}	1.60^{-5}	3.39^{-1}
	15	.72	3.7	86.8	.4543	401.9	23.88	17.14	5.19	2.84	8.82	0.0842	.1558
						8.84^{-2}	5.25^{-3}	3.77^{-3}	1.14^{-3}	6.25^{-4}	1.94^{-3}	1.85^{-5}	3.43^{-1}
	17	.49	3.8	72.3	.3795	285.0	20.21	11.92	4.50	2.19	6.89	0.0532	.1317
						7.58^{-2}	5.37^{-3}	3.17^{-3}	1.19^{-3}	5.82^{-4}	1.83^{-3}	1.41^{-5}	3.50^{-1}
	18	.47	2.4	61.7	.3535	243.0	19.12	11.44	3.80	1.95	4.49	0.0653	.1139
						6.78^{-2}	5.41^{-3}	3.23^{-3}	1.07^{-3}	5.51^{-4}	1.27^{-3}	1.84^{-5}	3.22^{-1}
	19	.52	2.1	80.9	.4281	295.6	20.23	12.36	4.30	2.27	5.29	0.0619	.1315
						6.90^{-2}	4.72^{-3}	2.88^{-3}	1.0^{-3}	5.30^{-4}	1.23^{-3}	1.44^{-5}	3.07^{-1}
	22	.46	2.2	41.9	.3797	283.1	19.36	11.21	4.03	1.88	4.92	0.0533	.1165
						7.45^{-2}	5.10^{-3}	2.95^{-3}	1.06^{-3}	4.95^{-4}	1.29^{-3}	1.40^{-5}	3.07^{-1}
W. Hack-berry Control	27	.39	4.2	43.6	.3624	264.2	19.57	11.16	3.78	1.80	4.49	0.0546	.1037
						7.29^{-2}	5.40^{-3}	3.08^{-3}	1.04^{-3}	4.96^{-4}	1.24^{-3}	1.50^{-5}	2.86^{-1}
	28	.36	3.7	44.2	.3238	246.9	18.60	10.20	3.46	1.72	4.10	0.0449	.0889
						7.62^{-2}	5.74^{-3}	3.15^{-3}	1.07^{-3}	5.31^{-4}	1.26^{-3}	1.38^{-5}	2.74^{-1}
	29	.38	3.3	52.3	.3465	276.9	18.76	11.54	3.25	1.62	4.48	0.0483	.0965
						7.99^{-2}	5.41^{-3}	3.33^{-3}	9.38^{-4}	4.67^{-4}	1.29^{-3}	1.39^{-5}	2.78^{-1}
	31	.36	3.7	44.3	.3540	262.3	20.01	10.57	3.25	1.70	3.92	0.0433	.0941
						7.41^{-2}	5.65^{-3}	2.98^{-3}	9.18^{-4}	4.80^{-4}	1.10^{-3}	1.22^{-5}	2.66^{-1}
	32	.31	2.4	36.1	.3304	237.9	20.44	9.82	2.99	1.71	3.35	0.0495	.0906
						7.20^{-2}	6.18^{-3}	2.97^{-3}	9.04^{-4}	5.17^{-4}	1.01^{-4}	1.50^{-5}	2.74^{-1}
Mississippi Delta Sediment (Trefry, 1978 per. comm.)					.5-.6		25-30		2-4		3.5-4.0	.04	

Table 3.3-2. Textural Characteristics of Sediments Distributed About the West Hackberry Brine Diffuser Site and Its Control Site.

Site	Station #	% Gravel	% Sand	% Silt	% Clays	% Fines
West Hackberry						
	7		16.5	33.0	50.5	83.5
	8		0.8	15.4	83.8	99.2
	9		9.2	31.6	59.2	90.8
	10	1.3	17.7	34.1	46.9	81.8
	12	0.4	25.4	32.3	41.9	74.2
	13		7.4	24.2	68.4	92.6
	14	1.7	31.8	28.4	38.1	66.5
	15	0.2	13.0	36.1	50.7	86.8
	16		2.9	31.8	65.3	
	17	0.7	27.0	27.2	45.1	72.3
	18		38.3	20.7	41.0	61.7
	19		19.1	22.4	58.5	80.9
	22	2.4	55.7	17.2	24.7	41.9
West Hackberry Control	27	1.7	54.6	20.6	23.0	43.6
	28	3.4	50.8	22.1	23.6	44.2
	29		47.7	26.4	25.9	52.3
	31		55.7	18.2	26.1	44.3
	32		63.9	28.5	7.6	36.1

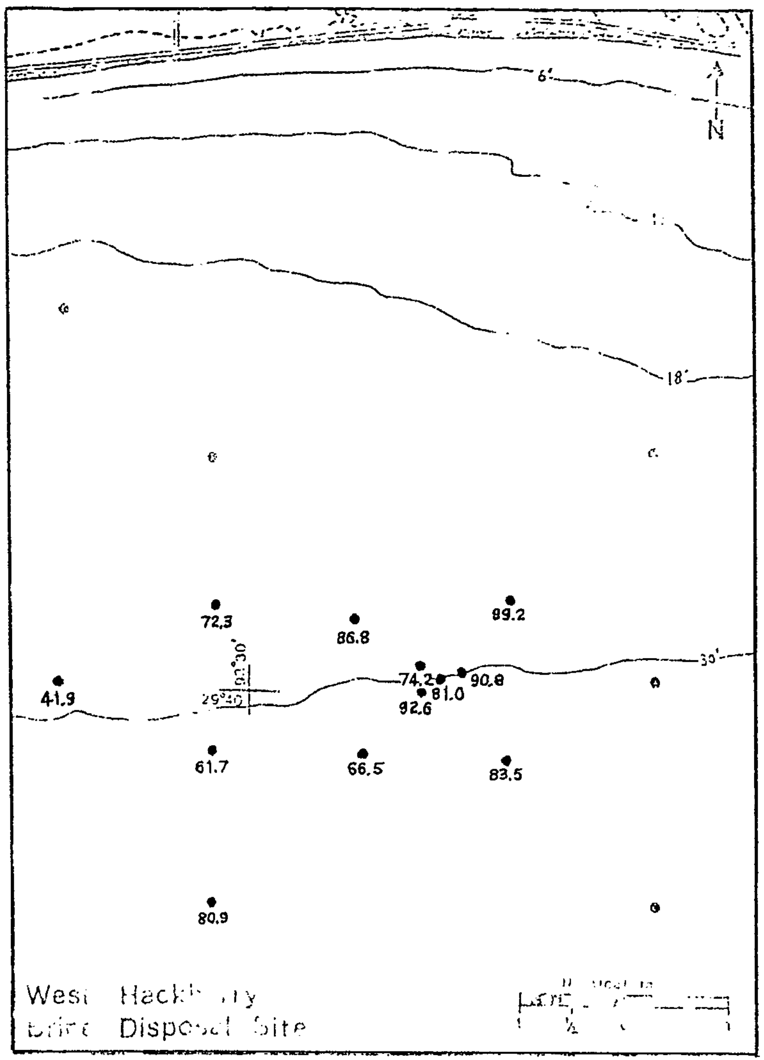


Figure 3.3-1. Percent Fines (Silt and Clay) at the Proposed West Hackberry Disposal Site.

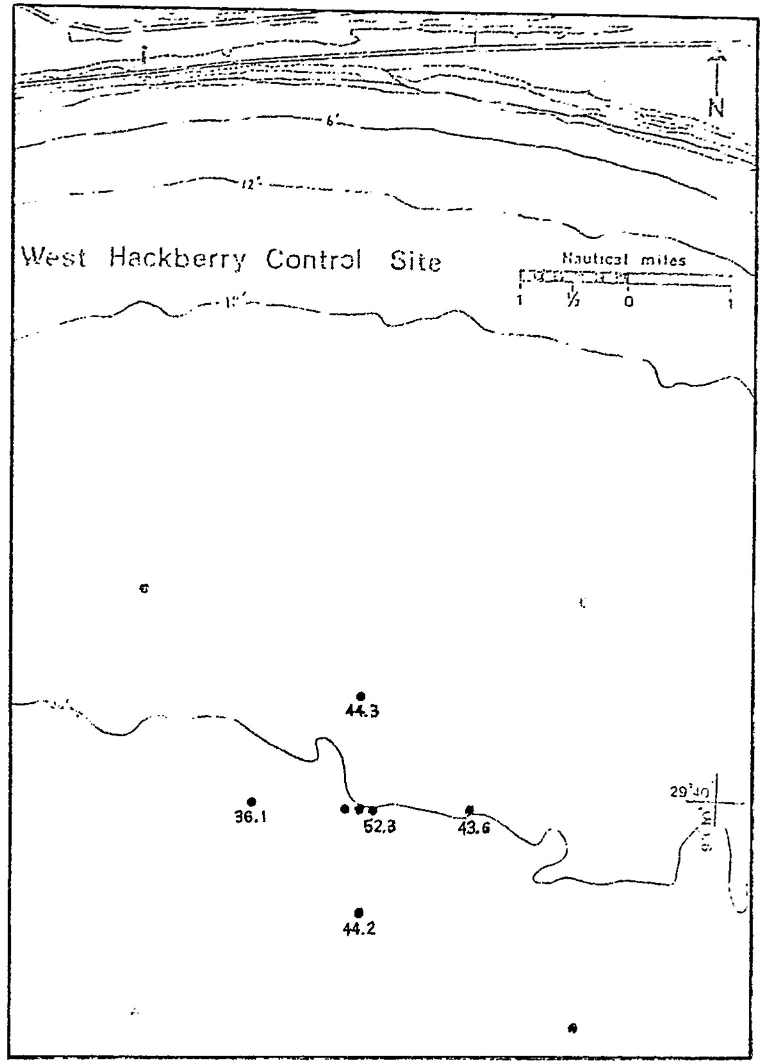


Figure 3.3-2. Percent Fines (Silt and Clay) at the West Hackberry Control Site.

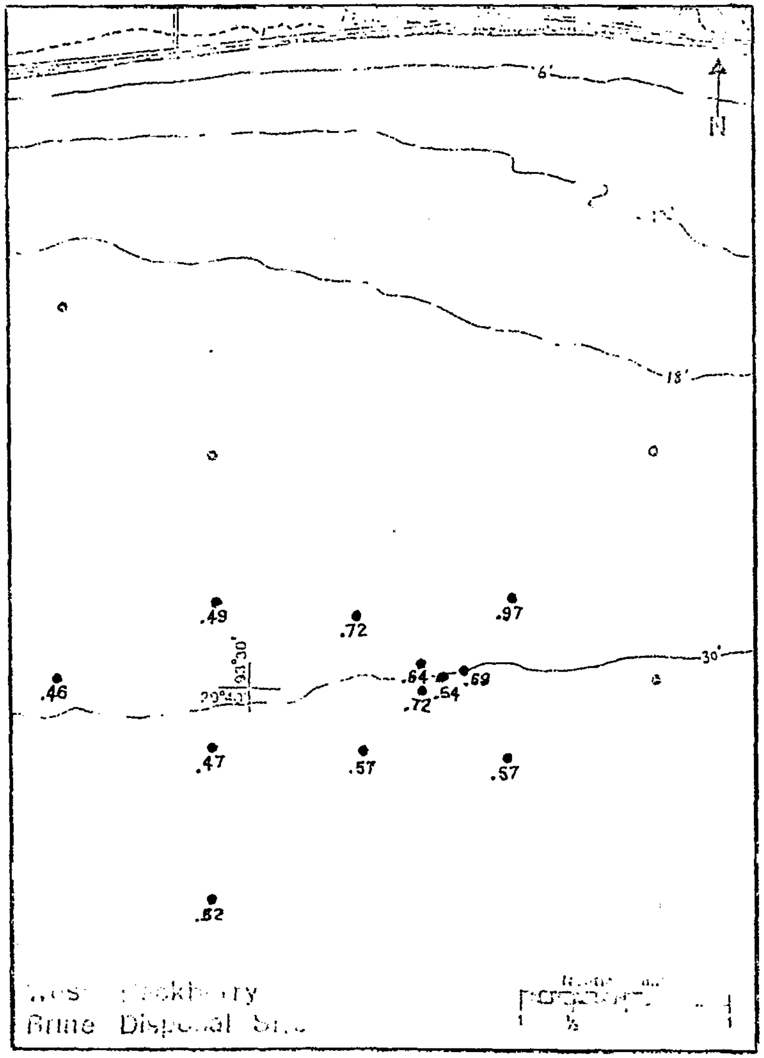


Figure 3.3-3. Total Organic Carbon (% by Weight) at the Proposed West Hackberry Disposal Site (Sediments).

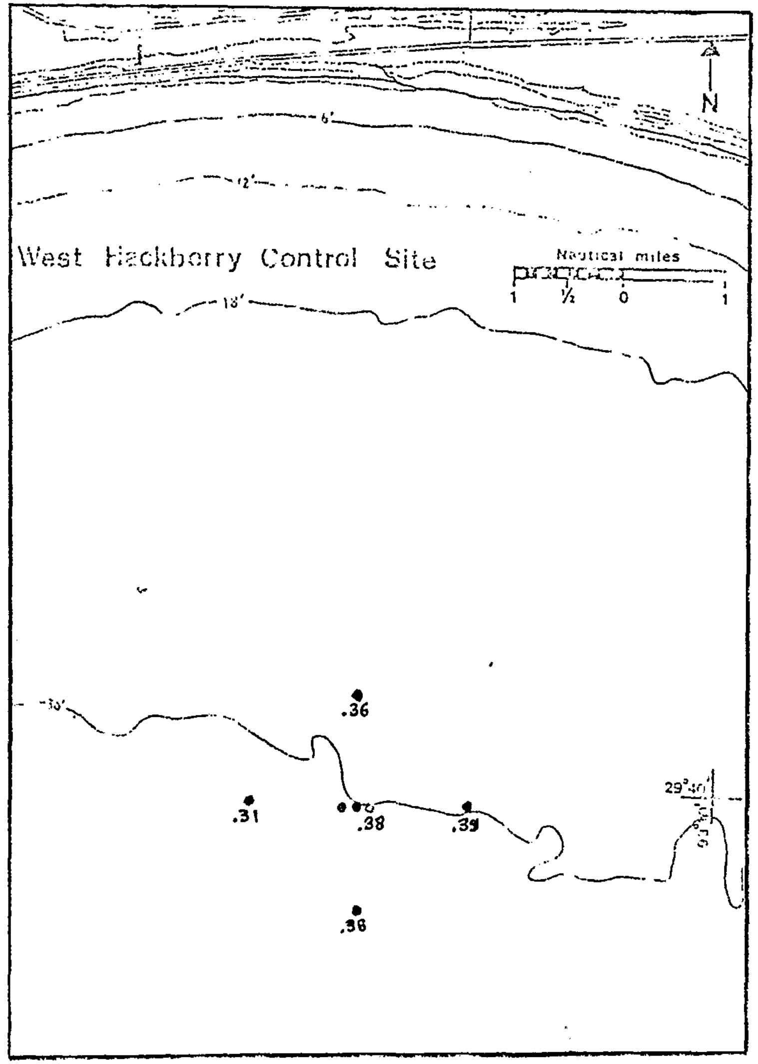


Figure 3.3-4. Total Organic Carbon (% by weight) at the West Hackberry Control Site (Sediments).

Figures 3.3-5 and 3.3-6 help illustrate the metal-to-sediment relationship as leachable Fe is plotted at the two sites. Extending the Fe distribution analysis to other metals in Table 3.3-1, it is readily apparent that leachable metal content is strongly influenced by mean grain size.

Included in Table 3.3-1 is the parameter "metal/iron ratio" which provides an extra dimension to interpretion. Fe is a transition metal like the other heavy metals and as a result has a geochemistry similar to most. However, it exists at per cent levels in most clay-rich sediments and cannot be easily altered by anthropogenic effects. It is therefore a good indicator of the source and residence of several of the metals. However, if it were as simple as just stated, then as Fe decreased with increasing mean grain size any of the other metals would also diminish and the metal/Fe ratio would be preserved.

As Table 3.3-1 shows, for Zn, Ni and Cr this hypothesis holds well. However, for Cu and Cd the concentration of each decreases much more rapidly than does that of Fe, resulting in a significant drop in the Cu/Fe and Cd/Fe ratios. What this means is that Cu and Cd have different biogeochemical pathways for getting to, and existing in, the sediment system. One explanation is that the two are related not only with grain size but also with total organic carbon content. Mn and Pb, on the other hand, show some slight metal/Fe ratio decrease, indicating that they are involved in some sort of flux mechanisms that are different than those of Fe.

In general, the sediment trace metal data trend remarkably within the expected range for the type sediments represented. There appear to be no anthropogenic alterations even from the oil platforms proximal to each site. The analyses performed are for most metals adequately sensitive and reproducible to serve as benchmark data. The sedimentary trace metal data provide two main contributions to the goals of this program: (1) they provide initial baseline coverage of the disposal and control sites and (2) they provide key sets of data for prognosticating, through dynamic models or mass-balance calculations, the ultimate geochemical effects of diffusing brine offshore into the environmental settings represented.

Water Column Dissolved and Particulate Phase Analyses

Besides the hydrocarbon analyses (discussed in Section 3.3.1.2), the water columm work in this program consisted of dissolved and particulate heavy metal determination, and particulate organic carbon (POC), dissolved organic carbon (DOC), total suspended matter (TSM), nutrient (Si, PO_4, NO_3), and major ion measurements. In addition, heavy metals, nutrients and major ions were measured in pore waters squeezed from sediments from several of the benthic stations.

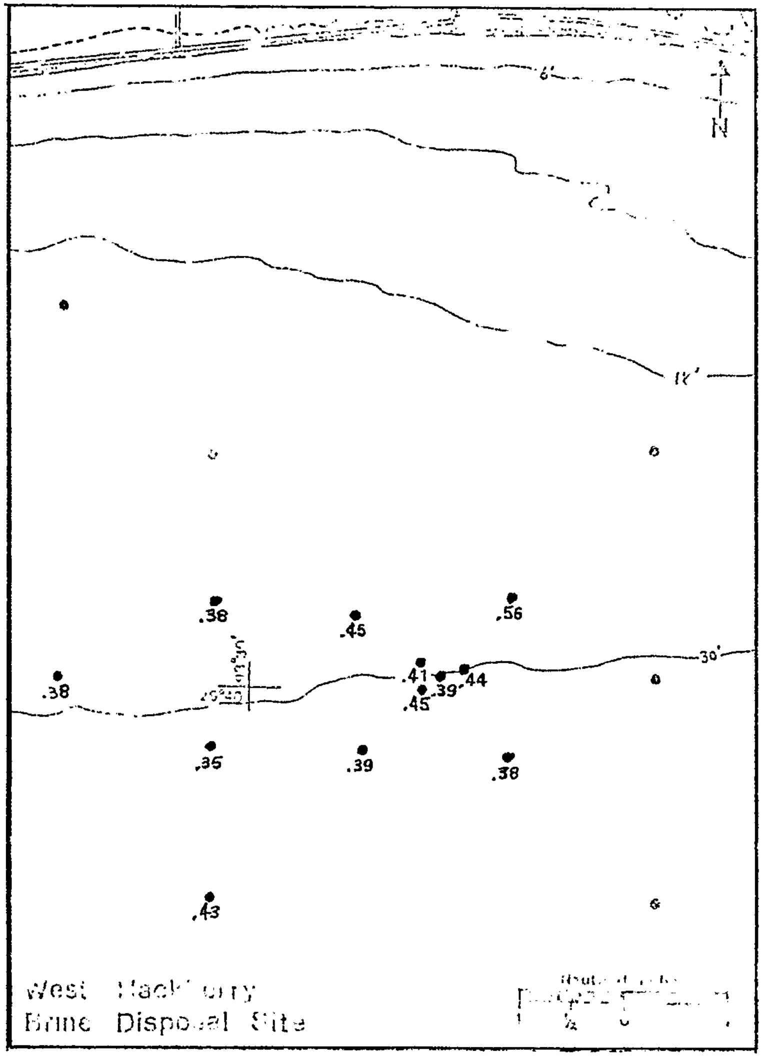


Figure 3.3-5. Percent Iron in West Hackberry Disposal Site Sediments.

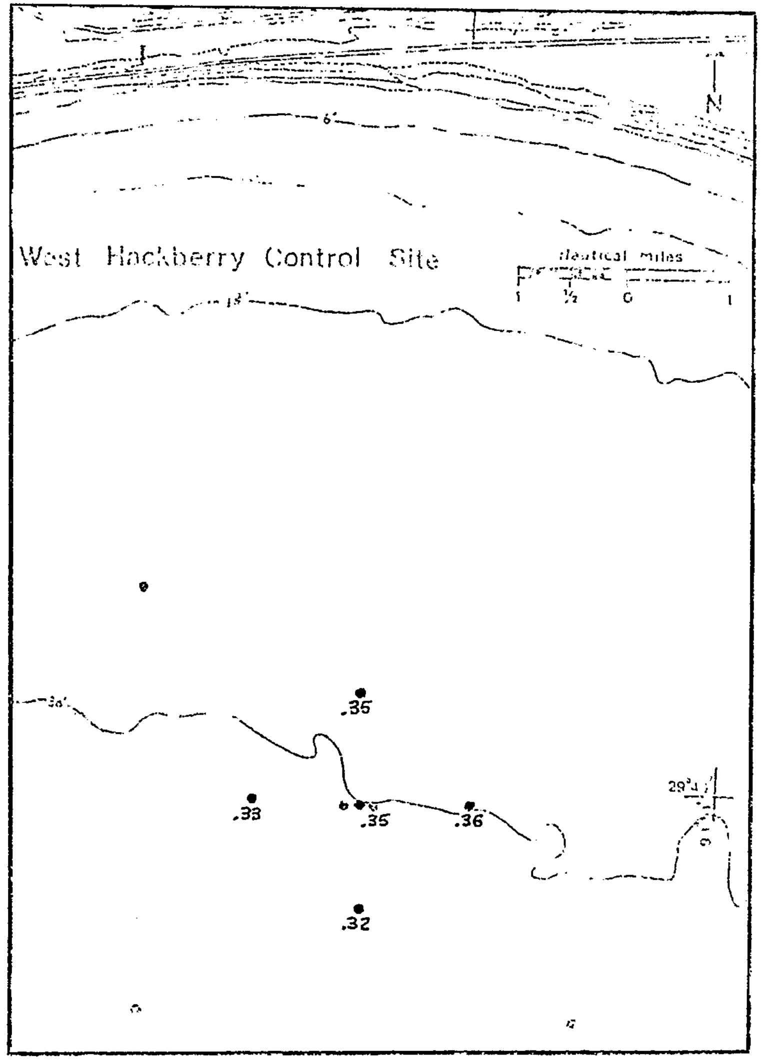


Figure 3.3-6. Percent Iron in West Hackberry Control Site Sediments.

The impetus for examining the seawater/suspended particulate system in a study such as this is the recognition of its important role in transporting metals (and hydrocarbons) to their eventual geochemical respository--the bottom sediment system. River-borne particulates dominate the flux of metals from conterminous land forms to the ocean bed (Trefry, 1977). After the injection of metal-bearing particulates into the oceans by rivers and before their eventual arrival on the sea floor, these materials and their chemical burdens are maintained in phase partitionings which can be altered drastically by changes in ionic strength, oxygen, Eh, and pH.

While we must be concerned with the potential of injecting brine-borne toxins into the system during SPR activity, the metal ion (or complex ion) balance, as it might be altered by contact with higher salinities, is likely to be of more environmental consequence. Certainly, the presence of what will be the major brine toxin for many organisms -- NaCl -- is important to consider as a water quality parameter. However, the water/suspended particulate system, and its coupling with the sediment/pore water system, must be recognized as a critical part of the chemical system which must be characterized.

Suspended particulate metal contents in marine systems support the major flux of several metals (Trefry, 1977). It is difficult to generalize concerning normal metal contents of suspended particulates since, although they have some resemblance to bottom sediments, the partitioning between particulate and dissolved phases is heavily dependent on fluctuations in salinity, POC, TSM, POC/TSM, DOC, and dissolved Si. In the coastal waters under the influence of the Mississippi and Atchafalaya Rivers, these parameters have been measured in this and other studies (Trefry, 1977) within a wide range of values: Cl, 2-20 o/oo; POC, .07-1.66 mgC/ℓ ; TSM, 1.5-65 mg/ℓ ; POC/TSM, .75-18.0%; DOC, .79-4.94 mgC/ℓ ; Si, 2.5-110 μM.

Figures 3.3-7 and 3.3-8 plot the chlorinities of surface, deep, and pore waters at the West Hackberry disposal and control sites, respectively. Table 3.3-3 contains metal, nutrient and bulk ion data for the water column and pore water. Both the disposal and control sites exhibited fairly constant salinities and metal concentrations in the water column and pore waters. The largest variations in station to station concentrations were for the nutrients (which are affected by fluctuating biological activity) and Cd (for which the analytical error was high). Metals concentrations in the sediments varied more in relation to grain size (i.e., sediment composition) than in response to water column concentration differences.

There are no observable fluctuations in pore water dissolved metals at the West Hackberry sites, nor are there variations in pore water salinities. Shokes (1978) found a significantly wider range of pore water salinities at proposed brine disposal sites off of the Atchafalaya delta. These same pore waters had only minor if any

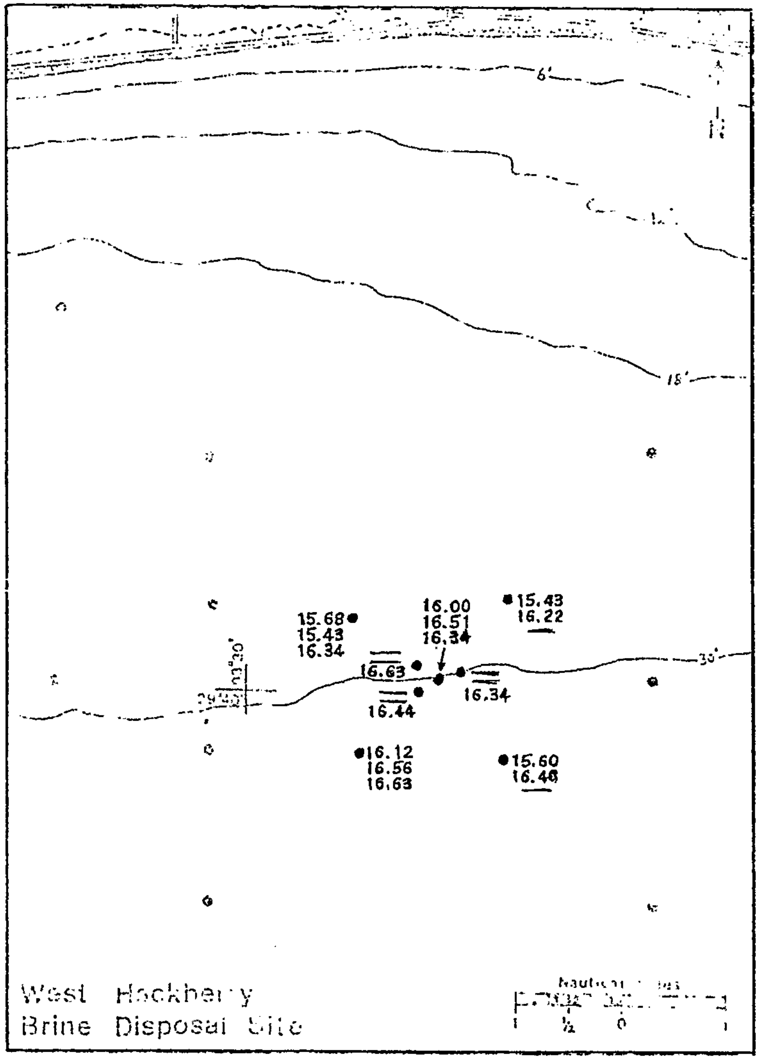


Figure 3.3-7. Chlorinity (mg/kg) at the West Hackberry Disposal Site (Surface/Deep/Pore Water).

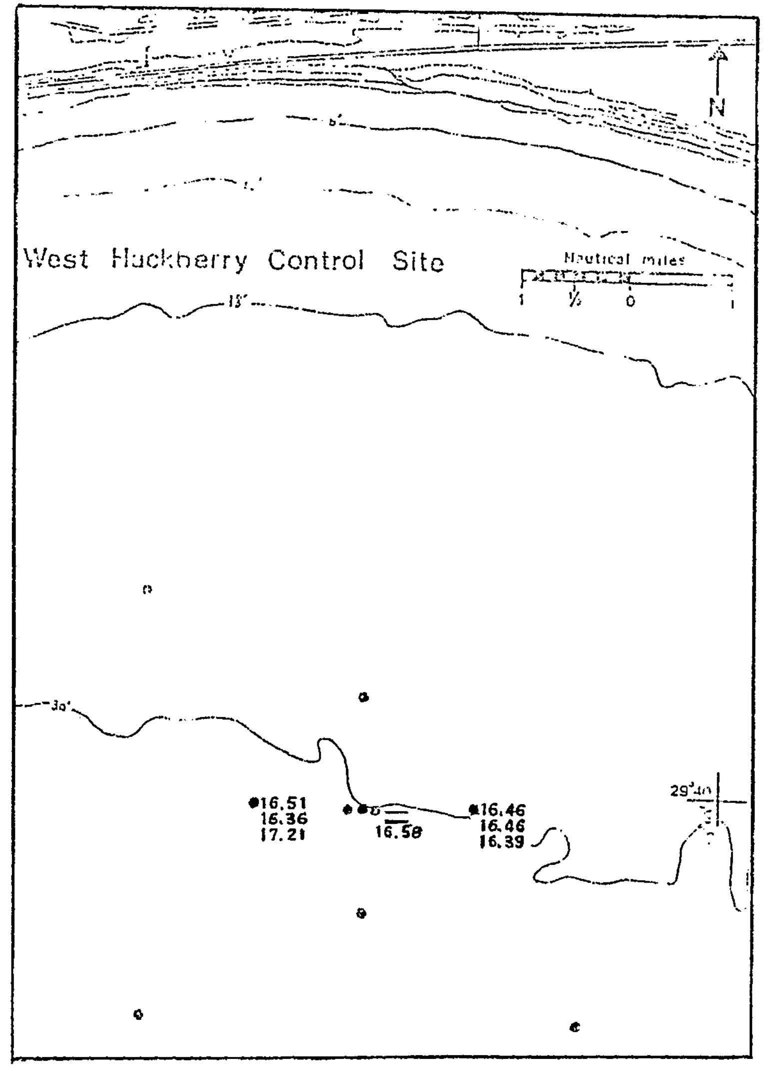


Figure 3.3-8. Chlorinity (mg/kg) at the West Hackberry Control Site (Surface/Deep/Pore Water).

fluctuations in metal contents. This observation does not particularly support the earlier hypothesis that significant ionic strength changes in the pore water system might be responsible for release (or uptake) of metals. However, it should be kept in mind that an alternative mechanism for heavy metal mobilization is possible. If the density of the near-bottom water is increased significantly by the presence of brine, the diffusion and mixing of oxygen into the sediment/pore water system could possibly be lowered to the point of supporting chemically reducing conditions which, in almost all cases, increase the solubilities of the metals in question.

Table 3.3-3 also tabulates dissolved metals in the water column and, although large variations occur, they are all within the generally low and accepted ranges found in previous investigations of coastal waters (Slowey and Hood, 1971). Because of the inherent high variability in dissolved trace metal levels, the nutrient and major ion data are probably more useful in characterizing the water quality of the two sites on a local basis.

Table 3.3-4 compares the relative contributions of metals by particulate and dissolved phases to the water column burden. The dominance of one phase over the other is typically in favor of particulates in areas of high suspended lead. These comparisons provide extremely important data for approaching the question of mass balance impact from adding brine to a system and potentially altering the partitioning coefficients of its heavy metal loads. Total suspended matter for the two sites is plotted in Figures 3.3-9 and 3.3-10.

Table 3.3-5 lists the per cent leachable fractions of heavy metals in the suspended particulates at each depth, and allows comparison of the leachable metal contents in particulates with those in the underlying sediments. The leachable fraction ranges to the typically low (<10%) Fe to several quite high values (~90-95%) for some metals, including Mn, Zn, and Cd.

Table 3.3-6 compares weak and leachable heavy metal concentrations in sediments with concentrations in pore water and the overlying water column.

Macrobiota and Plankton

Biota samples collected and analyzed for trace metals as part of this study for the West Hackberry disposal and control sites included specimens of P. setiferus (white shrimp), M. undulatus (croaker), L. brevis (squid), and zooplankton (mostly copepods with some chaetognaths and larval fish). (Figures 3.2-1 and 3.2-2 indicate trawl locations.)

Table 3.3-3. Dissolved Heavy Metals, Nutrients and Major Ionic Species from the Water Column and Underlying Pore Waters - West Hackberry Disposal Site and Control Site. See Figures 3.2-1 through 3.2-5 for station locations.

Date	Site	Station	Depth (m)	Fe µg/l	Mn µg/l	Zn µg/l	Pb µg/l	Cu µg/l	Cd µg/l	Hg µg/l	PO_4 mg/l	SiO_4 mg/l	NO_3+NO_2 mg/l	Cl g/l	SO_4 g/l	Na g/l	K g/l	Mg g/l	Ca g/l
Sept '77	West Hack-berry	7	1m	8	<2	<1	9	3	<0.3	<0.5	0.04	0.3	0.02	15.60	2.8	9.9	0.38	0.60	0.35
			8m	8	<2	3	2	7	<0.3	<0.5	0.04	0.2	0.03	16.46	2.9	10.5	0.42	0.66	0.36
			pore	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
		8	1m	12	<2	<1	<2	<3	<0.3	<0.5	0.07	0.7	0.05	15.43	2.8	9.2	0.39	0.60	0.34
			8m	12	<2	<1	<2	<3	<0.3	<0.5	0.07	0.6	0.08	16.22	2.6	9.6	0.39	0.65	0.36
			pore	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
		9	pore	<4	1.2	14	<2	<3	5.1	<100	0.03	3.1	0.98	16.34	2.7	8.9	--	0.37	0.36
		10	1m	<4	<2	3	<2	<3	<0.3	<0.5	0.05	0.3	0.02	16.00	3.1	9.5	0.39	0.66	0.36
			8m	<4	<2	<1	<2	<3	<0.3	<0.5	0.07	0.5	0.05	16.51	3.2	9.8	0.39	0.74	0.36
			pore	<4	0.4	4	<2	<3	4.8	<100	0.02	2.5	0.70	16.34	2.7	9.0	0.36	0.36	0.36
		12	pore	<4	0.3	2	<2	<3	4.5	<100	0.04	3.2	0.76	16.63	2.8	9.3	0.37	0.37	0.36
		13	pore	<4	1.4	5	<2	<3	2.8	<100	0.05	2.8	0.42	16.44	3.0	9.0	0.36	0.36	0.36
		14	1m	<4	<2	<1	<2	<3	<0.3	<0.5	0.03	0.2	0.03	16.12	2.6	9.5	0.38	0.67	0.36
			8m	<4	<2	<1	<2	<3	<0.3	<0.5	0.04	0.3	0.04	16.56	3.0	9.9	0.38	0.68	0.35
			pore	<4	1.9	4	<2	<3	3.0	<100	0.04	2.3	0.46	16.63	2.7	9.2	0.35	0.35	0.37
		15	1m	<4	<2	<1	<2	<3	<0.3	<0.5	0.04	0.2	0.02	15.68	2.9	9.3	0.38	0.61	0.34
			8m	<4	<2	<1	<2	<3	0.7	<0.5	0.03	0.3	0.03	15.43	3.1	9.3	0.38	0.65	0.34
			pore	<4	0.2	4	2	<3	2.9	<100	0.05	2.8	0.62	16.34	2.8	8.9	0.36	0.36	0.36
		27	1m	5	<2	2.1	6	<3	<0.3	<0.5	0.02	0.2	0.03	16.46	2.7	9.5	0.35	0.69	0.37
			8m	13	<2	5	<2	<3	<0.3	<0.5	0.04	0.2	0.02	16.46	2.9	9.3	0.38	0.67	0.36
			pore	<4	0.3	4	3	<3	3.8	<100	0.06	3.2	0.43	16.39	2.9	9.2	0.38	0.38	0.36
		29	pore	<4	0.3	4	<2	<3	2.9	<100	0.05	--	0.15	16.58	3.1	9.2	0.38	0.38	0.38
		32	1m	14	<2	3	<2	<3	<0.3	<0.5	0.03	0.2	0.01	16.51	3.1	9.5	0.38	0.68	0.37
			8m	<4	<2	<1	<2	<3	<0.3	<0.5	0.04	0.3	0.03	16.36	2.8	9.4	0.34	0.66	0.36
			pore	<4	0.1	3	<2	<3	3.5	<100	0.05	3.4	0.60	17.21	3.0	9.5	0.35	0.35	0.39
Standard Seawater (nutrients are typical open Gulf of Mexico)											.24	2.3	1.2	19.35	2.71	10.8	0.39	1.29	0.41
Marine Brine (Shokes _et al._, 1977)											7.8	21.6	0	149.5	3.66	91.5	0.63	1.05	1.09

Table 3.3-3. Dissolved Heavy Metals, Nutrients and Major Ionic Species from the Water Column and Underlying Pore Waters - West Hackberry Disposal Site and Control Site. See Figures 3.2-1 through 3.2-5 for station locations. (Continued)

			October				November				December			
Site	Station	Depth	PO_4 mg/l	SO_4 g/l	SiO_4 mg/l	NO_3+NO_2 mg/l	PO_4 mg/l	SO_4 g/l	SiO_4 mg/l	NO_3+NO_2 mg/l	PO_4 mg/l	SO_4 g/l	SiO_4 mg/l	NO_3+NO_2 mg/l
West Hackberry	7	1m	0.01	2.3	0.4	0.01	0.01	2.7	1.8	0.04	0.056	1.72	1.46	0.4
		8m	0.01	2.3	0.4	0.02	0.01	2.5	1.5	0.04	0.057	1.74	1.28	0.4
	8	1m	0.01	2.3	0.5	0.02	0.01	2.5	1.2	0.06	0.058	1.64	1.53	0.5
		8m	<0.01	2.4	0.5	0.03	0.01	2.5	1.7	0.06	0.040	1.87	1.25	0.4
	10	1m	<0.01	2.4	0.5	0.05	0.01	2.7	1.4	0.05	0.051	1.80	1.40	0.4
		8m	0.01	2.4	0.4	0.05	0.01	2.6	1.7	0.04	0.036	1.70	1.30	0.4
	14	1m	0.01	2.3	0.4	0.02	0.01	2.6	0.4	0.04	0.039	1.68	1.78	0.4
		8m	0.01	2.4	0.3	0.05	0.01	2.7	1.3	0.03	0.040	1.86	2.30	0.3
	15	1m	0.01	2.4	0.6	0.02	0.01	2.7	1.0	0.05	0.039	1.69	1.36	0.4
		8m	<0.01	2.4	0.6	0.04	0.01	2.6	1.0	0.06	0.032	1.67	1.52	0.3
West Hackberry Control	27	1m	<0.01	2.4	0.2	0.05	0.01	2.7	1.0	0.01	0.058	1.63	1.44	0.5
		8m	<0.01	2.3	0.4	0.04	0.01	2.6	1.6	0.04	0.026	2.38	0.74	0.2
	32	1m	<0.01	2.2	0.3	0.01	0.01	2.9	1.7	0.02	0.052	1.39	1.03	0.4
		8m	<0.01	2.2	0.3	0.03	0.01	2.7	0.8	0.03	0.038	2.01	0.66	0.2

Table 3.3-4. Relative Dissolved and Particulate Heavy Metal Burdens - West Hackberry Disposal Site and Control Site. See Figures 3.2-1 through 3.2-5 for station locations.

Site	Station	Depth (m)		TSM (mg/l)	POC (μgC/l)	POC/TSM (%)	DOC (mgC/l)	Fe (ng/l)	Mn (ng/l)	Zn (ng/l)	Pb (ng/l)	Ni (ng/l)	Cu (ng/l)	Cd (ng/l)
West Hack-berry	7	1m	Dissolved				1.79	8000	<2000	<1000	9000	----	3000	<300
			Particulate	1.33	329	25.		4.9×10^4	1366	1867	80	112	84	<.3
		8m	Dissolved				0.81	8000	<2000	3000	2000	----	7000	<300
			Particulate	0.81	233	29.		30×10^4	942	184	<7	62	47	<.3
	8	1m	Dissolved				1.22	1200	2000	1000	2000	----	<3000	<300
			Particulate	3.01	407	14.		1.3×10^5	3668	503	73	159	63	3
		8m	Dissolved				0.86	12000	<2000	<1000	<2000	----	<3000	<300
			Particulate	13.77	439	3.		6.1×10^5	2.1×10^4	1831	354	953	327	14
	10	1m	Dissolved				1.23	<4000	<2000	3000	<2000	----	<3000	<300
			Particulate	2.09	309	15.		7.9×10^4	2123	947	98	118	70	5
		8m	Dissolved				1.66	<4000	<2000	<1000	<2000	----	<3000	<300
			Particulate	3.63	216	6.		1.6×10^5	5485	606	100	198	100	8
	14	1m	Dissolved				0.76	<4000	<2000	<1000	<2000	----	<3000	<300
			Particulate	0.66	215	33.		2.0×10^4	442	900	37	63	43	8
		8m	Dissolved				1.63	<4000	<2000	<1000	<2000	----	<3000	<300
			Particulate	3.72	317	9.		1.6×10^5	4587	685	104	211	95	8
	15	1m	Dissolved				1.10	<4000	<2000	<1000	<2000	----	<3000	<300
			Particulate	1.31	346	26.		4.9×10^4	1413	252	36	84	51	7
		8m	Dissolved				1.36	<4000	<2000	<1000	<2000	----	<3000	700
			Particulate	1.52	261	17.		6.1×10^4	1821	331	55	158	56	6
West Hack-berry Control	27	1m	Dissolved				1.50	5000	<2000	2100	6000	----	<3000	<300
			Particulate	0.17	159	94.		4144	131	<5	<7	<53	<3	<.2
		8m	Dissolved				0.57	13000	<2000	5000	<2000	----	<3000	<300
			Particulate	0.34	173	51.		1.1×10^4	352	355	<8	<65	22	<.3
	32	1m	Dissolved				----	14000	<2000	3000	<2000	----	<3000	<300
			Particulate	1.29	152	12.		4.7×10^4	1464	3197	74	92	139	10
		8m	Dissolved				1.13	<4000	<2000	<1000	<2000	----	<3000	<300
			Particulate	0.63	177	28.		7.2×10^4	3163	972	71	122	75	1

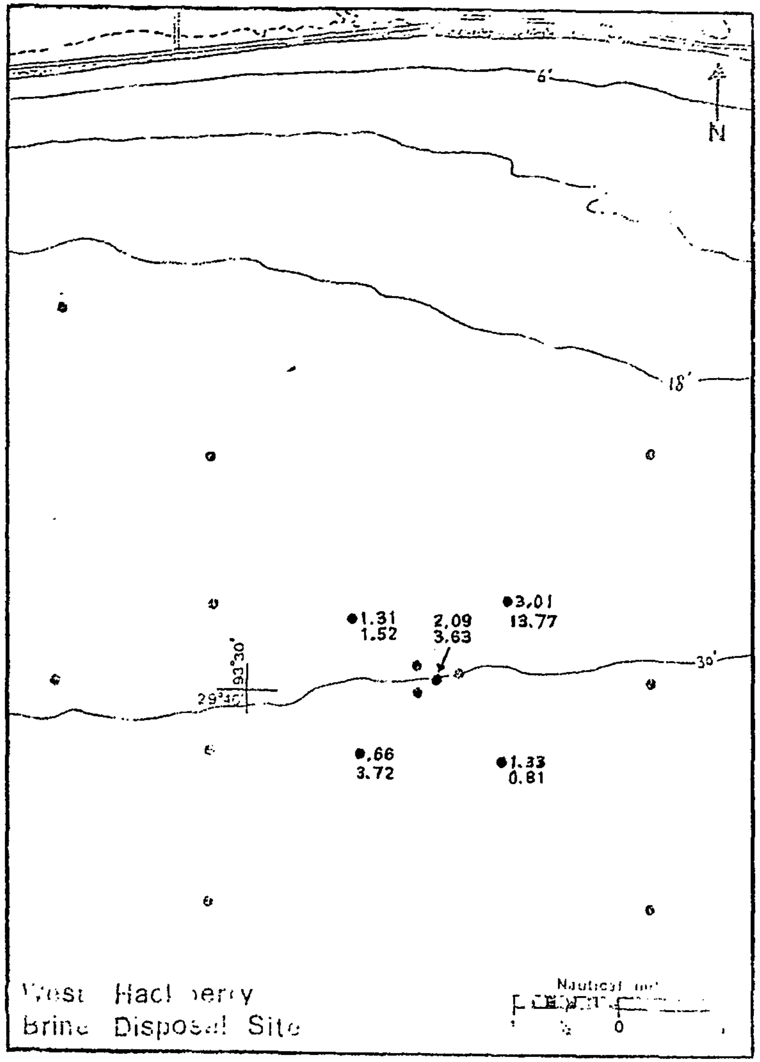


Figure 3.3-9. Total Suspended Matter (mg/l) Surface/Bottom for the West Hackberry Disposal Site Stations.

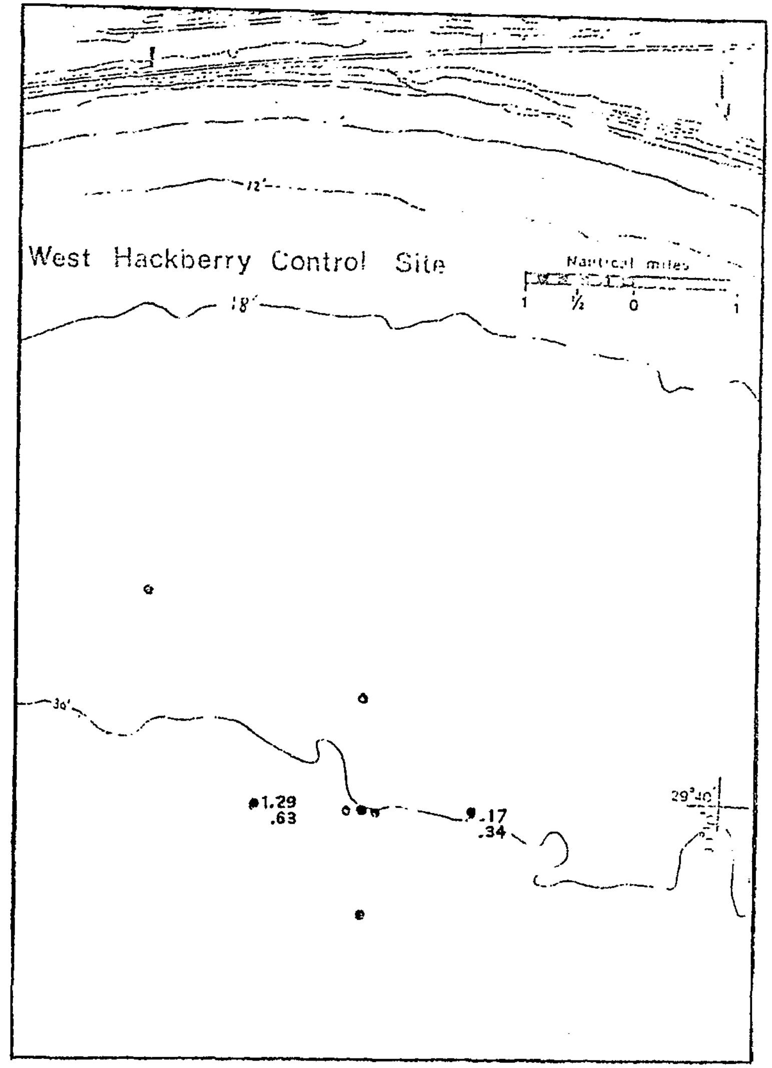


Figure 3.3-10. Total Suspended Matter (gm/l) Surface/Bottom for the West Hackberry Control Site Stations.

Table 3.3-5. Heavy Metal Contents of Suspended Particulate - West Hackberry Disposal Site and West Hackberry Control Site. See Figures 3.2-1 through 3.2-5 for station locations.

Site	Station	Depth (m)	P=Particulate	Fe(ppm)	Mn(ppm)	Zn(ppm)	Pb(ppm)	Ni(ppm)	Cu(ppm)	Cd(ppm)	Cr(ppm)
West Hackberry	7	1m	P-WAS+	2001	783	1303	31.6	<41.9	21.9	3.4	<2.1
			P-Total	36700	1027	1404	60.4	84.3	63.0	<.2	<21.0
			P-% Leach	5.5	76.2	92.8	52.3	<49.7	34.8	---	---
		8m	P-WAS	2371	922	166	19.0	<61.4	39.4	3.8	<3.1
			P-Total	37400	1163	227	<9.0	76.9	57.6	<.3	<30.7
			P-% Leach	6.3	79.3	73.1	---	<79.8	68.4	---	---
	8	1m	P-WAS	2524	822	69.4	8.6	<8.3	2.3	0.5	<0.4
			P-Total	42600	1291	167	24.4	52.9	20.8	1.0	82.4
			P-% Leach	5.9	63.7	41.6	35.2	<15.7	11.1	50.0	<0.5
		8m	P-WAS	2453	965	45.5	5.8	2.4	3.0	0.6	.1
			P-Total	44300	1549	133	25.7	69.2	23.8	1.0	6.0
			P- % Leach	5.5	62.3	34.2	22.6	3.5	12.6	60.0	1.7
	10	1m	P-WAS	2245	717	359	14.5	<14.9	10.4	2.2	<.8
			P-Total	38000	1016	453	46.3	56.7	33.7	2.5	83.8
			P-% Leach	5.9	70.6	79.2	31.3	<26.3	30.9	88.0	<1.0
		8m	P-WAS	1979	1036	85.0	10.4	<10.5	6.6	1.9	<0.5
			P-Total	42600	1511	167	27.6	54.7	27.4	2.1	73.2
			P-% Leach		68.6	50.9	37.7	<19.2	24.1	90.5	<0.7
	14	1m	P-WAS	1932	494	1248	26.0	<64.0	34.9	6.9	<3.2
			P-Total	29900	670	1363	56.0	94.7	65.4	12.0	<32.
			P-% Leach	4.7	73.7	91.6	46.4	<67.6	53.4	57.5	<10.
		8m	P-WAS	1995	734	93.2	9.4	<12.9	3.5	1.6	<0.7
			P-Total	43300	1232	184	28.0	56.8	25.6	2.0	6.7
			P-% Leach	4.6	59.5	50.7	33.6	<27.7	13.7	80.0	<10.5
	15	1m	P-WAS	2004	806	116	12.5	<25.5	12.7	4.8	<1.3
			P-Total	37500	1079	192	27.4	63.8	38.6	5.4	89.8
			P-% Leach	5.3	74.7	60.4	45.6	<40.0	32.9	88.9	<1.5
		8m	P-WAS	2029	867	129	12.9	<19.4	7.3	2.7	<1.0
			P-Total	40100	1198	218	36.5	104	37.0	4.1	112
			P-% Leach	5.1	72.4	59.2	35.3	<18.7	19.7	65.9	<0.9
West Hackberry Control	27	1m	P-WAS	3086	696	592	28.3	<275	69.21	<6.9	<13.7
			P-Total	24200	771	<27.5	<40.3	<313	<17.7	<1.4	137
			P-% Leach	12.8	90.3	---	---	---	---	---	<10.0
		8m	P-WAS	2964	870	994	33.7	167	48.8	26.6	<8.5
			P-Total	31700	1035	1045	<24.8	<192	65.2	<0.8	84.5
			P-% Leach	9.4	84.1	95.1	---	---	74.8	---	<10.1
	32	1m	P-WAS	2340	919	2321	38.5	<38.3	73.1	7.8	<1.9
			P-Total	36100	1135	2478	57.0	71.2	108.0	8.0	108
			P-% Leach	6.5	81.0	93.7	67.5	<53.8	67.7	97.5	<1.8
		8m	P-WAS	7042	3561	1304	48.7	<75.4	32.7	8.5	<4.0
			P-Total	114800	5021	1543	112.8	193	119.6	14.5	173
			P-% Leach	6.1	70.9	84.5	43.2	<39.1	27.3	58.6	<2.3
Mississippi Depth Suspended Particulate-Total (Trefry, 1977)				46400	1230	244	58	56	56	51	-

Table 3.3-6. Comparison of Heavy Metal Concentrations in Leached (1N HNO_3) Sediments, Pore Water and Overlying Water West Hackberry Disposal Site and West Hackberry Control Site. See Figures 3.2-1 through 3.2-5 for sampling locations.

Site	Station	%Fines (<62μm)	%CaCO$_3$	%TOC	Fe(ppm)	Mn(ppm)	Zn(ppm)	Pb(ppm)	Cu(ppm)	Cd(ppm)
West Hackberry										
	10 sediment	81.0	6.8	.54	3874	301.3	20.17	14.61	6.48	0.07
	pore H_2O				<.004	.0004	.004	<.002	<.003	0.0048
	near-bottom H_2O				<.004	<.002	.003	<.002	<.003	<.0003
	14 sediment	66.5	2.7	.57	3885	301.5	20.51	13.29	7.26	0.06
	pore H_2O				<.004	.0019	.004	<.002	<.003	0.0030
	near-bottom H_2O				<.004	<.002	<.001	<.002	<.003	<.00030
	15 Sediment	86.8	3.7	.72	4543	401.9	23.88	17.14	8.82	0.08
	pore H_2O				<.004	.0002	.004	.002	<.003	0.0029
	near-bottom H_2O				<.004	<.002	<.001	<.002	<.003	.0007
West Hackberry										
	27 sediment	43.6	4.2	.39	3624	264.2	19.57	11.16	4.49	0.05
	pore H_2O				<.004	.0003	.004	.003	<.003	0.0038
	near-bottom H_2O				.013	<.002	.005	<.002	<.003	<.0003
	29 sediment	52.3	3.3	.38	3465	276.9	18.76	11.54	4.48	0.05
	pore H_2O				<.004	.0003	.004	<.002	<.003	0.0029
	near-bottom H_2O				-	-	-	-	-	-
	32 sediment	36.1	2.4	.31	3304	237.9	20.44	9.82	3.35	0.05
	pore H_2O				<.004	.0001	.003	<.002	<.003	0.0035
	near-bottom H_2O				<.004	<.002	<.001	<.002	<.003	<.0003

Trace metal concentrations on a dry weight tissue basis are tabulated in Table 3.3-7 for the West Hackberry disposal site and control site samples. Examination of the data reveal several expected trends. First, the zooplankton and squid samples are significantly higher in all metals (except Cu) than the fish and shrimp samples. In part this is due to the concentrating ability of these primary consumers and also their extremely high surface area/mass ratios relative to macrofauna. However, this elevation is also an artifact of sampling caused by self-filtering by the plankton over the 202-μm mesh net, removing terrigenous clay particulates from sea water, as well as themselves. This effect can conceivably be corrected for by normalizing all metals to Al, but as has been found in the past, this approach has not been entirely satisfying, with relatively large and unaccountable variability hindering distributional (temporal and spatial) interpretation (Sims, 1975). High metals levels in the squid samples may be related to the fact that the whole organism was used.

Additionally, the white shrimp samples are generally the most metal-free with the possible exception being Zn and perhaps Cu, which have been implicated as important metabolites in shrimp (Bowen, 1966). The significant elevation in only the mineralogy-type metals (Fe, Mn, Al, Zn) in the croaker samples (especially the one whole flesh sample, 10/2) tends to point toward the possibility of sediment (or suspended matter) contribution. The elevated Fe in croaker and shrimp has been seen in samples analyzed by Dr. P. Boothe of TAMU participating in the Bureau of Land Management South Texas OCS Study (personal communication).

Comparison of the organism trace metal data gathered in this study with those found in previous work (Table 3.3-7) indicates quite good agreement. However the major void in our understanding of the ambient metal burdens in such biological systems has been the inherent difficulty of establishing limits of natural variability for species and environments of interest. Toward this goal, the main weakness of the chemical measurements made in biota in this study was the lack of sample numbers and coverage. The essence of establishing baseline limits is just that -- the establishment of natural limits of variability. In order to do this a number of faunal samples, adequately representing the natural populations of the site areas, must be collected and analyzed. Hopefully, this is an effort which would be pursued in any subsequent sampling programs.

Prediction Intervals as a Tool for Environmental Monitoring

One of the prime objectives of environmental baseline survey and monitoring is the ability to detect long term changes in the heavy metal contents of the various phases present and to relate them or not to future anthropogenic influence. This objective can potentially be met by regressing various metal-to-metal relationships and

Table 3.3-7. Heavy Metal Contents of Selected Organisms - West Hackberry Disposal Site and West Hackberry Control Site. See Figure 3.2-1 through 3.2-5 for trawl locations. (Concentrations on dry weight basis.)

Site	Station/Trawl		Sample Description (species)	Fe(ppm)	Mn(ppm)	Zn(ppm)	Pb(ppm)	Ni(ppm)	Cu(ppm)	Cd(ppm)	Cr(ppm)	Al(ppm)
West Hackberry	10	2	White Shrimp (P. setiferus) flesh	7.01	1.62	57.52	<0.007	0.057	24.18	0.023	<0.006	6.51
	10	2	Croaker (fish) (M. undulatus) flesh	146.5	43.36	52.22	16.28	0.178	3.84	0.031	0.119	138.
	10	2	Zooplankton (mostly copepods, some chaetognaths and larval fish), whole	606.9	37.86	118.8	0.324	3.24	16.69	2.27	0.564	745.
	14-15	3	White Shrimp (P. setiferus), flesh	9.3	2.23	54.4	0.041	0.034	13.77	0.049	<0.005	3.71
	14-15	3	Croaker (M. undulatus) filet	19.68	1.73	22.27	0.215	0.037	2.03	0.020	0.008	3.86
	14-15	3	Squid (L. brevis), whole	574.1	35.32	71.14	0.141	0.384	38.98	0.022	0.489	676.
	16		Zooplankton (mostly copepods, some chaetognaths and larval fish), whole	609.4	35.77	56.72	0.967	1.21	13.52	1.55	0.936	901.
	17-18	1	White Shrimp (P. setiferus) flesh	9.63	3.05	35.23	0.011	0.085	26.66	0.052	<0.005	2.32
	17-18	1	Croaker (M. undulatus), filet	18.37	7.07	21.89	<0.006	<0.029	1.46	0.011	0.005	10.2
	19		Zooplankton (mostly copepods, some chaetognaths and larval fish), whole	857.3	38.33	108.9	0.906	3.30	13.25	0.052	1.02	828.
West Hackberry Control	29-30	8	Squid (L. brevis), whole	319.3	13.68	78.09	0.158	0.137	21.30	0.012	0.234	107.
	29-30	8	Zooplankton (mostly copepods, some chaetognaths and larval fish), whole	9514.	247.6	548.7	32.20	11.00	30.09	6.39	15.81	3,716.
NW Gulf of Mexico (Sims, 1975)			Zooplankton #1	799	12.6	155	15.3	2.0	74.0	2.4	-	1,252
			#2	288	9.8	58	4.3	1.9	6.3	1.3	-	283
NW Gulf of Mexico (Boothe and Presley, 1977)			Macrobiota									
			Shrimp	4	-	63	.08	.21	.24	.09	-	-
			Red Snapper (flesh)	5.4	-	12.	.03	.06	.80	.03	-	-
			Winchman (flesh)	3.8	-	8.2	.04	.08	1.3	.02	-	-

constructing 95% prediction intervals around the regression lines. If such prediction intervals can be established with adequate data sets, then their utility is to compare future data with the expectation that 95% of subsequently collected samples should fall within the established intervals unless significant perturbations have occurred (Neter and Wasserman, 1974).

Representative natural populations of sediment or biota from a given area tend to maintain fairly distinctive metal ratios in constant proportions unless acted upon by element-altering effects which have not been present before. Al and Fe, specifically, have been used to normalize other metals for such prediction purposes. Both metals are found in significantly higher concentrations in both sediment and biological tissue than are the chemically-similar other trace heavy metals. At such high levels it will be difficult for a system's (sediment or biota) Fe or Al content to be altered by any anthropogenic effect which may contribute significantly to other metals. Therefore, a prediction interval constructed from a representative metal vs Fe plot can potentially be a sensitive tool for testing future baseline and monitoring data (Trefry, 1977).

Figure 3.3-11 shows Al plotted against Fe for the 1 N HNO_3 - leached sediments analyzed from West Hackberry, its control site and the Big Hill site. Several things are important. First, the relationship between Al and Fe for the 18 samples from the West Hackberry area is highly significant, even though visual inspection of the data (Table 3.3-1) indicates that West Hackberry Control site is characterized by lower metal contents than the actual disposal site to the west. However, the Al/Fe regression shows that both sites are of similar material relative to pollutant alteration. Another interesting observation is that the Big Hill sediments (see Table 3.3-15, Section 3.3.3-1) are apparently of a different population relative to intermetal relationships. Their location on the Al vs Fe plot indicates that less Al comprises the system per amount of Fe than does in the West Hackberry sediments.

Figure 3.3-12 (Cr vs Fe) shows that for Cr all stations (West Hackberry and Big Hill) are highly correlatable, with only one station at Big Hill (37) apparantly not within the population represented. One conclusion to draw from this is that the Big Hill sediments, derived from the Sabine River, are somewhat enriched in metals relative to Fe based on the Al to Fe ratios. Even though the Cr to Fe relationship seems to be the same at Big Hill as West Hackberry, the Al to Fe population is different, inferring a different population. The observation that Cr to Fe is not also different suggests an enrichment in Cr.

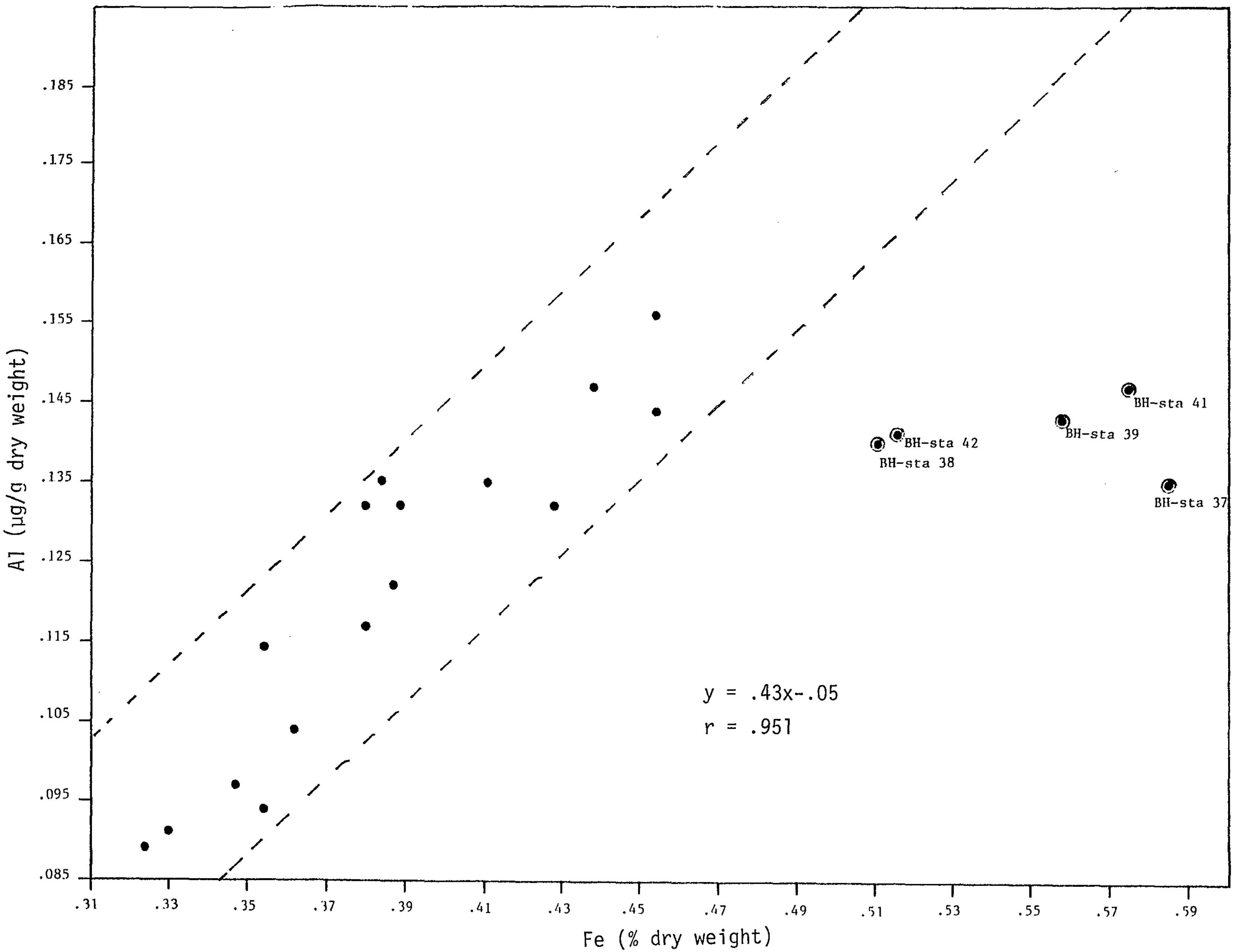


Figure 3.3-11. Mean regression of Al vs Fe for 1 N HNO_3-leached sediments from West Hackberry (unlabelled) and Big Hill stations. Dashed lines are 95% prediction intervals.

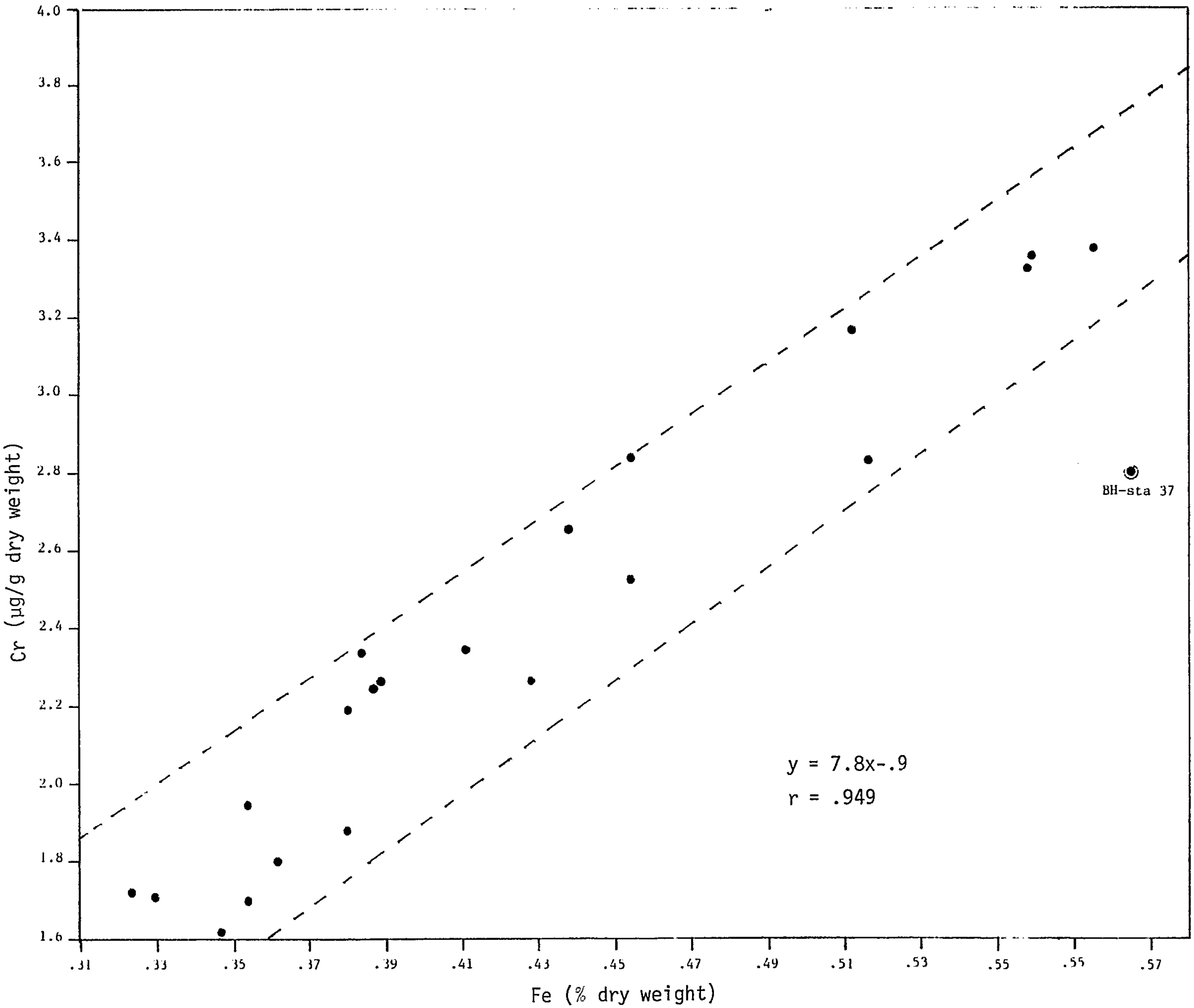


Figure 3.3-12. Mean regressions of Cr vs Fe for 1 N HNO_3-leached sediments from West Hackberry and Big Hill stations. Dashed lines are 95% prediction intervals.

On the other hand, the data may only be indicating that some slight source material differences exist between West Hackberry and Big Hill, and the small number of samples form Big Hill does not adequentely represent the distribution of metals in sediments populating that area. The addition of more data will strenghten our ability to interpret these prediction regressions.

Table 3.3-8 lists the regression line equations and corresponding correlation coefficients for the other metals measured in this study relative to Fe. This same kind of treatment can be applied to biological tissue metal contents (Gordon et al, 1978), especially if a single species from a somewhat limited geographical area is considered. To date in this study, however, insufficient data meeting these criteria exist for any particular species. At the end of one year's seasoned sampling, we should be able to apply this technique.

3.3.1.2 High Molecular Weight Hydrocarbons

Sediments

Although high molecular weight hydrocarbons (HMWHCs) as a general class of compounds exhibit marked hydrophobic tendencies, they do have finite solubilities in saline solutions. This fact has important implications to the overall Strategic Petroleum Reserve (SPR) and salt dome brine disposal program, particularly during the post-development period, and likely will result in an input of petroleum hydrocarbons to the vicinity of the brine disposal sites. The major source of this input will presumably be via brine solutions which will have been in direct contact with petroleum stored in the salt dome reservoirs. Thus, as SPR facilities become operational, the release of brine solutions (carrying dissolved and possibly suspended or emulsified hydrocarbon loads) will result in significant hydrocarbon burdens being introduced into the marine environment. After exiting from the diffusers, the hydrocarbons will be available to interact with and partition into a wide variety of marine phases -- i.e., remain in a dissolved or colloidal state, adsorb to abiotic suspended particulate matter and sediments or accumulate on or in a variety of pelagic and benthic biota. To adequately evaluate the ultimate impact from this influx and facilitate the subsequent monitoring programs which must be undertaken during post-development periods, the present (i.e., "baseline" or pre-development) levels and distributions of hydrocarbons were determined. With this baseline concept in mind, samples of surficial sediments, organisms, and water were collected and analyzed for their hydrocarbon contents. In each type of analysis, biogenic and petrogenic sources have been differentiated and identified wherever possible.

Table 3.3-8. Regression equations and correlation coefficients (r) for West Hackberry metal to Fe relationships. N= number of stations.

Metal/Fe	Regression Equation	r	N
Al/Fe	y = .43x - .05	.951	18
Mn/Fe	y = 1010x - 90	.922	18
Pb/Fe	y = 40x - 2.5	.894	18
Zn/Fe	y = 31.4x + 8.3	.919	18
Ni/Fe	y = 11x - .2	.894	18
Cr/Fe	y = 7.8x - .9	.949	18
Cu/Fe	y = 40x - 10	.934	16
Cd/Fe	y = .14x - .01	.693	18

From both a source determination and toxicological standpoint, the actual composition of hydrocarbon mixtures (i.e., specific compounds present) in the regions of the proposed brine disposal site is of critical importance. For example, the varying aqueous solubilities of different hydrocarbon compounds (McAuliffe, 1966; Sutton and Calder, 1974; Eganhouse and Calder, 1976) will most likely mean that the relative composition of dissolved hydrocarbons entering the marine environment from the oil-water system of the salt dome storage reservoirs will differ from that of the parent petroleum reserves. Individual hydrocarbon compounds also have different physical-chemical and toxicological properties that will affect their ultimate distributions in and impact upon the receiving ecosystem. These considerations regarding properties of individual compounds are equally applicable for studies conducted during the initial pre-development (i.e., "baseline") period of assessment of hydrocarbon levels at the proposed brine disposal sites. Consequently, our studies and analytical program were intended to give quantitative information about individual HMWHC compounds.

Since a major concern of this program will ultimately be to evaluate any actual input of stored petroleum reserves into the marine environment, identification of existing hydrocarbon burdens and sources is required. This is initially complicated however by the fact that background levels of biogenic hydrocarbons have not been adequately determined in most of the types of samples collected in this study. Furthermore, the marine environment in the proposed disposal areas is largely dominated and controlled by tidal currents and flows from local land run-off. Thus, our studies had to be designed and undertaken in a manner which allowed evaluation of existing hydrocarbon burdens from these and other sources as well. Specifically, the three major sources of hydrocarbons which exist at this time are: 1) terrestrial run-off (contributions from higher plants and anthropogenic hydrocarbons); 2) marine sources (plankton and sediment infauna); and 3) petrogenic hydrocarbons from fossil fuel exploration and development. These sources are both complex, and, in the case of the river run-off of anthropogenic hydrocarbons and oil production related sources, overlapping. To aid in the differentiation of the two petrogenic sources, the contribution of plant wax paraffins may be used to assess terrestrial relative to petroleum development sources.

Differentiation of biogenic from petroleum hydrocarbons can be undertaken by considering the specific composition of hydrocarbon components in the sample extracts. For example, petroleum hydrocarbons, in contrast to biogenic hydrocarbons, are generally characterized by: 1) much broader and more complex collections of compounds; 2) homologous series of compounds in which the sequential members (i.e., compounds with consecutive even and odd numbers of carbon atoms) are of approximately equal abundance; 3) a notable absence of olefinic compounds (except for some refined products) and

4) greater relative amounts of both cycloalkanes and aromatic constituents compared to alkanes (National Academy of Science, 1975). Furthermore, specific types of compounds may be characteristic of particular types of biota. For example, the predominant natural hydrocarbons reported to occur in zooplankton include groups of C-19 and C-20 isoprenoid alkanes and alkenes (Blumer et al., 1963; Blumer et al., 1964; Blumer and Thomas, 1965; Blumer, 1967; Blumer et al., 1969) and, in selected species, the polyunsaturated alkene, heneicosaheaxane (Blumer et al., 1970). Many other marine organisms contain n-alkane hydrocarbons with only one or two predominating which is not the case for either crude oils or refined products. In marine phytoplankton, normal alkanes with 15, 17, 19 or 21 carbon atoms are most abundant (Clark, 1966, Blumer et al., 1971) and in marsh grasses and benthic macroalgae, n-C_{21} to n-C_{29} odd chainlength hydrocarbons predominate (Clark, 1973).

Thus, general criteria do exist which allow mixtures of various petroleum, anthropogenic and biogenic hydrocarbons to be distinguished; however, detailed chemical analyses and specific compound identifications are required to apply these criteria and realistically evaluate the distributions and concentrations of these compounds in marine systems.

Sediments

The hydrocarbon composition of sediments reflects a good time-average of the contributing sources in any given depositional regime. The characterization of the molecular types of hydrocarbons detected in the sediment enables the assessment of the bioavailability of toxic as well as non-toxic constituents, since the sediment is a long-term repository for a number of contributing sources.

As mentioned previously, the sediment textural properties between the disposal and control sites are markedly different (Table 3.3-2). The disposal site is texturally finer and shows much greater variation than the control site. This variability at the disposal site is expressed as a East to West coarsening of grain size. The sediment texture also appears to coarsen with distance from shore. These trends are not evident at the control site and may be governed by the disposal site's location west of Calcasieu Pass. The sediment TOC values follow textural trends with the average value for the disposal site (0.63%) exceeding that for the control site (0.36%) by almost a factor of two.

Total hydrocarbon concentration data as determined by gas chromatography along with certain ratio information are listed in Table 3.3-9. The average hydrocarbon concentration for the disposal (13.94 μg/gm) and control (6.16 μg/gm) are well correlated with the TOC values for the two sites. At both sites, the resolved hydrocarbons comprise only 12 per cent of the hydrocarbons. The majority of the

Table 3.3-9. Sediment hydrocarbon data for the West Hackberry disposal and control sites.

	In-House ID	Station	Hexane Fraction µg/gm Resolved	Hexane Fraction µg/gm Unresolved	Benzene Fraction µg/gm Resolved	Benzene Fraction µg/gm Unresolved	Total	n-alkanes/ Branched	OEP**	R.D.* MPO
West Hackberry Disposal	835	8	0.939	10.40	0.210	0.266	11.81	0.43	2.95	0.250
	833	9	0.950	9.277	0.516	0.784	11.52	0.478	2.03	0.116
	834	9 (replicate)	1.017	9.359	0.460	0.704	11.54			
	831	10	0.767	6.812	0.431	1.871	9.88	0.754	2.69	0.149
	832	10 (replicate)	0.666	8.784	0.310	1.153	10.91	0.722	2.65	0.216
	841	12	1.201	10.654	0.349	1.387	13.59	1.37	3.28	0.167
	848	13	1.256	12.024	0.623	2.645	16.55	0.800	4.05	0.182
	847	14	1.852	15.390	0.371	1.529	19.14	1.116	3.92	0.141
	844	15	1.161	11.323	0.538	3.555	16.58	0.962	4.43	0.175
	845	15 (replicate)	1.613	16.448	0.509	4.683	23.25	0.790	3.19	
	828	16	1.450	14.137	1.254	3.927	20.77	1.221	2.94	0.110
	859	17	0.984	8.82	0.088	0.298	10.19	1.250	4.96	0.194
	861	18	0.586	5.688	0.236	1.071	7.58	0.593	2.26	0.195
	830	19	1.003	8.329	0.355	4.320	14.00	0.602	3.00	0.357
	842	22	0.741	6.665	0.699	3.666	11.77	1.333	4.29	0.087
	Mean		1.079	10.274	0.464	2.124	13.94			Mean TOC = 0.63% Mean TIC = 0.38% or 3.17% $CaCO_3$
West Hackberry Control	852	32	0.385	3.489	0.169	0.412	4.46	1.37	3.39	0.230
	853	32 (replicate)	1.041	8.930	0.161	0.902	11.03	0.767	3.06	0.253
	857	27	0.756	6.176	0.229	0.822	7.98	1.68	1.673	0.215
	858	29	0.030	2.846	0.149	0.268	3.29	1.04	3.16	0.188
	864	31	0.220	2.114	0.274	0.838	3.44	0.54	1.99	0.209
	863	28	0.768	5.279	0.174	0.665	6.89	0.27	2.28	0.530
	Mean		0.533	4.806	0.193	0.651	6.183			Mean TOC = 0.36% Mean TIC = 0.41% or 3.43% $CaCO_3$

* Relative dominance of marine polyolefins between KOVAT 2025 and 2170

** OEP = odd/even carbon preference ratio hydrocarbon content is composed of an unresolved complex mixture (UCM). The UCM is associated with the contribution of weathered petroleum.

Examples of two chromatographic profiles of the hexane fraction from stations 10 and 19 (disposal site) are shown in Figures 3.3-13 and 3.3-14. Both samples are similar in the prominent occurrence of the unresolved envelope (UCM) and the presence of n-alkanes above n-C_{23} with strong odd carbon preference. As mentioned previously, the UCM is attributed to petroleum derived sources. The n-alkanes with strong odd-carbon preference are associated with the contribution of higher plants. The marine component is expressed in the peaks eluting between n-C_{20} and n-C_{22}. Olefins eluting within this boiling point range have been detected in sediments from Southern California (Kaplan _et al_., 1976), the Gulf of Mexico (Gearing _et al_., 1976) and the eastern coast of the United States (Rington and Tripp, 1977). The relative contribution of this marine component is listed in Table 3.3-9 as RD, MPO (i.e., relative dominance of marine polyolefins). The marine component for station 10 is about 22 per cent of the resolved peaks, whereas for station 19 it comprises almost 36 per cent. Not only is the relative magnitude of the marine component greater at station 19, but its composition is markedly different. In both samples, the major or base peak elutes at KOVAT 2077 and the peak at KOVAT 2100 comprises about thirty (30) per cent of the base peak. However, the prominent peaks with KOVAT indices of 2027, 2045, and 2126 are not present at station 10.

At the disposal site the marine component is quite variable and likely reflects the variation in the sediment textural properties as well as the influence of Calcasieu Pass.

For the disposal site, the base peak in the marine component varies substantially between stations. The compound eluting at KOVAT 2100 is the most prominent at stations 12, 15, and 17 with a compound at 2081 showing secondary abundance. At stations 9, 10, 13, 14, and 18 the trend is reversed with the peak at 2081 becoming the prominent olefin. At station 9, a peak at 2045 exceeds 2100 in concentration. At stations 7, 19, and 16 the prominent olefin elutes at KOVAT 2077. The secondary peak at station 16 elutes at 2100 whereas that for stations 7 and 19 elute at 2027. The western-most station (22) contains 2045 as its dominant olefin with the secondary abundance of 2100.

Similarly, the benzene fractions for the disposal site reflect the same degree of variation in the minor components. However, the major components in all samples elutes at KOVAT 2090. The chromatographic profile for the benzene fraction of station 10 is shown in Figure 3.3-15. As with the hexane fractions, the profile is dominated by the UCM. The peaks at KI 2370 and 2550 are suspected laboratory contaminants (dioctyl adipate and dioctyl phthalate, respectively).

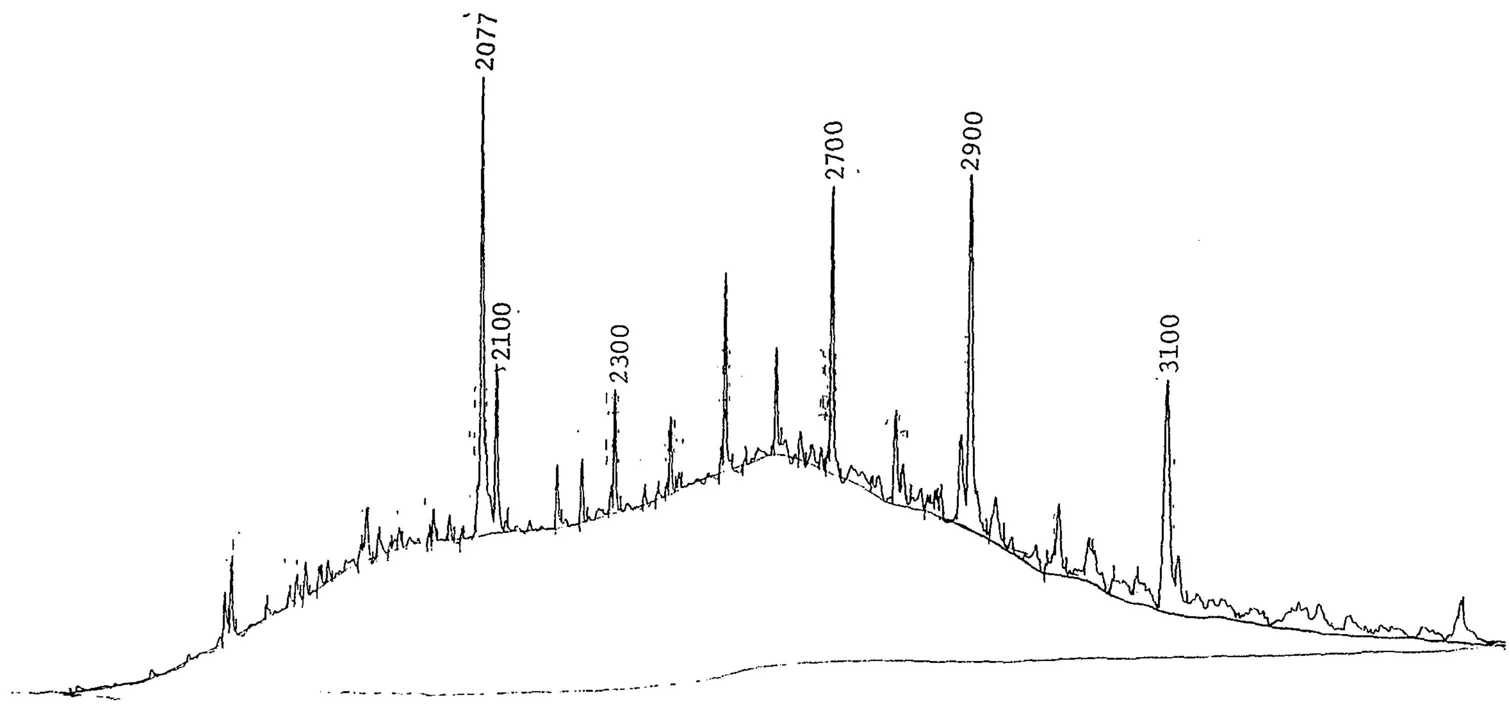


Figure 3.3-13. Gas chromatographic trace of the hexane fraction of surficial sediment at station 10, West Hackberry Disposal.

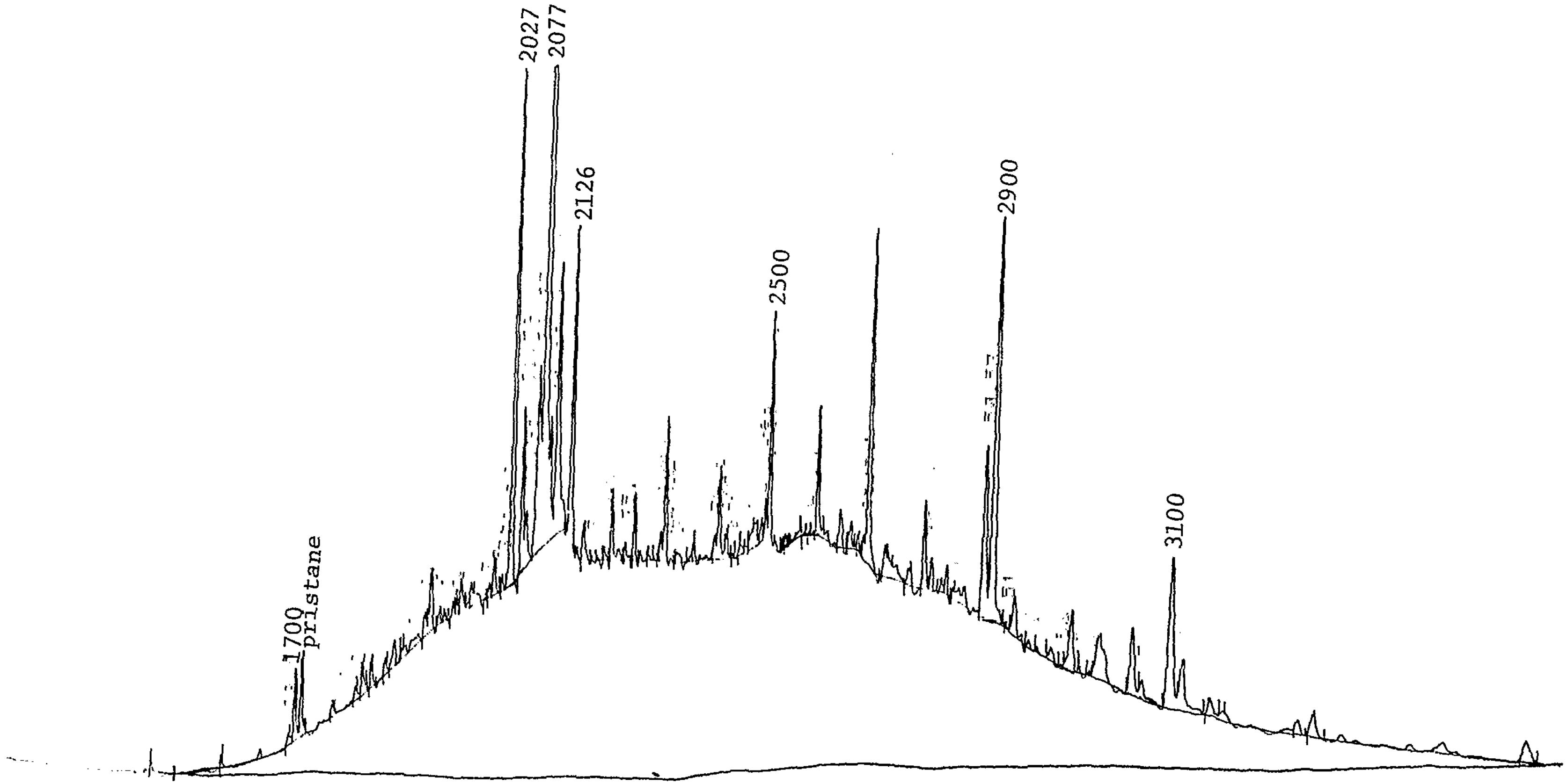


Figure 3.3-14- Gas chromatographic trace of the hexane fraction of surficial sediment at station 19, West Hackberry Disposal.

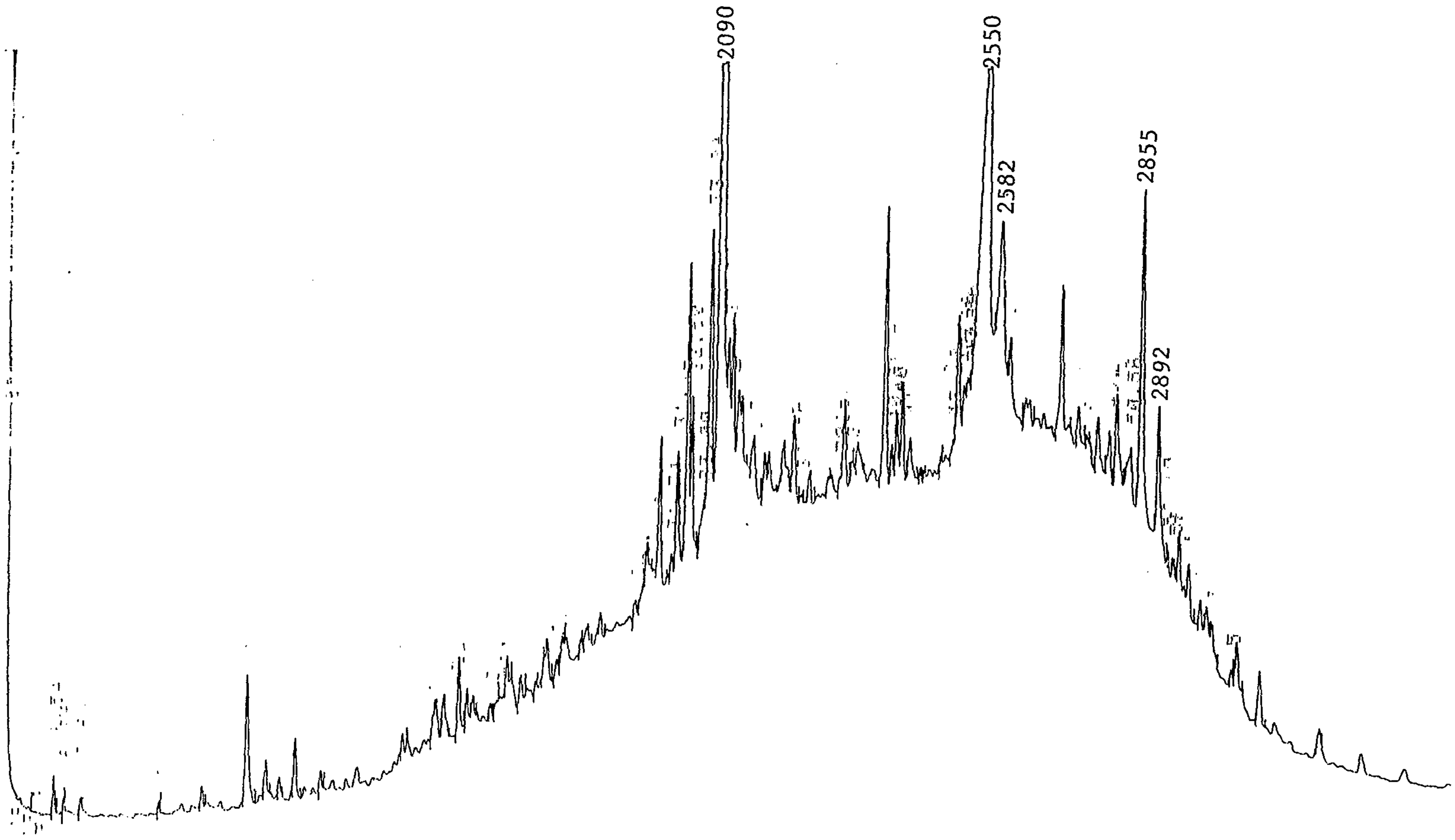


Figure 3.3-15. Gas chromatographic trace of the benzene fraction of surficial sediment from station 10, West Hackberry Disposal.

Figures 3.3-16 and 3.3-17 illustrate the chromatographic profiles for the hexane and benzene fractions of West Hackberry Control at station 29. The profiles are similar to those for station 10 except for the greater relative abundance of the marine component at station 29. The benzene fraction of station 29 differs from station 10 with the prominent occurrence of a triterpane eluting at 3186. The prevalent olefins in the hexane fractions for the control site are 2081 and 2100 with)comprises 53% of the resolved hydrocarbons in the hexane fractions.

The variability in the marine component for the control site is not as great as observed for the disposal site although its relative dominance is greater. The larger relative abundance of the marine component for the control site (27% vs. 17% for the disposal site) is attributed to its coarser texture (i.e. lesser contribution of plant detritus). The lesser abundance of plant waxes is reflected in the lower OEP (odd/even carbon preference) values for the control site.

Seawater

Although HMWHCs are characterized by very low aqueous solubilities (McAuliffe, 1966; Sutton and Calder, 1974; Eganhouse and Calder, 1976), previous monitoring efforts in marine aquatic environments have shown that a significant, and frequently major, portion of the hydrocarbons in the water column are contained in the "particulate-free" fraction of seawater (Levy, 1971; Zsolnay, 1972; Marty and Saliot, 1976; Parker et al., 1976; Payne et al., 1977a; Calder, 1977). This relative abundance may be somewhat misleading, however, and is most likely due to the typically low natural levels of suspended particulate matter. If present in high enough concentrations, as in the depositional regions of the Mississippi and Atchafalaya Rivers, particulate matter could presumably act as an efficient scavenger (i.e., adsorber) of hydrophobic HMWHCs and accentuate the importance of the particulate processes. Thus, it is a significant shortcoming of this study, that hydrocarbon levels were not determined in suspended particulate matter samples.

The fact that significant quantities of HMWHCs exist in a particulate-free (i.e., "dissolved") state has important implications to both three-dimensional transport processes and interactions with biological systems. For considerations of spatial distributions, hydrocarbons which are not incorporated into or onto vertically sinking particulate matter should have longer residence times in water columns and consequently be subject to a more extensive areal dissemination under the influence of water mass movements. From a biological standpoint, a number of studies investigating the uptake of toxic hydrocarbons by marine biota have noted a generally high degree of correlation between residue concentrations in seawater and those in the exposed marine biota (Lee et al., 1972a and b; Lee, 1975; Neff and Anderson, 1975; Corner et al., 1976a and b; Sanborn

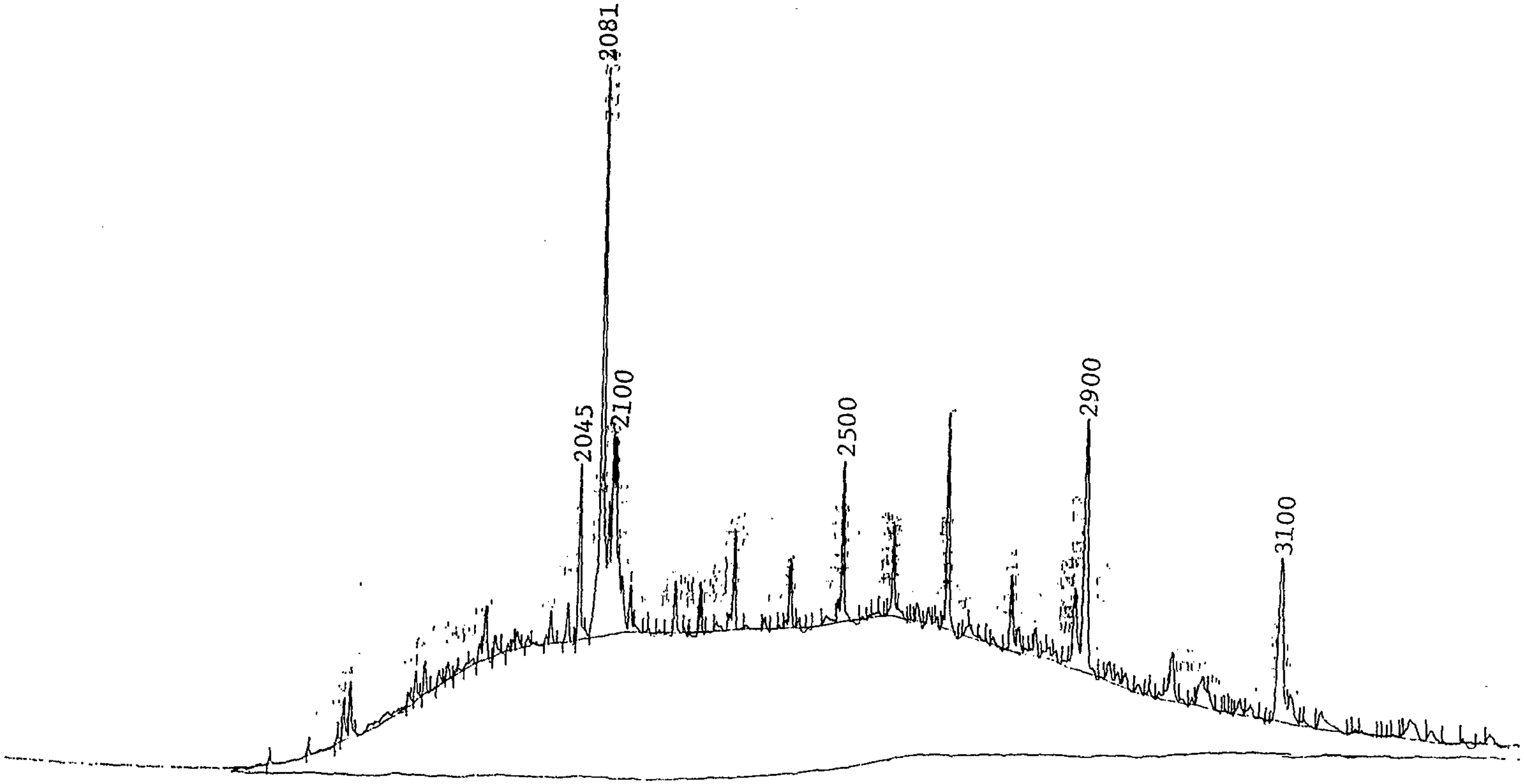


Figure 3.3-16. Gas chromatographic trace of the hexane fraction of surficial sediment at station 29, West Hackberry Control.

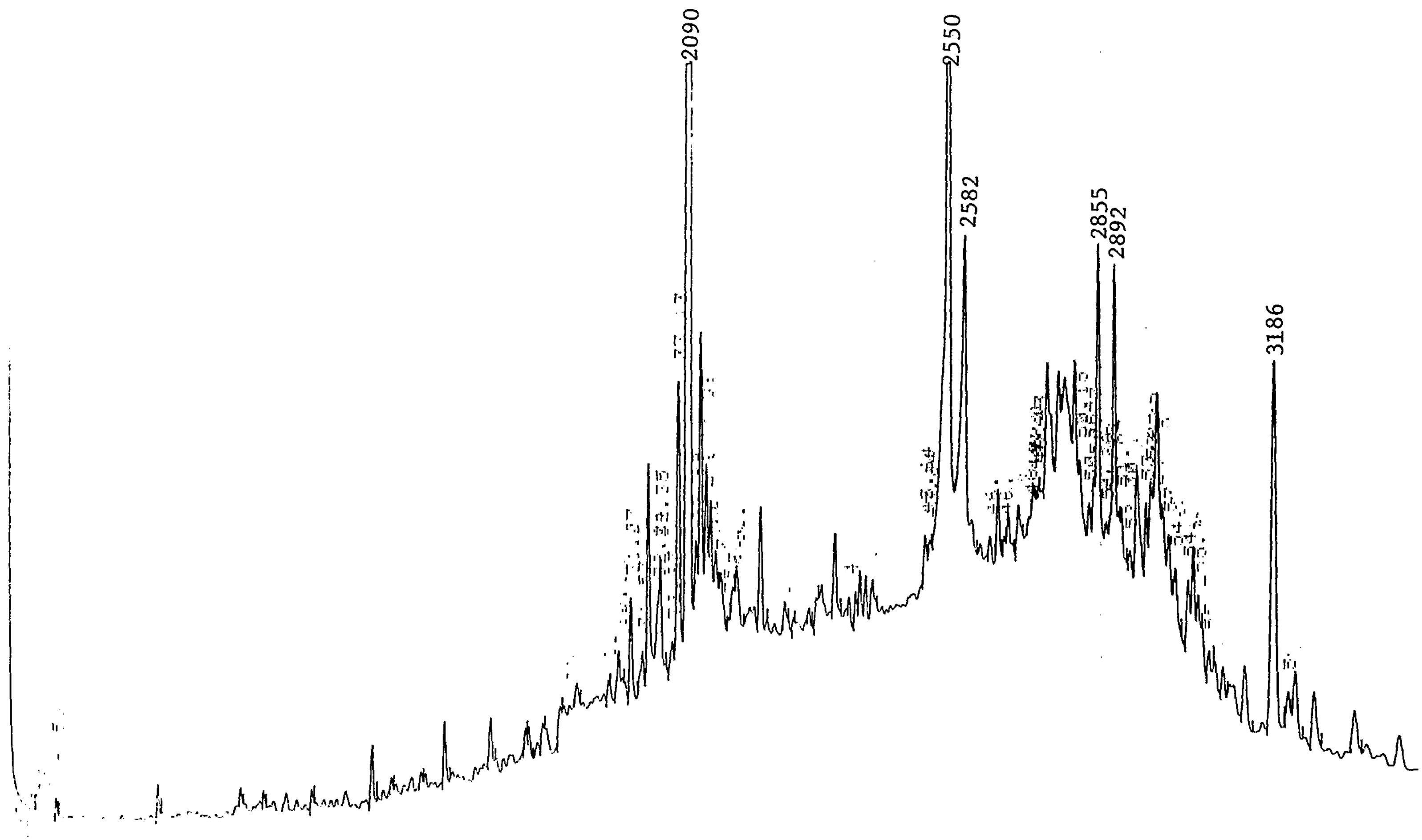


Figure 3.3-17. Gas chromatographic trace of the benzene fraction of surficial sediment at station 29 West Hackberry Control.

and Malins, 1977). This latter correlation appears to result from direct exchanges of the compounds between the aqueous medium and the biota.

Literature values of total hydrocarbon concentrations in the Gulf of Mexico range from 0.1 μg/l to over 50 μg/l, (Parker et al., 1976; Calder, 1977), however, they were not obtained in the area of the proposed brine disposal sites.

Total hydrocarbon concentrations as determined by gas chromatography are low, ranging from 200 ng/l at the control site to just over 3 μg/l at the disposal site. Table 3.3-10 lists the gas chromatographic data for the surface and deep samples from the two sites. The average concentration for the disposal site is about 900 ng/l but drops to one-half that value when the bottom sample at station 15 is removed. The control site shows an average concentration of about 750 ng/l. This value is largely controlled by a surface sample (station 32) containing a large UCM in the hexane fraction.

Figures 3.3-18 and 3.3-19 illustrate the chromatographic profiles for the hexane fraction of the surface and bottom samples of station 15 at the disposal site. Both samples are compositionally similar in containing a moderate UCM and a homologous series of n-alkanes with strong odd carbon preference of n-C_{15} and n-C_{17}. Other notable resolved peaks occur at KOVATs 1717, 1932, and 2147, and, along with n-C_{15}, are more abundant in the surface sample. The benzene fraction for the near-bottom water sample (Figure 3.3-20) shows a cluster of olefins near n-C_{20} with KOVAT 2030 being the dominant compound. Due to probable overlap of the hexane LC fraction, the profile also shows an apparent series of n-alkanes from n-C_{23} to n-C_{25} and abundant squalene (KOVAT 2810). Squalene is a $C_{30}H_{50}$ triterpane and is the precursor for steroid synthesis. The profiles illustrated in Figures 3.3-18 through 3.3-20 and the surface-to-near bottom trends are also typical of station 14. The only difference between the two stations is the very strong prominence of n-alkanes with little OEP in the surface sample of station 14. This may be due to relatively large quantities of petroleum in the water at the time of sampling or the sampling of the surface film when the ship was pitching.

As observed for stations 14 and 15, station 10 contains higher concentrations of n-C_{15} in the surface water sample. However, neither sample at station 10 contains the compounds at KI 1717, 1932, and 2147. Additionally, the peak at 2030 in the benzene fractions of stations 14 and 15 is absent at station 10. The surface-to near-bottom trends for the samples at the disposal site are reflected in the greater ratios of normal/branched hydrocarbons for the surface samples (Table 3.3-10). As in the case of the sediment samples, the contributing sources for the water appear to be both biogenic and petrogenic. n-C_{15} is the dominant hydrocarbon in marine brown algae

Table 3.3-10. Hydrocarbon data for filtered sea water samples from the West Hackberry disposal and control sites.

	In-House #	Station	Hexane Fraction ng/liter* Resolved	Hexane Fraction ng/liter* Unresolved	Benzene Fraction ng/liter* Resolved	Benzene Fraction ng/liter* Unresolved	Total*	OEP	Normal/ Branched	Pristane/ $n-C_{17}$	Phytane/ $n-C_{18}$	Pristane/ Phytane
	2030 surface	14	256	149	92	137	634	1.25	6.85	0.52	0.23	1.65
	2033 bottom	14	25	335	4	0	364	2.66	1.68	3.71	0.35	14.23
West	2031 surface	10	24	150	18	99	291	1.77	3.32	0.75	1.13	1.57
Hackberry	2041 bottom	10	8	209	22	45	284	1.81	0.97	2.09	0.33	1.48
	2032 surface	15	28	508	20	114	670	7.25	3.65	0.69	0.45	3.0
	2034 bottom	15	84	2923	27	141	3175	1.09	2.31	0.97	0.29	2.51
West	2046 surface	32	19	1535	44	206	1804	2.16	3.75	0.57	0.66	.448
Hackberry	2035 bottom	32	6	196	10	6	218	3.77	1.34	0	0.70	--
Control	2044 surface	27	8	126	19	66	219	1.07	1.64	0	--	--
	2036 bottom	27	9	162	--	--	--	3.64	1.59	0.95	0.72	1.29

* Units in nanograms/liter (parts per trillion)

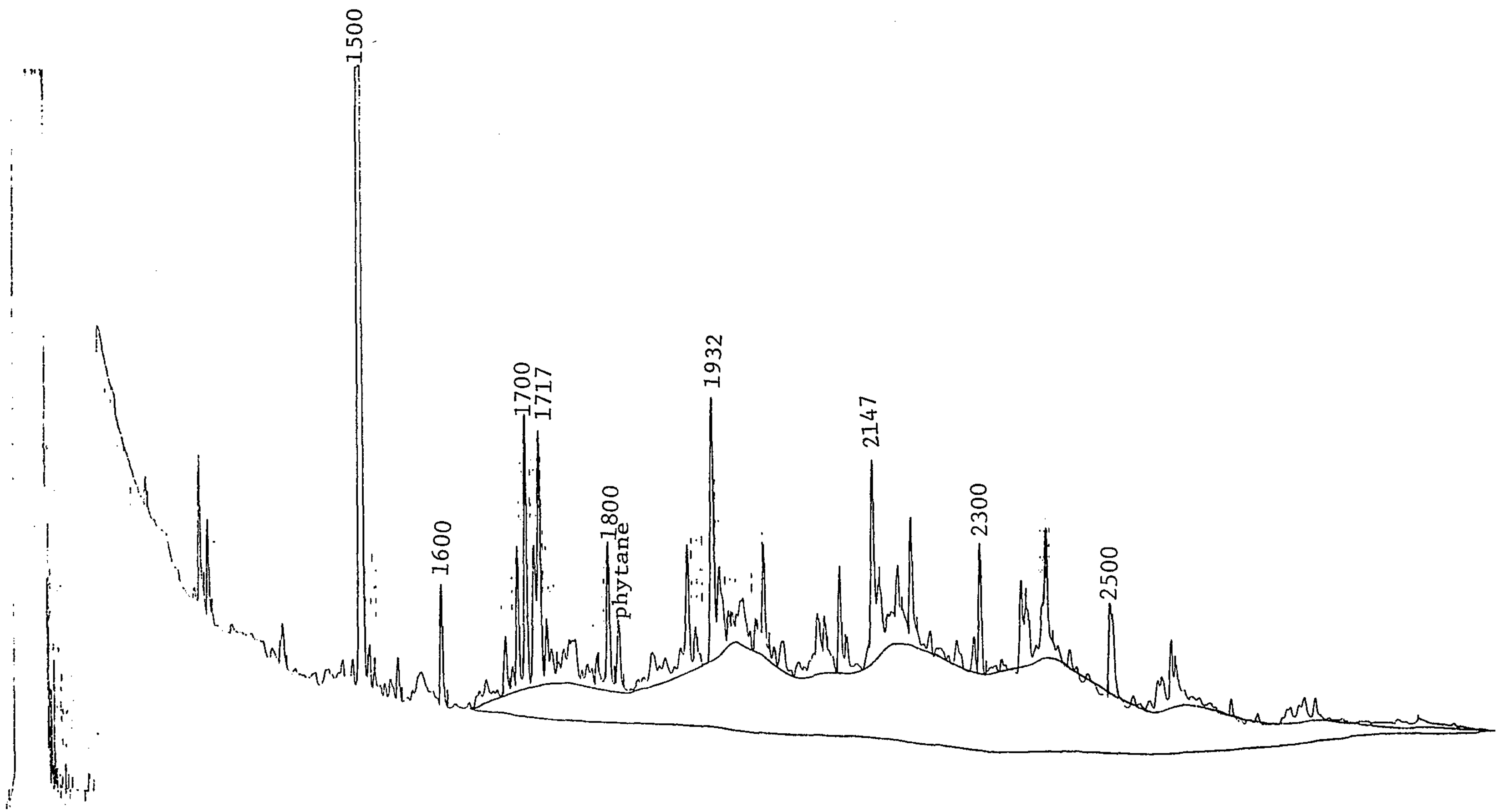


Figure 3.3-18. Gas chromatographic trace of the hexane fraction of the surface filtered sea water sample from station 15, West Hackberry Disposal.

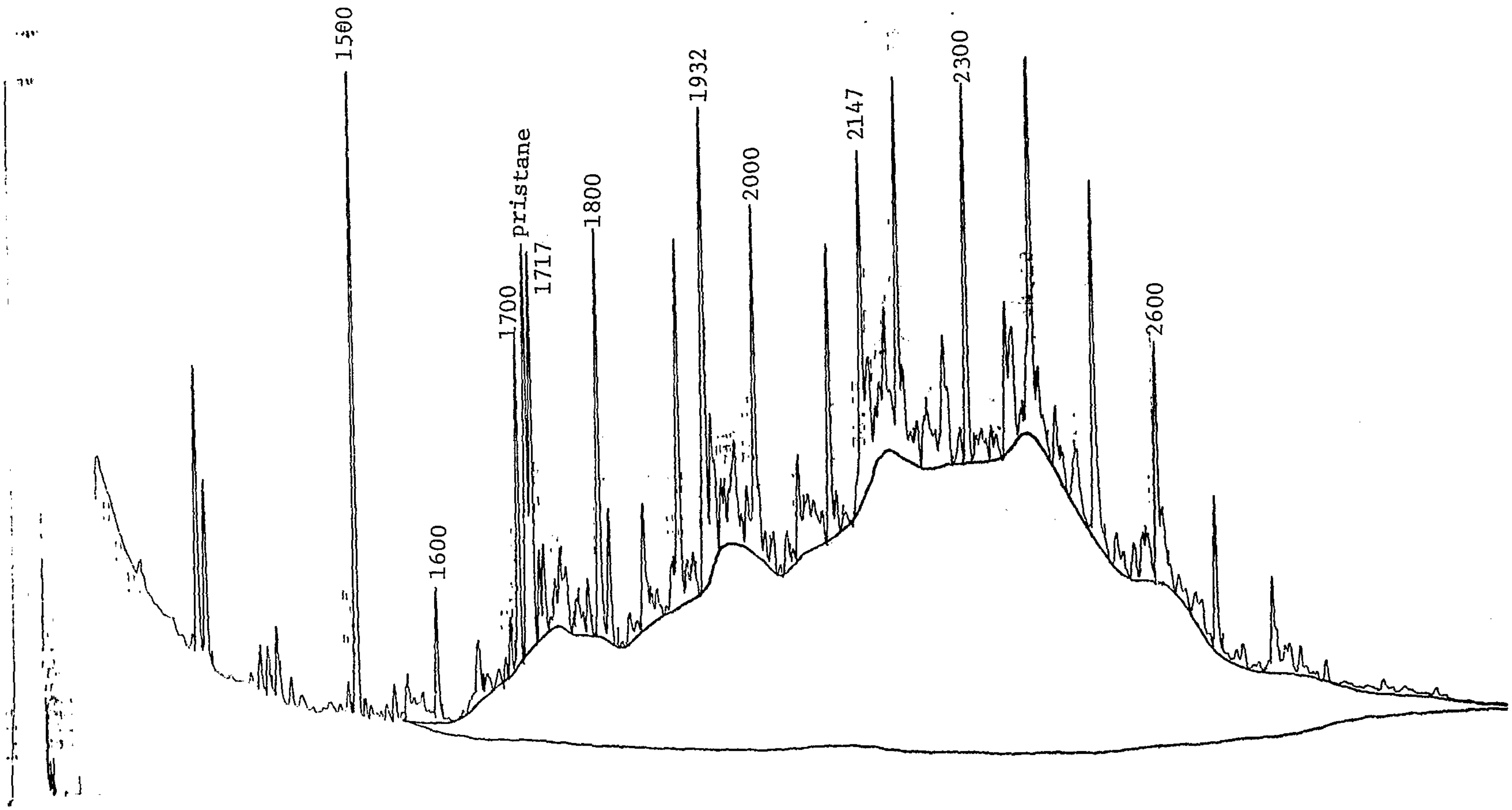


Figure 3.3-19. Gas chromatographic trace of the hexane fraction of the near-bottom filtered sea water sample at station 15, West Hackberry Disposal.

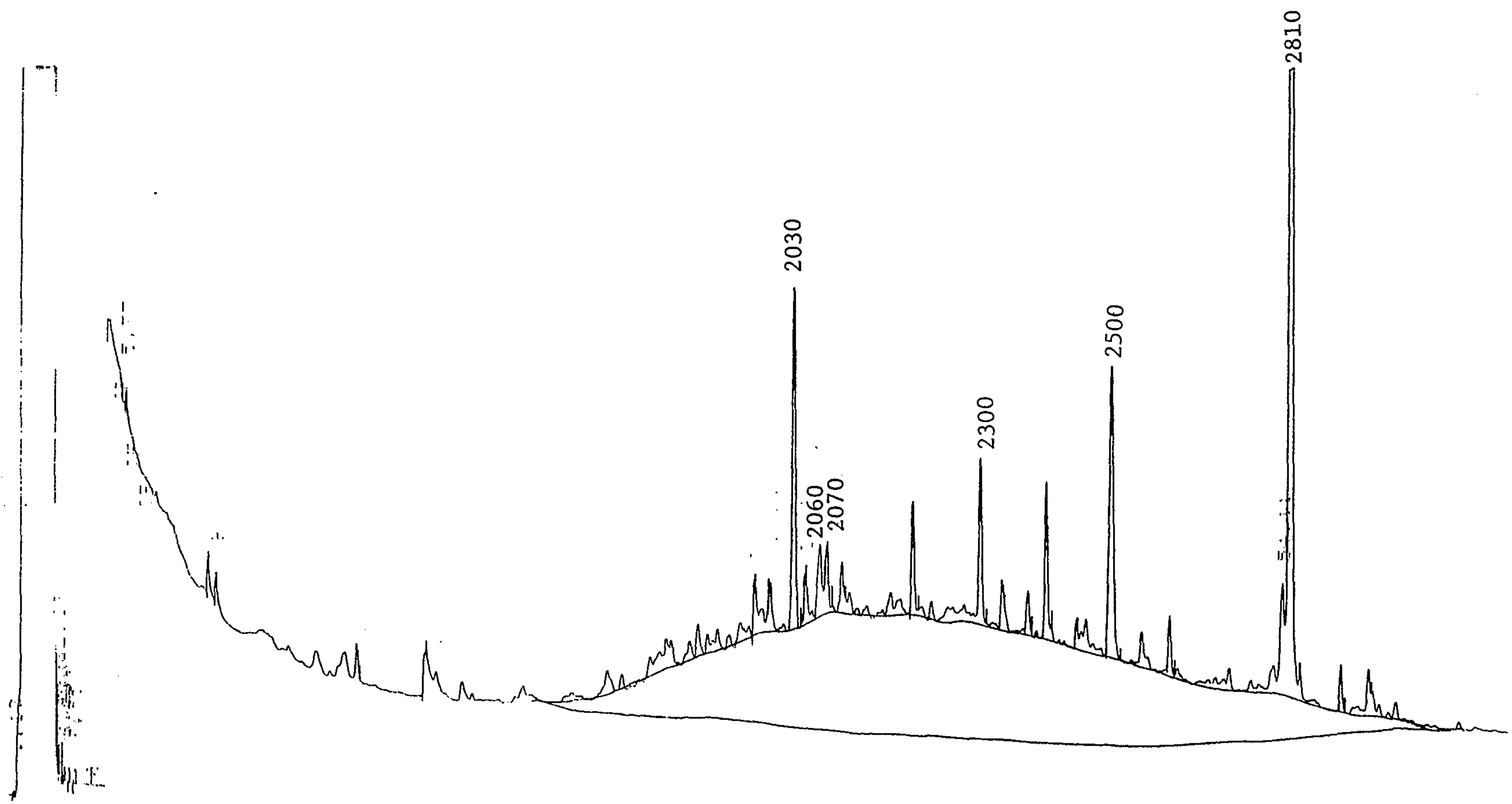


Figure 3.3-20. Gas chromatographic trace of the benzene fraction of the near-bottom filtered sea water sample at station 15, West Hackberry Disposal.

and n-C_{17} is the prominent paraffin in many green and blue-green algae. Since the occurrence of the compounds at KI 1717, 1932, and 2147 appear to be associated with an olefin (KI 2030) in the benzene fraction, they are presumed to reflect a biogenic (zooplankton?) source. The homologous series of n-alkanes above n-C_{17} and the moderate UCM may be attributed to a petroleum source. However, higher molecular weight n-alkanes with low OEP values have also been associated with certain bacteria in marine sediments.

The composition of water samples from the control site is notably different from the disposal site. Figures 3.3-21 and 3.3-22 illustrate the hexane and benzene fractions, respectively, for the bottom water sample at station 32. The hexane fraction (Figure 3.3-21) shows a series of n-alkanes with little odd carbon preference (except n-C_{25}) superimposed on a moderate UCM. The prevalence of n-C_{25} accounts for the greater OEP values for the near-bottom sea samples at the control site. This profile is similar to the hexane fractions of all the samples at the control site and the bottom sample at station 10 (disposal site). The benzene fraction (Figure 3.3-22) is most unique in exhibiting very prominent peaks from KI 1850 to 2100. These compounds are thought to be biogenic olefins; and peaks with similar elution positions have been detected in both the sediments and faunal (fish) samples. In the benzene fractions of other water samples from the control site, these olefins are present only in very low concentrations.

Macrobiota

Of particular importance in the assessment of the ultimate impacts of Strategic Petroleum Reserve brine disposal is an evaluation of possible increases of petroleum residues in commercially important members of the exposed benthic communities. As is the case with pelagic organisms, hydrocarbons in both benthic macrocrustacea and demersal fin-fish have been shown to directly exchange with residues "dissolved" in the aqueous medium (Lee et al., 1972). Field studies have also demonstrated distinct similarities between HMWHC residues in benthic fauna and associated sediments (Mackie et al., 1974). On this latter point it is interesting to note, however, that certain benthic fauna do not appear to accumulate HMWHCs from hydrocarbon-laden sediments that are directly ingested (Anderson et al., 1977; Rossi and Anderson, 1977). Consequently, the sediment-benthic hydrocarbon relationships noted by Mackie et al. (1974) may be the result of residue exchanges within spatially intimate three-phase systems (i.e., sediment-water-biota) rather than direct sediment-biota interactions. The relevant point to be made from these studies, however, is that the distributions of hydrocarbons in benthic fauna may be directly related to residues in either the adjacent water or sediment phases. Thus, petroleum hydrocarbons released during the SPR operation and brine disposal may find their way into the food web and eventually into commercially important

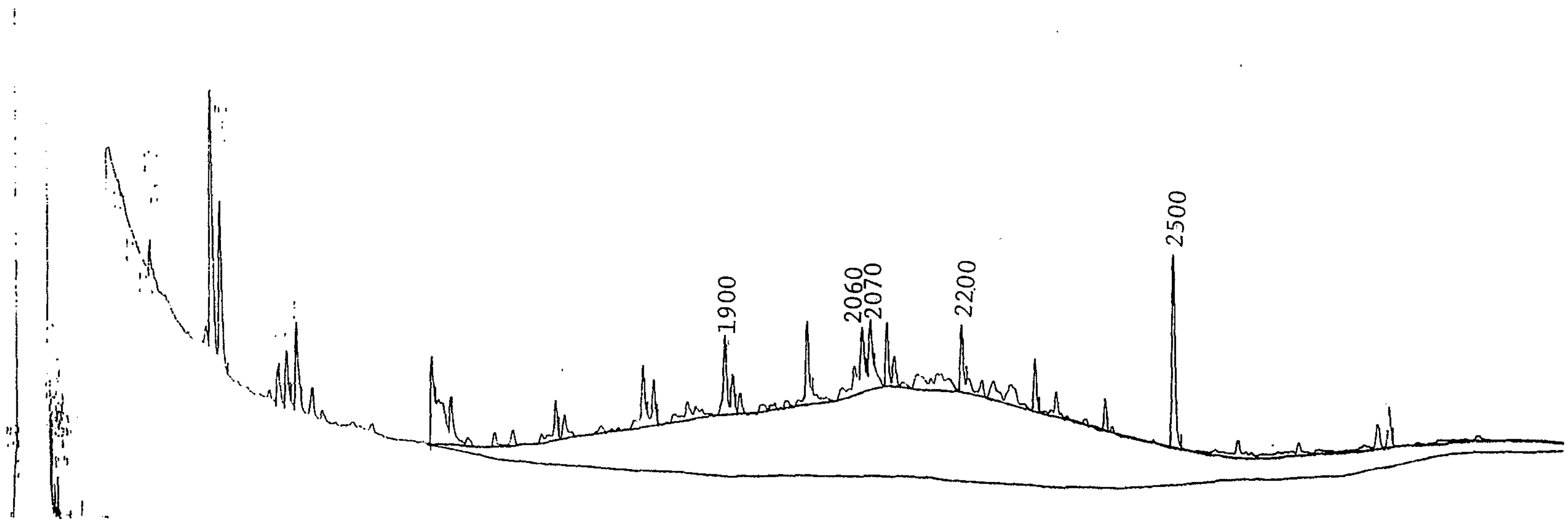


Figure 3.3-21. Gas chromatographic trace of the hexane fraction of the near-bottom filtered sea water sample at station 32, West Hackberry Control.

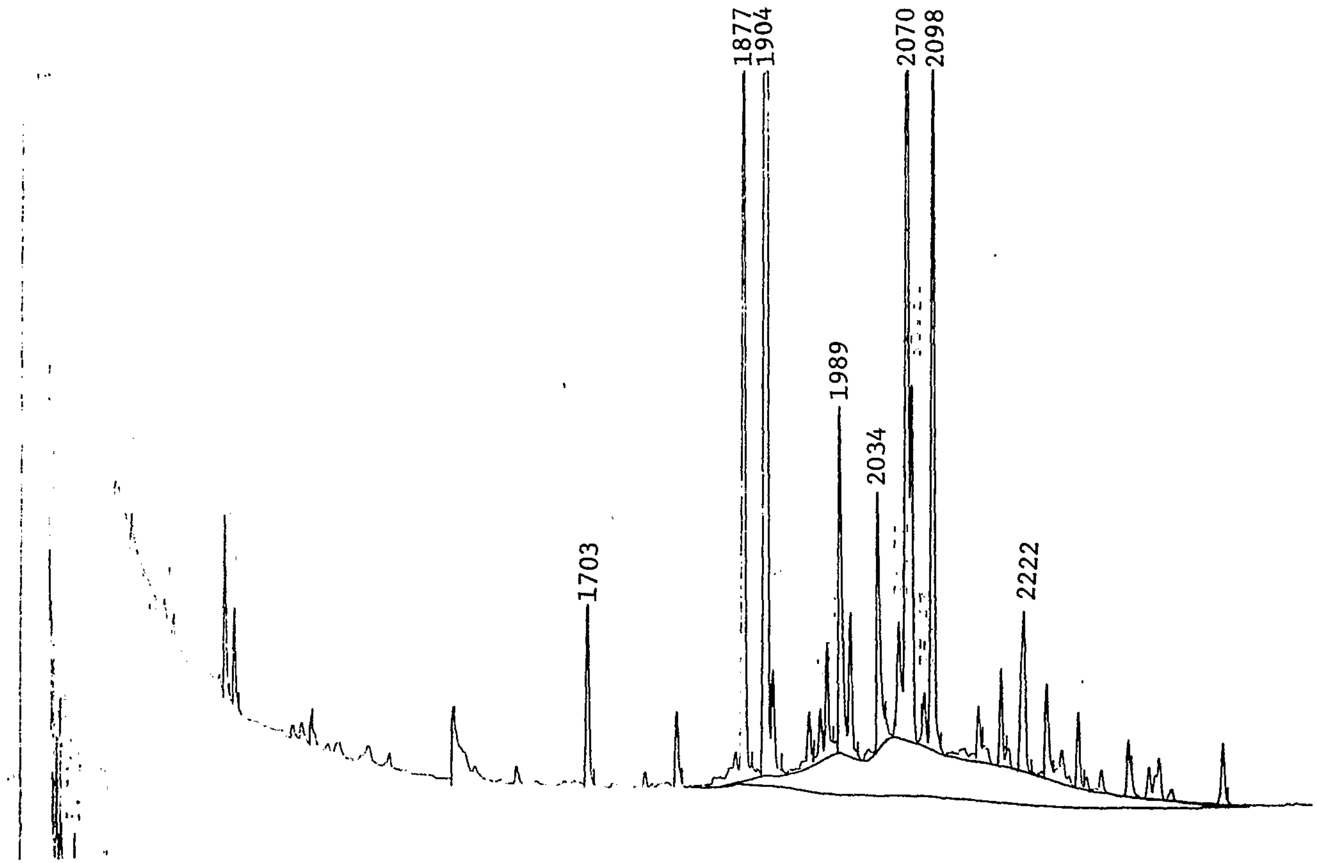


Figure 3.3-22. Gas chromatographic trace of the benzene fraction from the near-bottom filtered sea water sample at station 32, West Hackberry Control.

epifauna or fin-fish. A purpose of this study should therefore be to evaluate existing levels of HMWHCs against which change in overall concentrations could be measured in post- development monitoring programs.

Faunal samples collected for West Hackberry disposal and control sites included P. setiferus (white shrimp), M. undulatus (croaker) and P. triacanthus (butterfish). Concentration and ratio data are presented in Table 3.3-11. Since the same species were not collected from all sites, intersite comparisons are not possible. The only biota sample collected from the disposal site was croaker, while the control site collection consisted of butterfish and white shrimp samples. The two fish samples are similar chromatographically and largely exhibit biogenic hydrocarbons. Figures 3.3-23 and 3.3-24 illustrate the hexane fraction for the croaker and butterfish samples, respectively. The most prominent compound for both samples is pristane. The primary difference between the samples is the relative abundance of the secondary peaks. The croaker sample contains a greater abundance of n-C_{17} and n-C_{15} whereas the butterfish contains more prominent olefins (KI 1890 and 2084). Whether the compositional and concentration differences are due to different sites or species cannot be determined from the data. The high concentrations for the benzene fractions suggest that a large portion of the fraction may be 'contaminated' with fatty acid methyl esters, especially in the croaker sample. The benzene fraction of the butterfish sample has been subjected to GCMS analysis in order to confirm this suspicion (see Appendix 3-A).

In contrast to the fish, the detritus feeding shrimp sample is compositionally quite different. The hexane fraction (Figure 3.3-25) shows pristane as the dominant peak with a series of n-alkanes with little odd carbon preference and a slight UCM. The benzene fraction shows an apparent olefin at KI 1890 and a high molecular weight olefin at 3084 as the prominent compounds. This latter compound comprises over 50% of the resolved peaks (Figure 3.3-26).

3.3.2 BLACK BAYOU DISPOSAL SITE

3.3.2.1 Heavy Metals Chemistry

Sediments

No metals analyses were performed on sediments from the Black Bayou disposal site. In the event that the Black Bayou Site is selected for development, analyses can be performed on samples obtained during early construction activity before discharge of brine.

Table 3.3-11. Gas chromatographic data for faunal samples analyzed from the West Hackberry disposal and control sites.

In-House ID	Station/ Transect	Type	Hexane Fraction μgm/gm Resolved	Hexane Fraction μgm/gm Unresolved	Benzene Fraction μgm/gm Resolved	Benzene Fraction μgm/gm Unresolved	Pristane/ $n-C_{17}$	Phytane/ CB	Pristane/ Phytane	Pristane/ $C_{19}:1$
1009	WHI-T-2	Croaker	4.334	1.297	37.96	0	7.44	0.42	148.00	27.9
1011	WHC	Butterfish	7.04	4.81	15.436	5.088	37.38	0.90	157.00	17.1
1012	WHC	White Shrimp	0.141	4.537	3.93	0	4.54	1.11	7.01	--

* Fatty acid methyl ester "contamination"

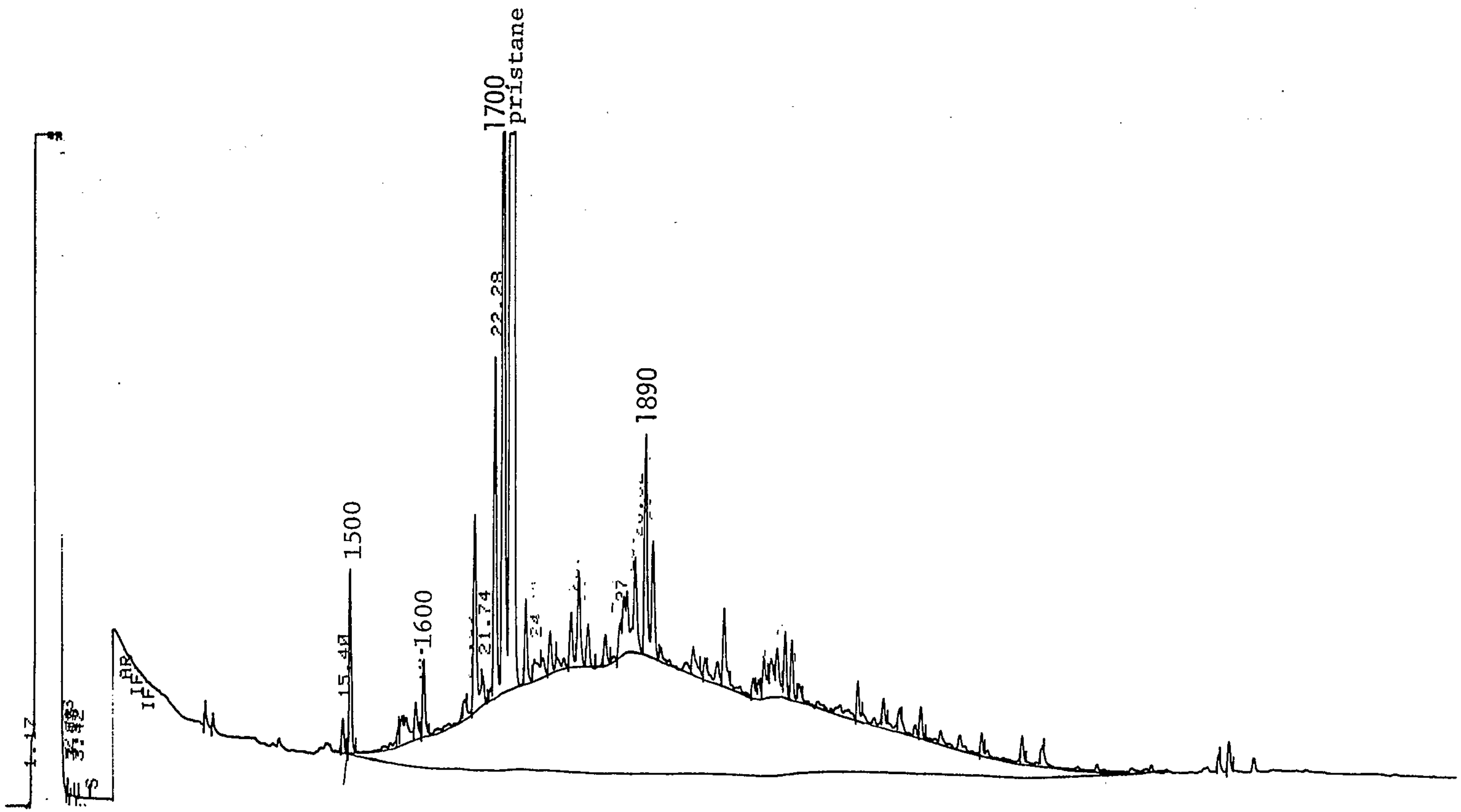


Figure 3.3-23. Gas chromatographic trace for the hexane fraction of croaker from West Hackberry Disposal.

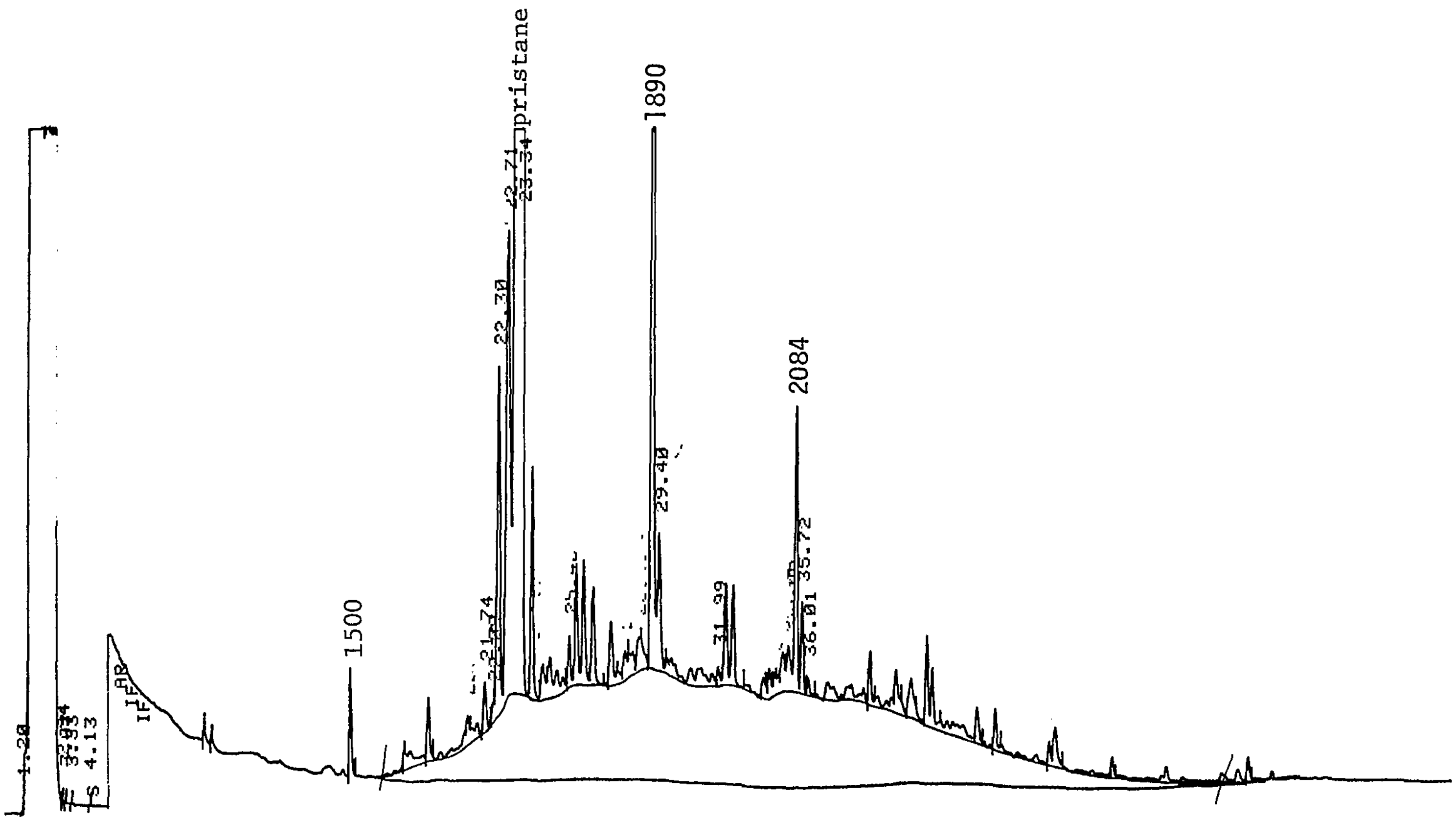


Figure 3.3-24. Gas chromatographic trace of the benzene fraction of butterfish from West Hackberry Control.

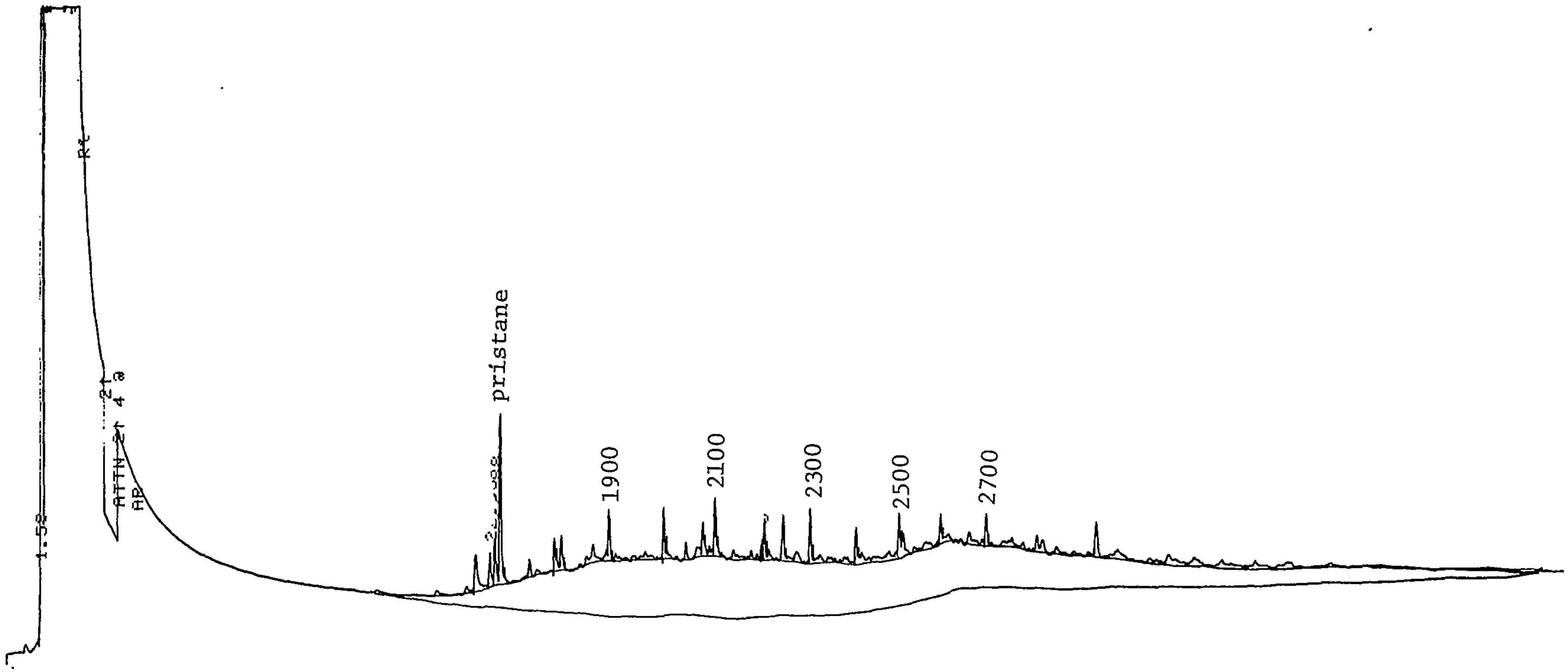


Figure 3.3-25. Gas chromatographic trace of the hexane fraction of white shrimp from West Hackberry Control.

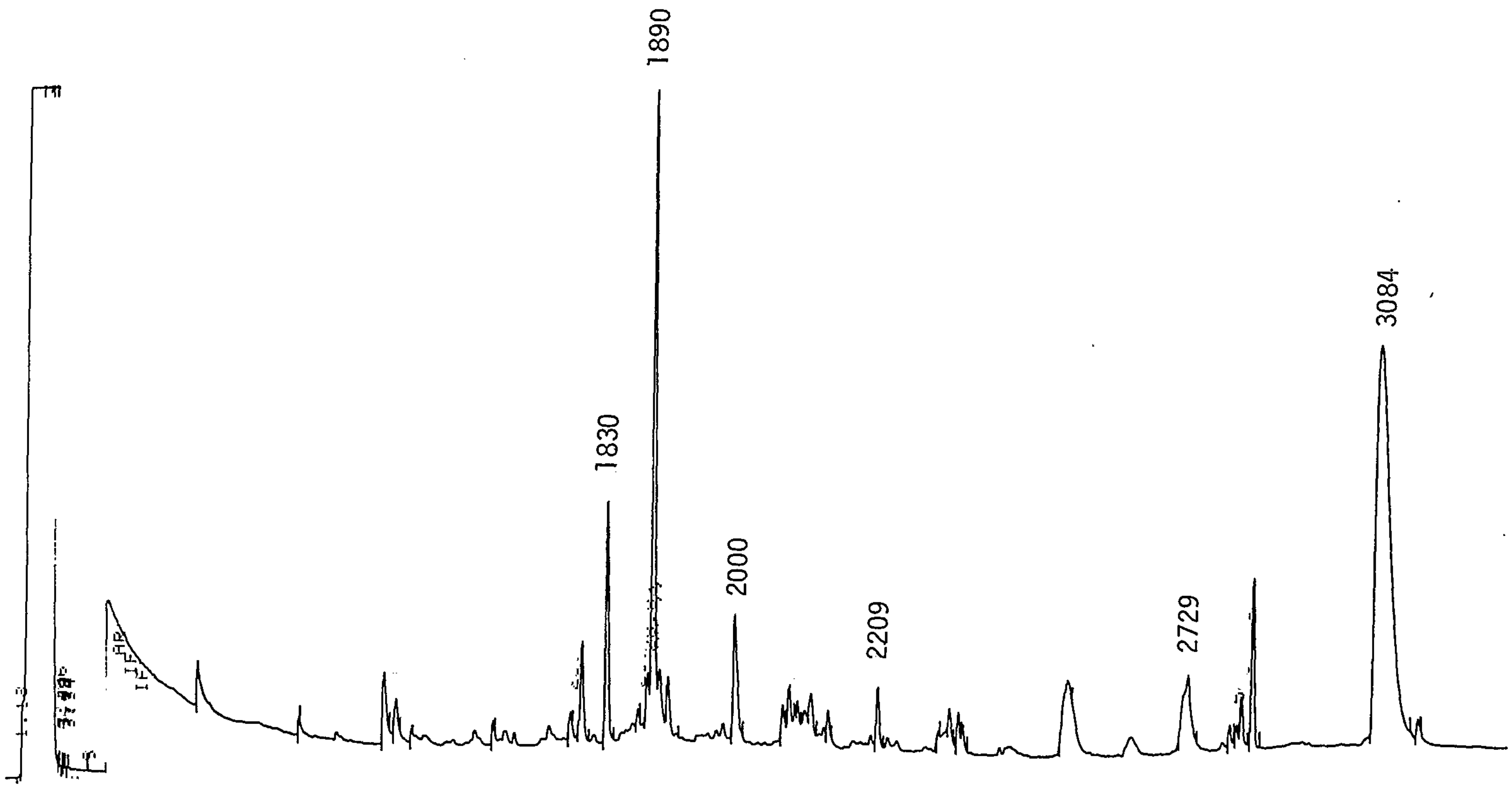


Figure 3.3-26. Gas chromatographic trace of the benzene fraction of white shrimp from West Hackberry Control.

Water Column Dissolved and Particulate Phase Analyses

Analyses on samples from the Black Bayou disposal site covered only nutrient measurements for correlation with biota sampling. Results are given in Table 3.3-12. Refer to Figure 3.2-3 for station locations.

Macrobiota

Organisms collected and analyzed for trace metals as part of this study for the Black Bayou disposal site included L. Brevis (squid) and A. mitchilli (anchovy). Table 3.3-13 contains the results of the analyses for metals. The concentrations of the various metals were not significantly different for the various organisms than found for collections at the West Hackberry Sampling locations.

3.3.2.2 Hydrocarbon Chemistry

Sediments

No sediments were collected from the Black Bayou site for hydrocarbon analyses.

Seawater

No seawater samples were collected from the Black Bayou site for hydrocarbon analyses.

Macrobiota

Three types of biota samples were analyzed for their hydrocarbon content: L. brevis (squid), A. mitchilli (anchovy), and M. undulatus (croaker). The gas chromatographic data for these samples are listed in Table 3.3-14. The only species for intersite comparison is M. undulatus (croaker), which was also collected from the West Hackberry Disposal site. As for the West Hackberry site, the prominent hydrocarbon in the croaker sample from Black Bayou is pristane (Figure 3.3-27). However, the analyses from Black Bayou shows secondary peaks at KI 1700 ($n\text{-}C_{17}$), a greater abundance of the olefins at KI 1890 and 2091, and the occurrence of compounds at 2287 and 2317. Additionally, $n\text{-}C_{29}$ and $n\text{-}C_{31}$ are moderately abundant. These additional peaks found in the Black Bayou sample account for the greater concentration for this sample.

The lowest concentration for biota samples at Black Bayou is for squid. The chromatographic traces for the hexane and benzene fractions are shown in Figures 3.3-28 and 3.3-29, respectively. The hexane fraction of the squid, although in lower concentration, shows a similar profile to the croaker sample from this site. In addition to pristane, peaks eluting at 1890, 2090, and 2287 are common to both

Table 3.3-12. Data from Water Column Analysis for Nutrients and Other Anions Black Bayou Disposal Site (September through December). See Figure 3.2-3 for station locations.

Station	Depth	SEPTEMBER Sulfate (g/l)	Chloride (g/l)	Silicate (mg/l)	Phosphate (mg/l)	Nitrate/Nitrite (mg/l)	OCTOBER Sulfate (g/l)	Silicate (mg/l)	Phosphate (mg/l)	Nitrate/Nitrite (mg/l)
47 East	1m	2.7	16.02	0.1	0.04	0.08	2.3	0.4	<0.01	0.04
	8m	2.8	16.26	0.3	0.04	0.07	1.8	0.3	<0.01	0.01
47 West	1m	2.7	16.26	0.1	0.04	0.06	2.5	0.4	<0.01	0.03
	8m	2.6	16.17	0.1	0.04	0.08	2.5	0.4	<0.01	0.06
		NOVEMBER					DECEMBER			
47 East	1m	2.6	----	1.0	0.01	0.01	1.80	1.00	0.047	0.4
	8m	2.6	----	0.4	0.01	0.02	2.13	1.12	0.035	0.2
47 West	1m	2.6	----	0.7	0.01	0.01	2.27	0.95	0.062	0.4
	8m	2.6	----	2.1	0.01	0.01	2.03	0.72	0.024	0.2

Table 3.3-13. Heavy Metal Contents of Selected Organisms - Black Bayou Disposal Site. See Figure 3.2-3 for trawl locations.

Station/Trawl	Sample Description (Species)	Fe(ppm)	Mn(ppm)	Zn(ppm)	Pb(ppm)	Ni(ppm)	Cu(ppm)	Cd(ppm)	Cr(ppm)	Al(ppm)
47	Squid (*L. brevis*), whole	13.77	21.57	65.26	0.014	0.031	39.79	1.34	<0.005	2.03
47	Anchovy (*A. mitchilli*), whole	207.5	14.61	133.6	0.082	0.237	2.95	1.28	0.131	212.

Table 3.3-14. Gas chromatographic data for faunal samples analyzed from the Black Bayou site.

In-House ID	Station/ Transect	Type	Hexane Fraction µgm/gm Resolved	Hexane Fraction µgm/gm Unresolved	Benzene Fraction µgm/gm Resolved	Benzene Fraction µgm/gm Unresolved	Pristane/ $n\text{-}C_{17}$	Phytane/ $n\text{-}C_{18}$	Pristane/ Phytane	Pristane/ $C_{19}:1$
1000	BB	Croaker	6.973	6.341	FAME*		13.67	0.45	191.3	18.00
1003	BB	Anchovies	9.470	2.451	6.604	0.813	5.18	2.52	11.04	--
1004	BB	Anchovies	8.115	4.156	0.153	0.656	4.14	0.104	51.07	--
1005	BB	Squid	0.573	0.858	3.34	0	15.90	0.445	107.39	2.92

* Fatty acid methyl ester "contamination"

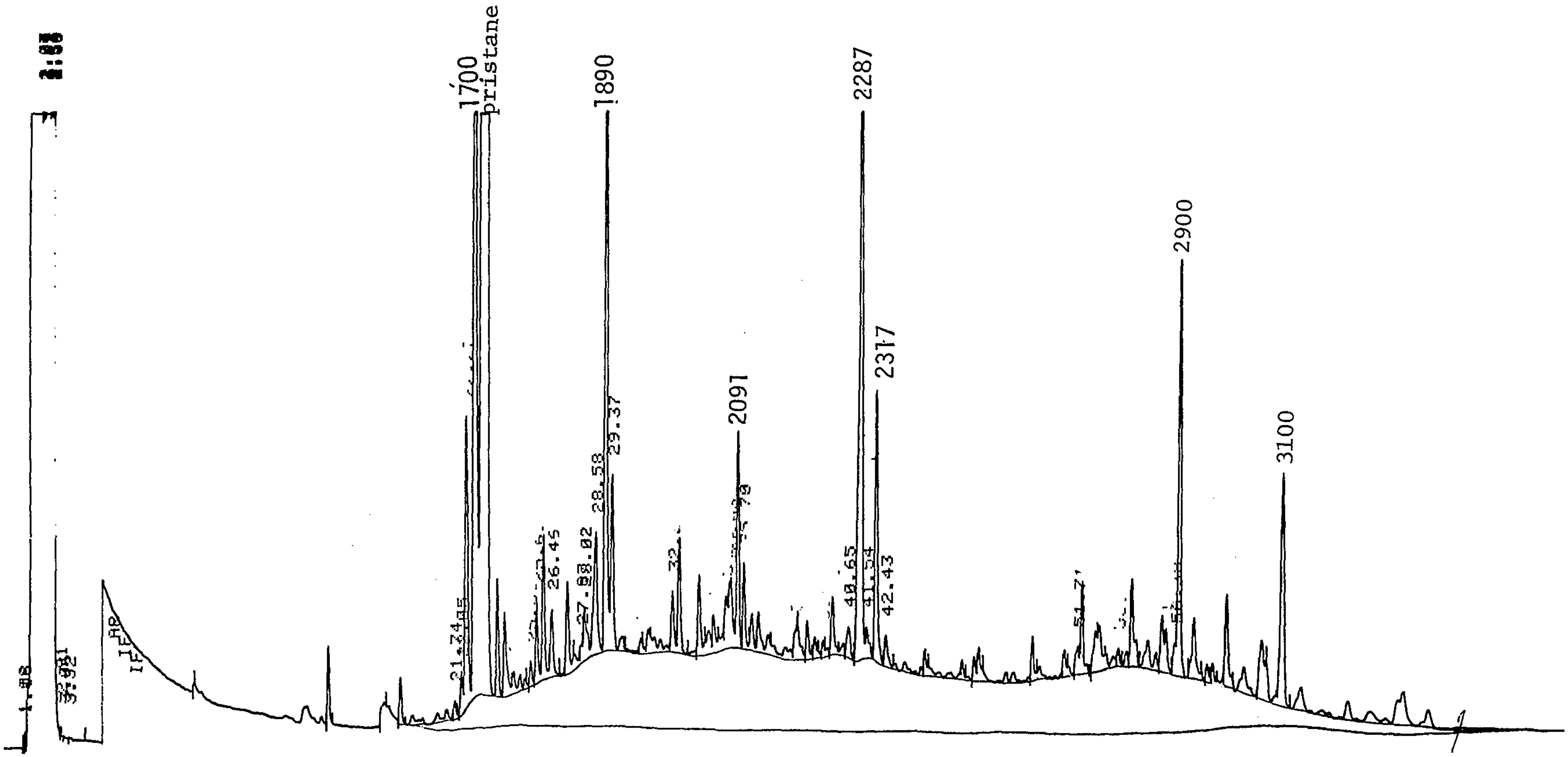


Figure 3.3-27. Gas chromatographic trace of the hexane fraction of croaker from Black Bayou.

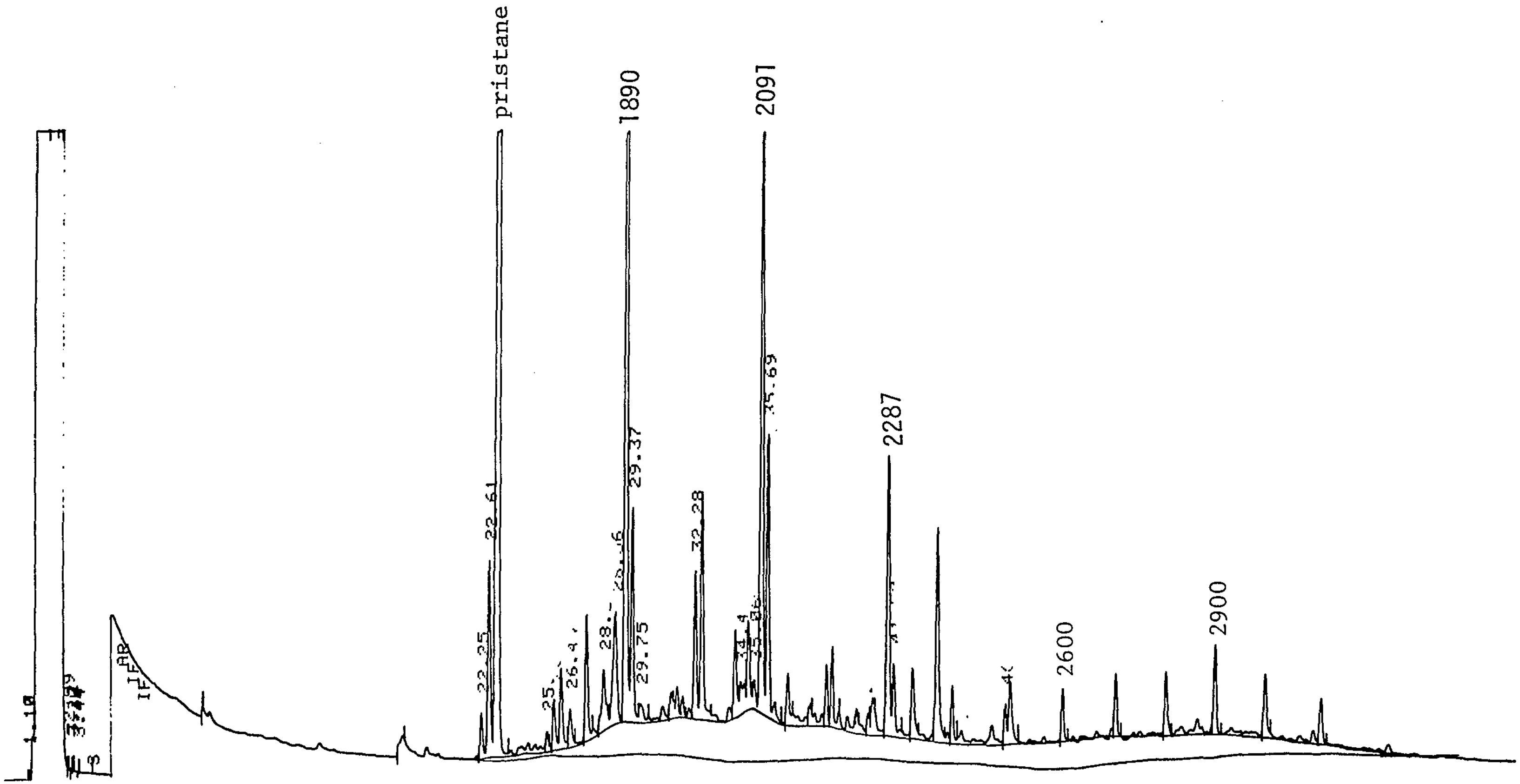


Figure 3.3-28. Gas chromatographic trace of the hexane fraction of squid from Black Bayou.

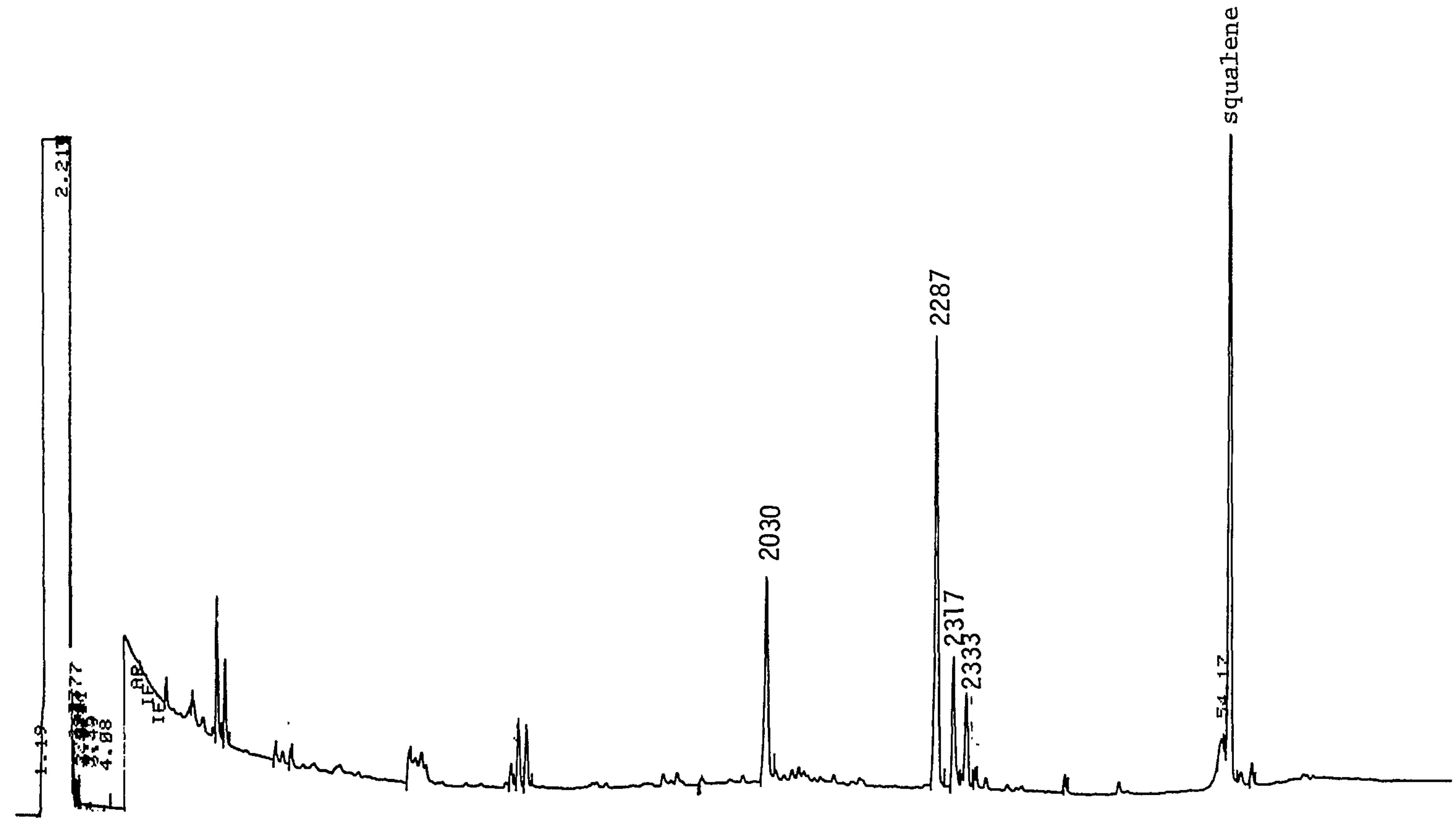


Figure 3.3-29. Gas chromatographic trace of the benzene fraction of squid from Black Bayou.

samples. The main difference between the hexane fractions of the two species is the lack of n-C_{17} in the squid sample and the greater odd carbon preference of the n-alkanes above n-C_{25} for the croaker specimen. The benzene fraction of the squid is largely comprised of an olefin 2030, a compound eluting at 2287, and squalene (2810).

The concentrations and chromatographic data for the two samples of anchovy look similar except the resolved portion of the benzene fraction of 1003 is largely comprised of fatty acid methyl esters. The chromatographic traces for the hexane and benzene fractions are illustrated in Figures 3.3-30 and 3.3-31. Although the lower molecular weight n-alkanes between n-C_{17} and n-C_{20} are present, the sample is dominated by branched (pristane) and olefinic compounds (1790, 1877, 1862, 1990, 2070, 2084). Also, the triplet (2287, 2312, 2333), and squalene (2817) which were prominent in the squid sample are also present. The benzene fraction for this sample (Figure 3.3-31) is largely composed of apparent olefins at 1982 and 2081.

3.3.3 BIG HILL DISPOSAL SITE

3.3.3.1 Heavy Metals Chemistry

Goals for the baseline sampling at the Big Hill Disposal Site were identical to those at the West Hackberry Site. However, as part of an alternate storage facility, the Big Hill Disposal Site was not sampled as extensively as was the West Hackberry Disposal Site. All aspects of the program were otherwise identical.

Sediments

The techniques utilized for sediment heavy metals analysis were identical to those used at the West Hackberry Disposal Site. These techniques approximate removal of loosely sorbed metal content subject to alteration due to changing ionic strength and other effects of brine intrusion.

The sediment trace metal data presented in Table 3.3-15 appear to be most related to the sedimentary parameters of total organic carbon (TOC) and grain size distribution (in Table 3.3-16). Figures 3.3-32 through 3.3-34 plot per cent fines (weight fraction <63 μm), per cent TOC and per cent Fe over the areal dimensions of the sampling site. As indicated in Tables 3.3-1 and 3.3-15, the per cent fines and per cent Fe are higher at the Big Hill Disposal Site than at the West Hackberry Sites, indicating more input of Fe into the sediments. Except for Cd and Cu the available concentrations of heavy metals are higher at Big Hill Stations than at West Hackberry Stations. Not only are metal concentrations higher, the metal-to-Fe ratios are higher for Mn and Pb. These observations indicate considerable difference in the sediment geochemistry at the West Hackberry and Big Hill disposal sites.

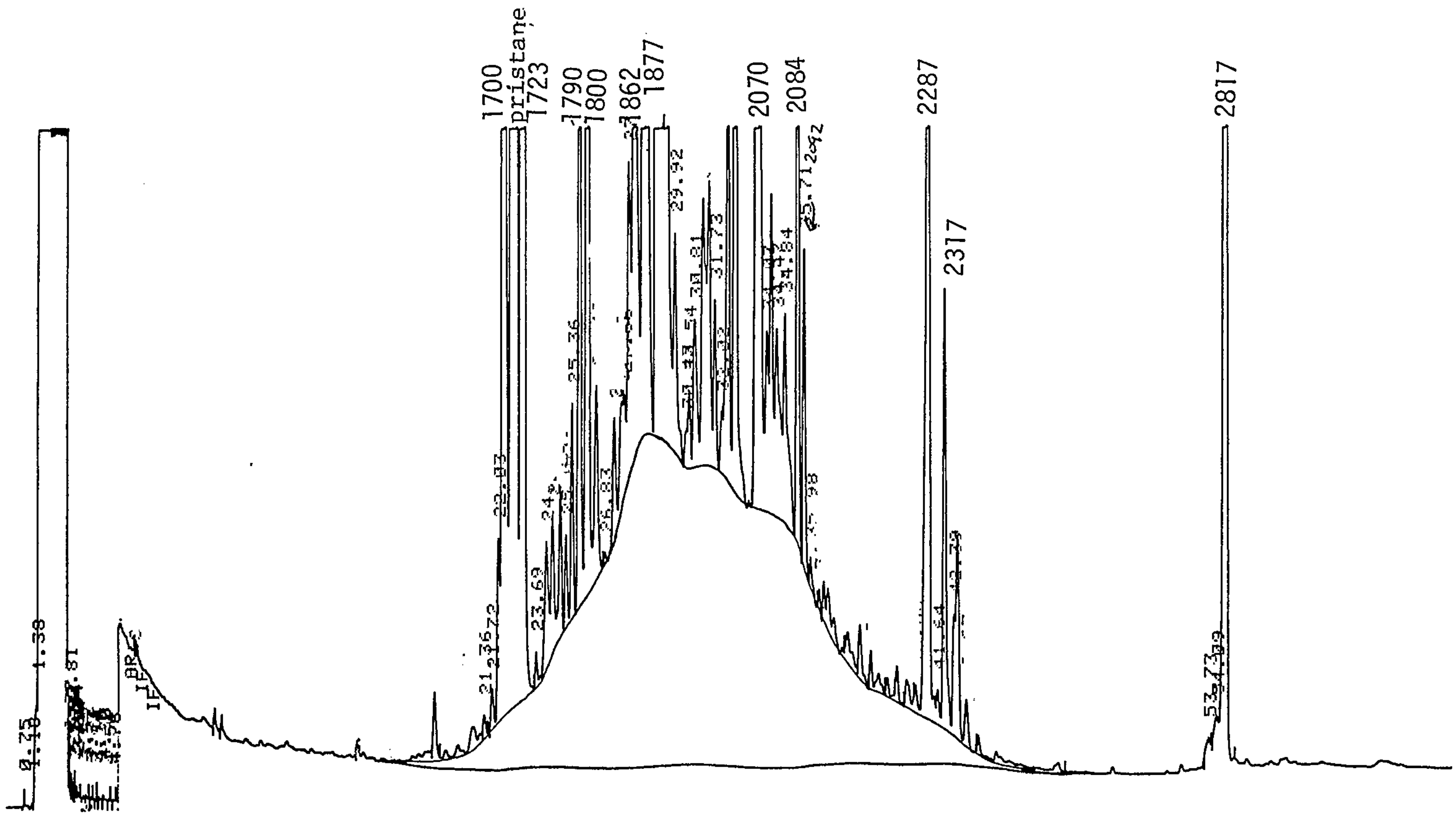


Figure 3.3-30. Gas chromatographic trace of the hexane fraction of anchovy from Black Bayou.

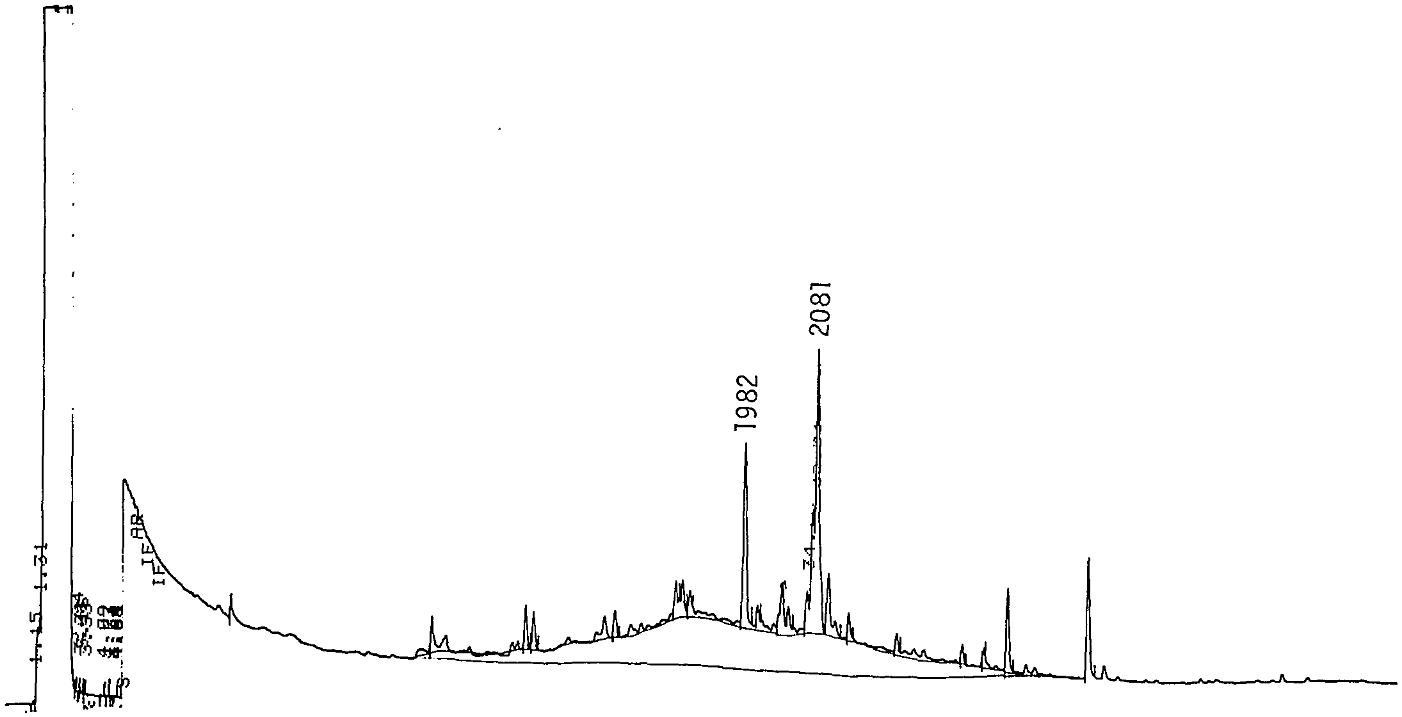


Figure 3.3-31. Chromatographic trace of the benzene fraction of anchovy from Black Bayou.

Table 3.3-15. Heavy Metal Distributions in Sediments from around the Big Hill Brine Diffuser Site. (from 1N HNO_3 leach; concentrations as dry weight of sediment). See Figures 3.2-1 through 3.2-5 for station locations.

Station	TOC(%)	$CaCo_3$(%)	Fines(%)	Fe(%)	Mn(ppm)	Zn(ppm)	Pb(ppm)	Ni(ppm)	Cr(ppm)	Cu(ppm)	Cd(ppm)	Al(%)
37	0.97	2.5	99.1	,5847	693,7* ,119**	24,35 $4{,}16\times10^{-3}$	21.48 3.67×10^{-3}	4,98 $8{,}52\times10^{-4}$	2,80 $4{,}79\times10^{-4}$	8.61 1.47×10^{-3}	0.0642 1.10×10^{-5}	.1351 .2311
38	0.93	2.4	99,0	,5109	488,8 $9{,}57\times10^{-2}$	24.80 $4{,}85\times10^{-3}$	19,79 $3{,}87\times10^{-3}$	4,97 $9{,}73\times10^{-4}$	3,17 6.20×10^{-4}	6.21 1.22×10^{-3}	0.0666 1.30×10^{-5}	.1398 .2736
39	0.97	1,7	87,5	,5584	567,8 ,102	25,89 $4{,}64\times10^{-3}$	21,11 $3{,}78\times10^{-3}$	5.71 $1{,}02\times10^{-3}$	3,33 $5{,}96\times10^{-4}$	9.81 1.76×10^{-3}	0.0884 1.58×10^{-5}	.1430 .2561
41	0.91	2.4	98,2	,5749	611,7 ,106	25,88 $4{,}50\times10^{-3}$	21,35 $3{,}7\times10^{-3}$	5.64 9.81×10^{-4}	3.38 5.88×10^{-4}	7.70 1.34×10^{-3}	0.0696 1.21×10^{-5}	.1465 .2548
42	0.89	1.9	83.6	,5163	547,1 .106	22,51 $4{,}35\times10^{-3}$	19,39 $3{,}76\times10^{-3}$	5,15 $9{,}97\times10^{-4}$	2.83 $5{,}48\times10^{-4}$	8.99 1.74×10^{-3}	0.0763 1.48×10^{-5}	.1410 .2731

* metal concentration
** metal/iron ratio

Table 3.3-16. Textural Characteristics of Sediments Distributed About the Big Hill Diffuser Site

Station #	% Gravel	% Sand	% Silt	% Clay	% Fines
37		0.9	35.9	63.2	99.1
38		1.1	39.3	59.7	99.0
39		12.5	27.9	59.6	87.5
41		1.8	27.7	70.5	98.2
42		16.4	23.2	60.4	83.6

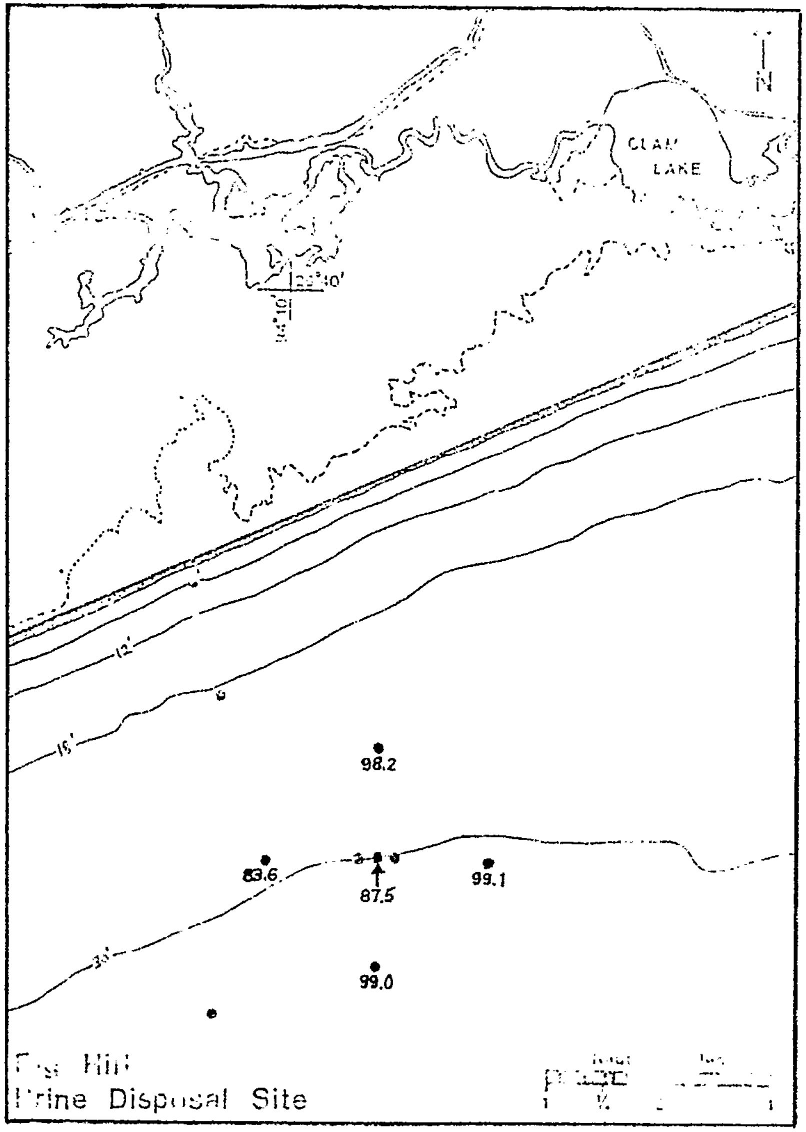


Figure 3.3-32. Percent Fines (Silt and Clay) at the Proposed Big Hill Disposal Site.

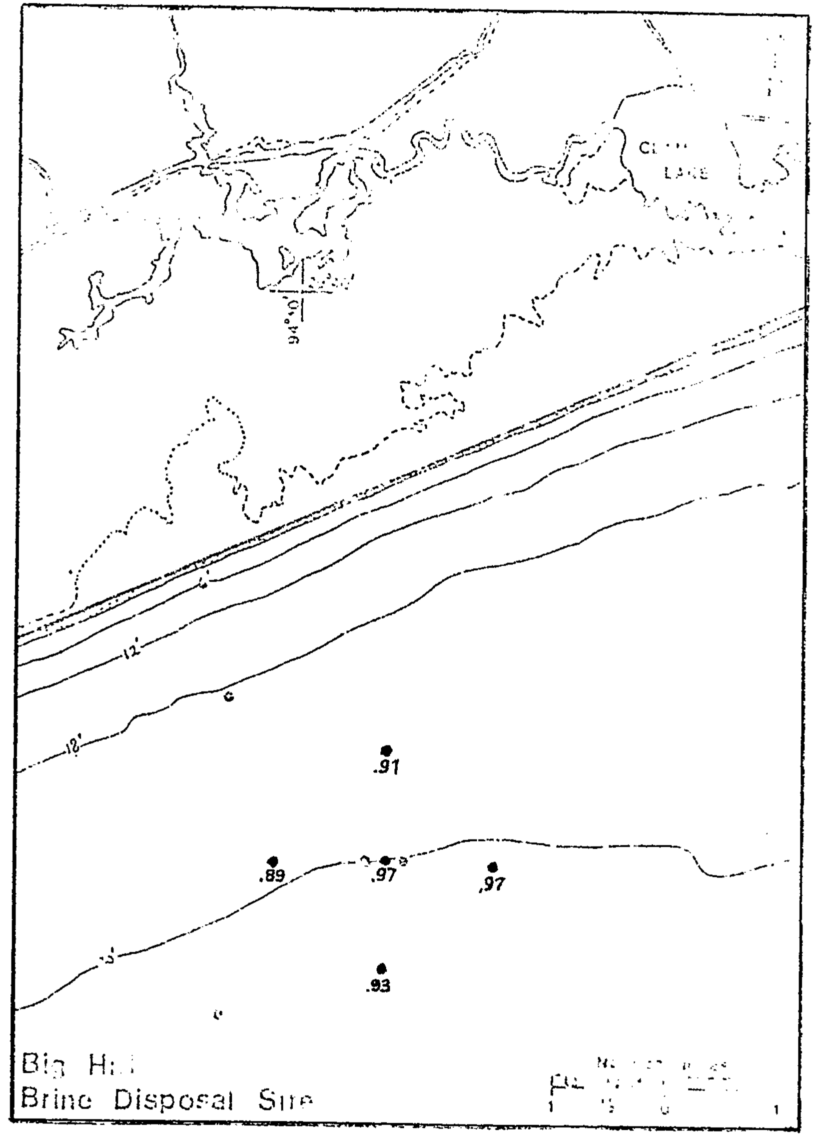


Figure 3.3-33. Total Organic Carbon (% by Weight) at the Big Hill Disposal Site (Sediments)

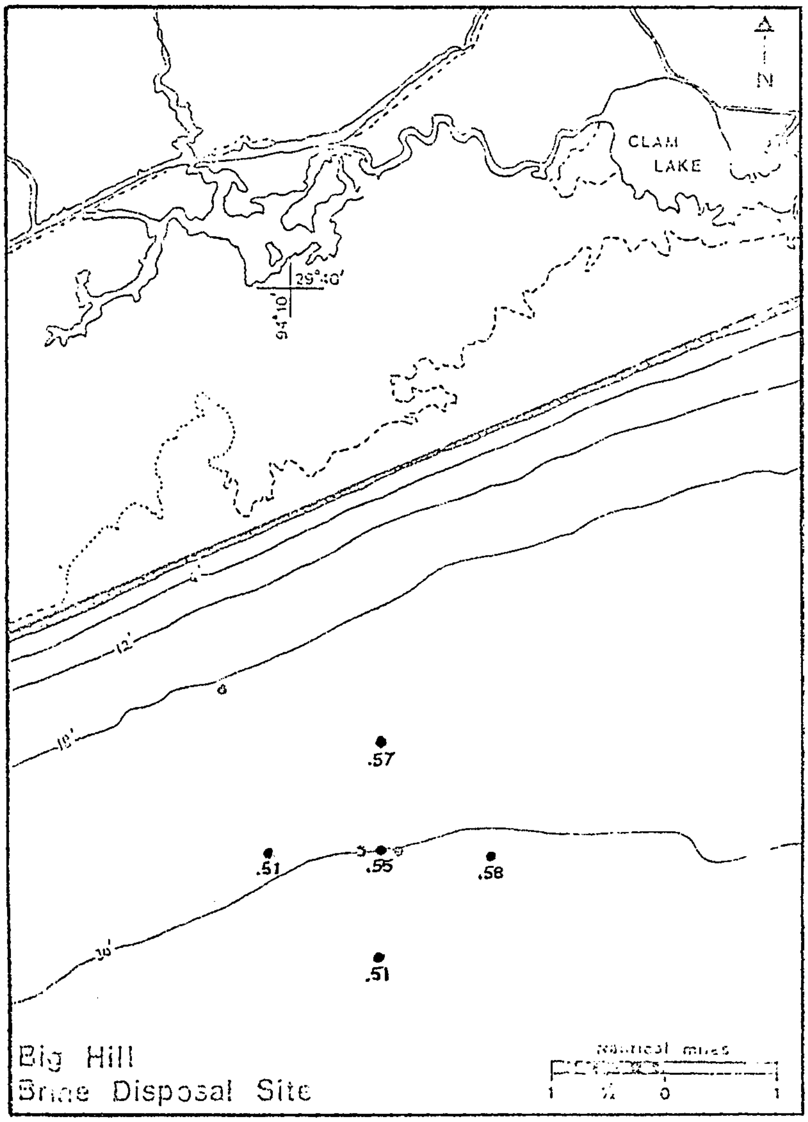


Figure 3.3-34. Percent Iron in Big Hill Disposal Site Sediments.

Variations in metal concentrations from station to station appear small at the Big Hill site. The relative constancy of these levels over the site tends to indicate no point source anthropogenic alterations.

Water Column Dissolved and Particulate Phase Analyses

Besides the hydrocarbon analyses discussed in the next section, the water column work at this site consisted of the same dissolved and particulate heavy metal, particulate organic carbon (POC), dissolved organic carbon (DOC), total suspended matter (TSM), nutrient (Si, PO_4, NO_3), and major ion measurements made at the West Hackberry site. As before, heavy metals, nutrients and major ions were measured in squeezed sediment pore waters from several of the benthic stations.

As mentioned earlier, the impetus for examining the seawater/suspended particulate system resulted from recognition of its importance as a transport mechanism for metals (and hydrocarbons). River-borne particulates dominate the flux of metals from conterminous land forms to the ocean bed. After the injection of metal-bearing particulates into the oceans by rivers and before their eventual arrival on the sea floor, these materials and their chemical burdens are maintained in phase partitionings which can be altered by changes in ionic strength, oxygen, and pH.

While we must be concerned with the potential of injecting brine-borne toxins into the system during SPR activity, the metal ion (or complex ion) balance, as it might be altered by contact with higher salinities, is likely to be of more environmental consequence. Certainly, the presence of what will be the major brine toxin for many organisms -- NaCl -- is important to consider as a water quality parameter. However, the water/suspended particulate system, and its coupling with the sediment/pore water system, must be recognized as a critical part of the chemical system which must be characterized.

Data for the Big Hill disposal site is presented in the same format as was presented earlier for the West Hackberry disposal site.

In Figure 3.3-35 are plotted the chlorinities of surface, deep, and pore waters at the Big Hill disposal site. Table 3.3-17 contains metal, nutrient and bulk ion data for the water column and pore water. Additional nutrient concentration data for the months of October, November and December are presented in Table 3.3-18. The Big Hill disposal site exhibited fairly constant salinities and metal concentrations in the water column and pore waters. The largest variations in station to station concentrations were for the Cu, Cd and the monthly nutrient values. Metal concentrations in the sediments do not appear to be especially related to any particular

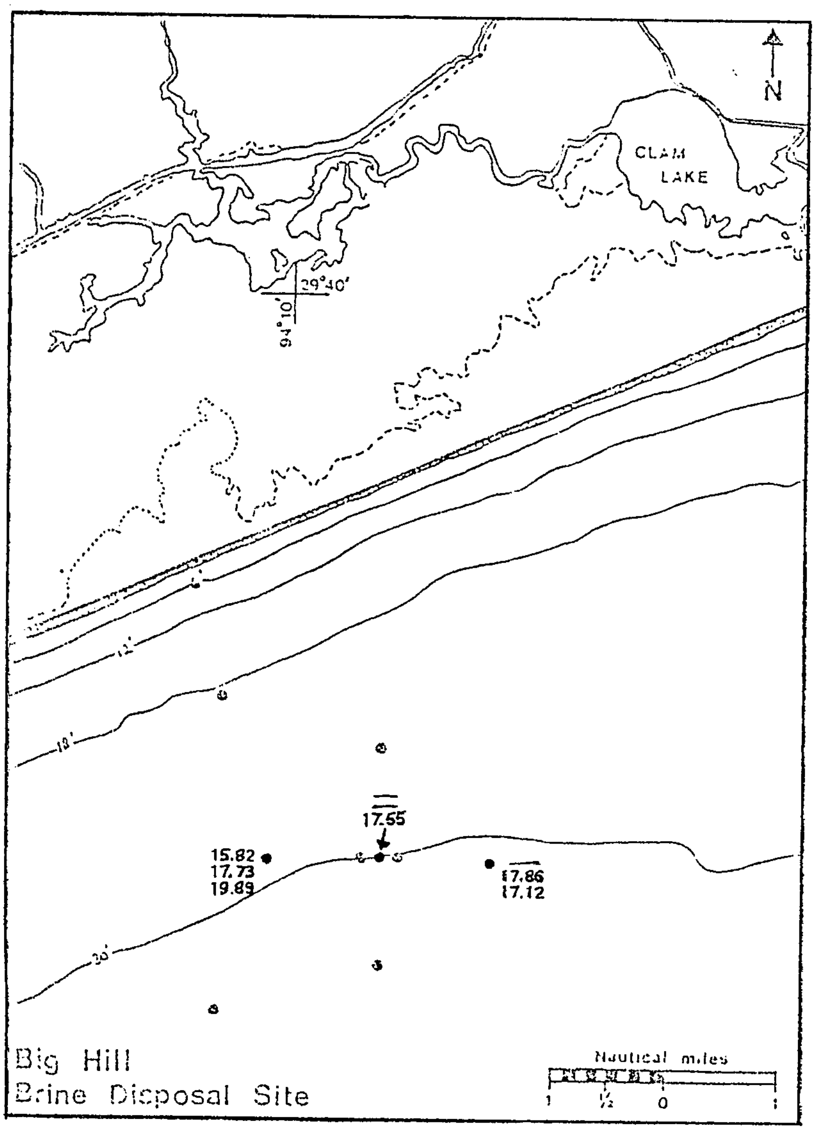


Figure 3.3-35. Chlorinity (mg/kg) at the Big Hill Disposal Site (Surface/Deep/Pore Water).

Table 3.3-17. Dissolved Heavy Metals, Nutrients and Major Ionic Species from the Water Column and Underlying Pore Waters - Big Hill Disposal Site. See Figures 3.2-1 through 3.2-5 for station locations.

Station	Depth (m)	Fe (μg/l)	Mn (μg/l)	Zn (μg/l)	Pb (μg/l)	Cu (μg/l)	Cd (μg/l)	Hg (μg/l)	PO_4 (mg/l)	SiO_4 (mg/l)	NO_2+NO_3 (mg/l)	Cl (g/l)	SO_4 (g/l)	Na (g/l)	K (g/l)	Mg (g/l)	Ca (g/l)
37	1m	15	<2	<1	3	<3	<0.3	<0.5	---	---	---	---	---	9.3	0.36	0.64	0.36
	8m	4	<2	2	<2	<3	<0.3	<0.5	0.04	0.3	0.02	17.86	2.8	10.0	0.38	0.76	0.39
	pore	<4	0.6	10	<2	<3	4.5	<100	0.05	4.0	0.25	17.12	3.2	9.4	0.33	0.33	0.38
39	1m	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	8m	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
	pore	<4	0.4	5	<2	<3	4.0	<100	0.04	2.5	0.13	17.55	3.1	9.6	0.36	0.36	0.38
42	1m	15	<2	<1	6	8	0.6	0.5	0.04	0.4	0.02	15.82	2.7	9.3	0.36	0.63	0.34
	8m	11	<2	2	2	<3	<0.3	<0.5	0.03	0.1	0.02	17.73	2.7	10.2	0.40	0.78	0.38
	pore	4	0.2	3	<2	<3	3.1	100	0.02	2.7	0.10	19.89	3.0	9.6	0.35	0.35	0.38

Table 3.3-18. Dissolved Nutrient and Ionic Species Data for the Big Hill Control Site. See Figures 3.2-1 through 3.2-5 for station locations.

		SEPTEMBER					OCTOBER			
Station	Depth	Sulfate (g/l)	Chloride (g/l)	Silicate (mg/l)	Phosphate (mg/l)	Nitrate+Nitrite (mg/l)	Sulfate (g/l)	Silicate (mg/l)	Phosphate (mg/l)	Nitrate+Nitrite (mg/l)
50 East	1m	2.6	16.85	0.1	0.04	0.02	2.4	0.4	0.01	0.02
	8m	2.8	17.81	0.1	0.04	0.04	2.4	0.4	0.01	0.01
50 West	1m	3.2	16.61	0.2	0.03	0.02	2.4	0.4	<0.01	0.03
	8m	2.8	17.76	0.1	0.03	0.03	2.5	0.3	<0.01	0.02
		NOVEMBER					DECEMBER			
50 East	1m	2.8	----	1.3	0.01	0.01	1.93	1.14	0.074	0.4
	8m	2.4	----	0.4	0.01	0.01	1.57	0.40	0.038	0.1
50 West	1m	2.8	----	1.6	0.01	0.01	1.61	0.86	0.043	0.2
	8m	2.7	----	0.2	0.01	0.01	2.12	0.73	0.081	0.2

parameter except a rather general association with grain size. Although there are some fluctuations in pore water dissolved metals at the Big Hill site, these variations do not seem to be particularly related to salinity.

Table 3.3-17 also tabulates dissolved metals in the water column and, although large variations occur, they are all within the generally low and accepted ranges found in previous investigations of coastal waters. The dissolved nutrient and major ion data are substantially more useful in characterizing the water quality of the site on a local basis.

Table 3.3-19 compares the relative contributions of metals by particulate and dissolved phases to the water column burden. The dominance of one phase over the other (usually in favor of particulates in high TSM areas) is not unexpected. These comparisons will provide important data for eventually assessing the mass balance impact of adding brine to a system and potentially altering the partitioning coefficients of its heavy metal loads. Total suspended matter for the site is plotted in Figure 3.3-36.

Table 3.3-20 lists the per cent leachable fractions of heavy metals in the suspended particulates at each depth, and compares the leachable metal contents in particulates with those in the underlying sediments. The leachable fraction ranges to the typically low (<10%) Fe to several quite high values (~90-95%) for metals, including Mn, Zn, and Cd.

Table 3.3-21 compares weak and leachable heavy metal concentrations in sediments, with concentrations in pore water, and the overlying water column.

Macrobiota and Plankton

Biota samples collected and analyzed for trace metals as part of this study for the Big Hill disposal site included P. setiferus (white shrimp) and M. undulatus (croaker). Figures 3.2-4 and 3.2-5 indicate trawl locations.

Trace metal concentrations on a dry weight tissue basis are tabulated in Table 3.3-22 for the Big Hill disposal site samples. Examination of the data reveal several expected trends. The whole M. undulatus from Big Hill contained approximately the same heavy metal concentration as a comparable sample from the West Hackberry site. However, Fe and Fe-associated metals such as Ni and Cr were higher in the Big Hill sample, probably due to higher Fe levels in particulates and sediments at the Big Hill site. Also, this elevation may be an artifact of sampling caused by self-filtering by the plankton over the 202 m mesh net, removing terrigenous clay particulates from seawater, as well as themselves. This effect can conceivably be

Table 3.3-19. Relative Dissolved and Particulate Heavy Metal Burdens - Big Hill Disposal Site. See Figures 3.2-1 through 3.2-5 for station locations.

Station	Depth		TSM (mg/l)	POC (µgC/l)	POC/TSM (%)	DOC (mgC/l)	Fe (ng/l)	Mn (ng/l)	Zn (ng/l)	Pb (ng/l)	Ni (ng/l)	Cu (ng/l)	Cd (ng/l)	Cr (ng/l)
37	1m	Dissolved				1.79	15000	<2000	<1000	3000	----	<3000	<300	----
		Particulate	1.00	219	22.		4.23×10^4	1.14×10^3	608	59	72	198	22	29
	8m	Dissolved				0.81	4000	<2000	2000	<2000	----	<3000	<300	----
		Particulate	2.58	228	9.		1.09×10^5	2.56×10^3	503	83	167	77	5	248
42	1m	Dissolved				0.82	15000	<2000	<1000	6000	----	8000	6000	----
		Particulate	1.45	267	18.		1.4×10^5	1.8×10^3	690	104	147	132	10	152
	8m	Dissolved				1.47	1100	<2000	2000	2000	----	<3000	<300	----
		Particulate	3.10	255	8.		2.6×10^{-5}	4.15×10^3	1.91×10^3	154	200	169	32	233

Table 3.3-20. Heavy Metal Contents of Suspended Particulates - Big Hill Disposal Site. See Figures 3.2-1 through 3.2-5 for station locations. WAS (*) indicates weak acid soluble metal concentration.

Station	Depth (m)	P=Particulate	Fe(ppm)	Mn(ppm)	Zn(ppm)	Pb(ppm)	Ni(pm)	Cr(ppm)	Cu(ppm)	Cd(ppm)
37	1m	P-WAS*	2704	821	496	28.8	<23.8	<1.2	37.2	7.7
		P-Total	42300	1138	608	59.4	72.1	29.0	76.6	8.5
		P-%Leach	6.9	72.1	81.6	48.5	<33.0	<4.1	48.6	90.6
	8m	P-WAS	2136	703	81	9.2	<7.8	<0.4	6.5	1.1
		P-Total	42200	993	195	32.2	64.8	96.2	29.8	1.9
		P-%Leach	5.06	70.8	41.5	28.6	<12.0	<0.4	21.8	57.9
42	1m	P-WAS	3605	911	332	34.4	<41.1	<2.1	49.2	6.0
		P-Total	97100	1255	476	71.7	101	105	90.8	7.0
		P-%Leach	3.71	72.6	69.7	48.0	<40.7	<2	54.2	85.7
	8m	P-WAS	2987	979	492	26.3	<16.8	<0.8	19.6	9.6
		P-Total	85200	1339	616	49.7	64.4	75.1	54.6	10.2
		P-%Leach	3.51	73.1	79.9	52.9	<26.1	<1.1	35.9	94.1

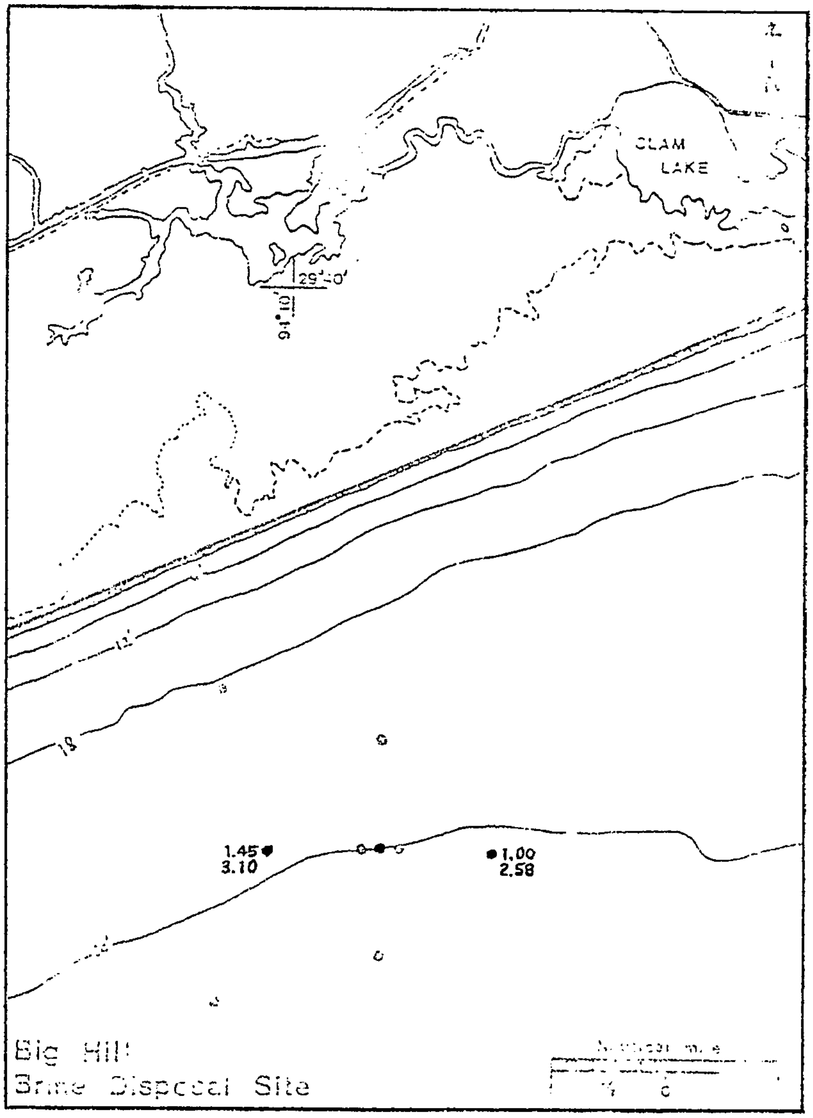


Figure 3.3-36. Total Suspended Matter (gm/l) Surface/Bottom for the Big Hill Disposal Site Stations.

Table 3.3-21. Comparison of Heavy Metal Concentrations in Leached (1N HNO_3) Sediments, Pore Water and Overlying Water - Big Hill Disposal Site. See Figure 3.2-4 for station locations.

Station		% Fines (<62 µm)	% $CaCO_3$	% TOC	Fe(ppm)	Mn(ppm)	Zn(ppm)	Pb(ppm)	Cu(ppm)	Cd(ppm)
37	sediment	99.1	2.5	0.97	5847	693.7	24.35	11.48	8.61	0.064
	pore H_2O				<0.004	0.0006	0.010	<.002	<.003	0.0045
	near bottom H_2O				0.004	< 0.002	0.002	<.002	<.003	<0.0003
39	sediment	87.5	1.7	0.97	5584	567.8	25.89	21.11	9.81	0.088
	pore H_2O				<0.004	0.0004	0.005	<.002	<.003	0.0040
	near bottom H_2O				----	----	----	----	----	----
42	sediemnt	83.6	1.9	0.89	5163	547.1	22.51	19.39	8.99	0.076
	pore H_2O				0.004	0.0002	0.003	<.002	<.003	0.0031
	near bottom H_2O				0.011	<0.002	0.002	0.002	<.003	<0.0003

Table 3.2-22. Heavy Metal Contents of Selected Organisms - Big Hill Disposal Site. See Figure 3.2-4 for trawl locations.

Station/Trawl	Sample Description (species)	Fe(ppm)*	Mn(ppm)	Zn(ppm)	Pb(ppm)	Ni(ppm)	Cu(ppm)	Cd(ppm)	Cr(ppm)	Al(ppm)
36-37 Trawl 12	White Shrimp (*P. setiferus*), flesh	10.23	1.69	58.14	0.060	0.063	26.56	0.024	0.012	14.7
36-37 Trawl 12	Croaker (*M. undulatus*), whole	2072.	37.91	52.93	12.44	0.354	3.985	0.049	0.447	368.
39-40 Trawl 11	White Shrimp (*P. setiferus*), flesh	10.05	1.38	56.16	0.028	0.032	26.76	0.023	0.006	4.72
39-40 Trawl 11	Croaker (*M. undulatus*), filet	22.07	3.279	17.26	0.032	0.052	1.571	0.012	0.008	24.7

*Concentration of all metals on ppm dry weight basis.

corrected for by normalizing all metals to Al concentrations, but as has been found in the past, this approach has not been entirely satisfying, with relatively large and unaccountable variability hindering distributional (temporal and spatial) interpretation (Sims, 1975).

As seen earlier, the white shrimp samples are generally the most metal-free with the possible exception being Zn and Cu. In these macrofauna, this trend is almost certainly due to preferential incorporation of these trace metals into the metabolic uptake of shrimp. The significant elevation in only the mineralogy-type metals (Fe, Mn, Al, Zn) in the croaker samples tends to point toward the possibility of sediment (or suspended) contribution. The elevated Fe in croaker and shrimp has been seen in samples analyzed by Dr. P. Boothe of TAMU participating in the Bureau of Land Management South Texas OCS Study (personal communication).

3.3.3.2 Hydrocarbon Chemistry

Sediments

The gas chromatographic data for the Big Hill sediments are listed in Table 3.3-23. The Big Hill site sediments contain the highest levels of hydrocarbons relative to the West Hackberry sites. While the difference in concentration data between West Hackberry disposal (13.94 μg/g) and control (6.16 μg/g) is comparable to the difference in organic carbon content, the hydrocarbon burden at Big Hill (35.25 μg/g) is much greater than could be attributed to the increase in TOC (0.93% average). A comparison of the hydrocarbon-to-TOC ratio for the three sites shows West Hackberry disposal and control at 22 and 17, respectively, whereas the ratio for Big Hill is 38. The higher hydrocarbon levels at Big Hill are due, in part, to the larger relative contribution of the UCM which comprises 93% of the gas chromatographically determined hydrocarbons. The marine component of hexane fraction is relatively constant between stations, with the dominant and secondary olefins eluting at KI 2081 and 2100, respectively (Figure 3.3-37). As noted at the other sites, KI 2091 is the prominent olefin in the benzene fractions (Figure 3.3-38). Additionally, the marine polyolefins only comprise 10% of the resolved hydrocarbons versus 17% and 27% for the West Hackberry disposal and control sites, respectively. This decrease in the marine component can be attributed, in part, to the finer texture of the Big Hill site (i.e., greater contribution of plant waxes and possibly petroleum-derived hydrocarbons).

Seawater

The gas chromatographic data for the water samples at Big Hill disposal and control are listed in Table 3.3-24. The concentrations for the Big Hill disposal and control sites were the highest

Table 3.3-23. Sediment Hydrocarbon Data for the Big Hill Site.

In-House ID	Station	Hexane Fraction µg/gm		Benzene Fraction µg/gm		Total	n-alkanes/ Branched	OEP**	R.D.* MPO
		Resolved	Unresolved	Resolved	Unresolved				
856	39	2.308	34.369	0.216	6.458	43.35	0.434	3.52	0.092
850	42	1.846	30.440	0.610	6.424	39.32	0.938	3.37	0.097
851	42 (replicate)	1.631	19.480	0.373	4.049	25.53			0.095
854	37	2.275	26.604	0.442	3.484	32.81	1.066	3.38	0.125
Mean		2.015	27.723	0.410	5.104	35.25			Mean TOC = 0.93% Mean TIC = 0.26% or 2.18% $CaCO_3$

* Relative dominance of marine polyolefins between KOVAT 2025 and 2170

** OEP = odd/even carbon preference ratio

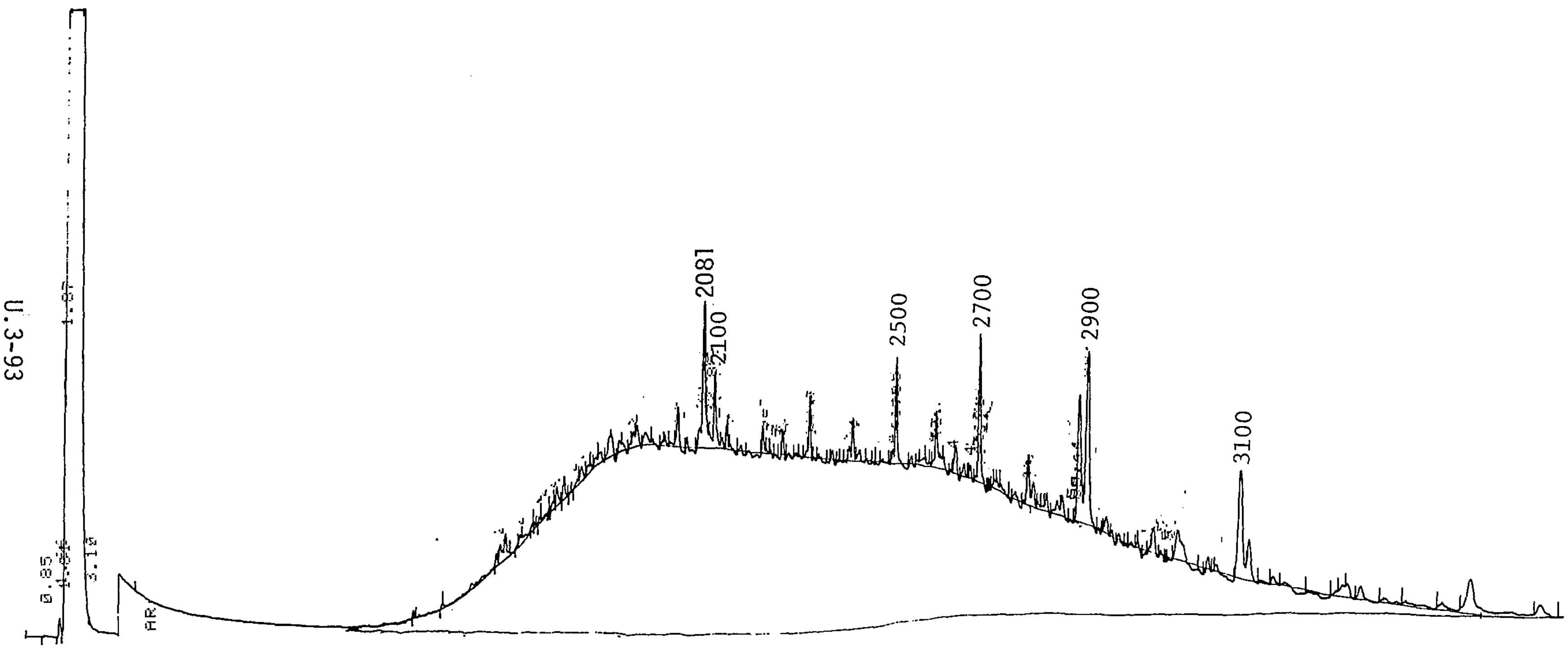


Figure 3.3-37. Chromatographic trace of the hexane fraction of sediment at Station 39, Big Hill.

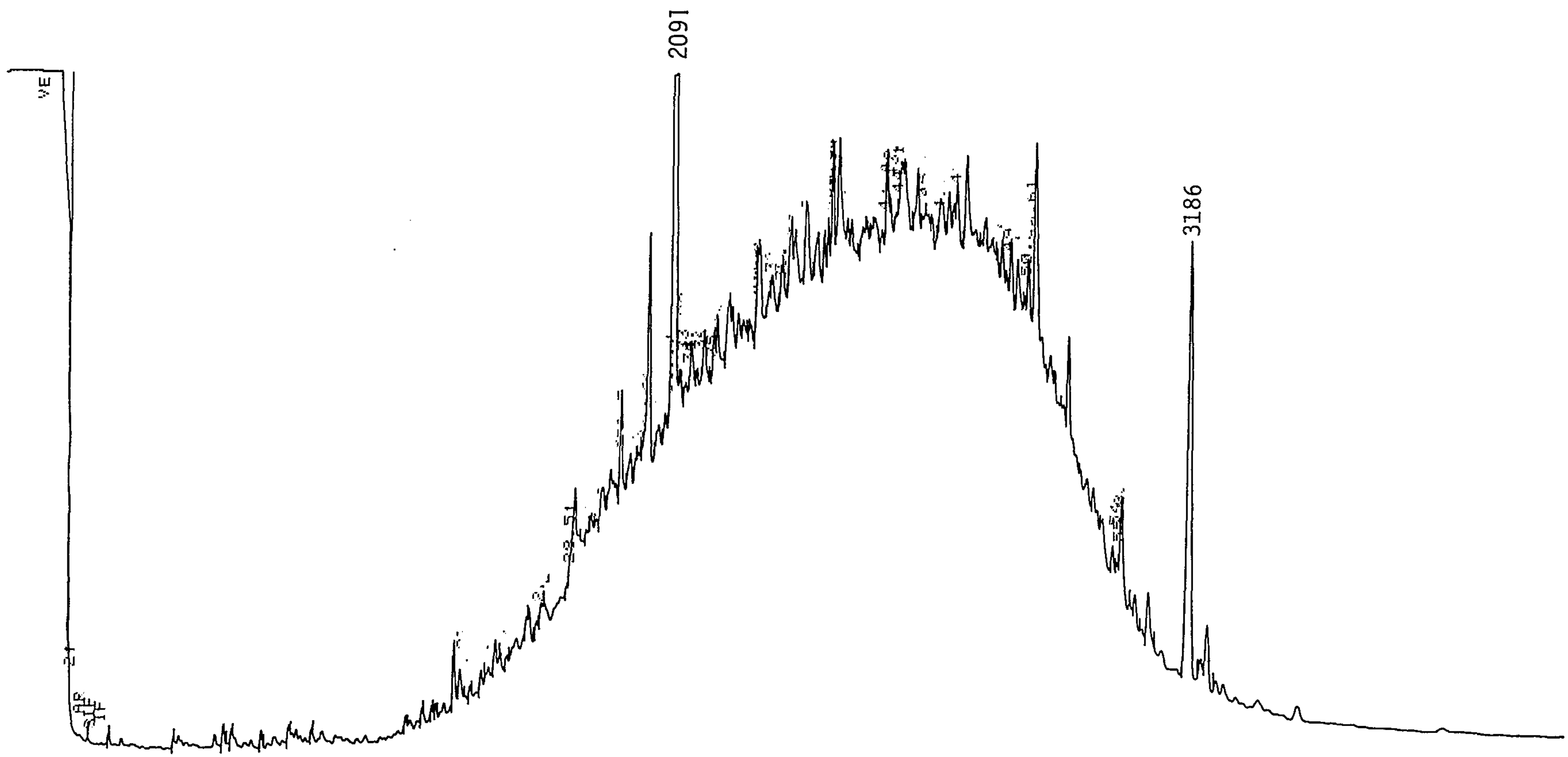


Figure 3.3-38. Chromatographic trace of the benzene fraction of the sediment at station 39, Big Hill.

Table 3.3-24. Hydrocarbon data for water samples from the Big Hill disposal and control sites.

	In-House #	Station	Hexane Fraction ng/liter* Resolved	Hexane Fraction ng/liter* Unresolved	Benzene Fraction ng/liter* Resolved	Benzene Fraction ng/liter* Unresolved	Total*	OEP	Normal/ Branched	Pristane/ $n-C_{17}$	Phytane/ $n-C_{18}$	Pristane/ Phytane
Big Hill	2037 bottom	37	22	1556	12	291	1881	1.58	7.07	0.89	0.80	0.88
	2038 surface	37	24	197	87	31	339	1.50	1.92	0.66	0.66	0.76
	2039 bottom	42	54	368	47	121	590	1.19	0.28	0.48	0.59	0.93
	2040 surface	42	10	550	30	385	975	1.22	2.49	0.99	0.84	1.33
Big Hill Control	2042 surface	BH Control	27	721	37	107	892	7.71	1.52	1.36	0.27	8.62
	2043 bottom	BH Control	19	596	46	183	844	2.59	2.12	0.20	0.36	1.89

* Units in nanograms/liter (parts per trillion)

measured. On the average, however, the majority of the concentrations still fall below 1 $\mu g/l$, a level which is compatible with other values reported in the literature. As with the sediments, a majority of the concentration is due to a large UCM. Figures 3.3-39 and 3.3-40 illustrate the gas chromatographic profiles for the near-bottom seawater sample at station 37. The hexane fraction consists of primarily n-alkanes, pristane and phytane superimposed on a large UCM. The hexane fraction from the remaining three samples from the disposal site appears identical to that portrayed in Figure 3.3-39. The benzene fraction for the same sample is largely comprised of unresolved material. On the basis of retention data, very few of the resolved peaks in the benzene fraction can be ascribed to biogenic sources with the possible exception of the peak eluting at 2035. The benzene fractions of the remaining samples at the disposal site are different chromatographically in showing a less prominent UCM and peaks eluting at 1915, 2164 and 2267.

The composition and surface-to-bottom trends of the Big Hill control station are identical to those of station 15 at the West Hackberry disposal site, although the UCM is slightly higher for the Big Hill control sample.

Macrobiota

No organisms were collected from the Big Hill site for hydrocarbon analyses.

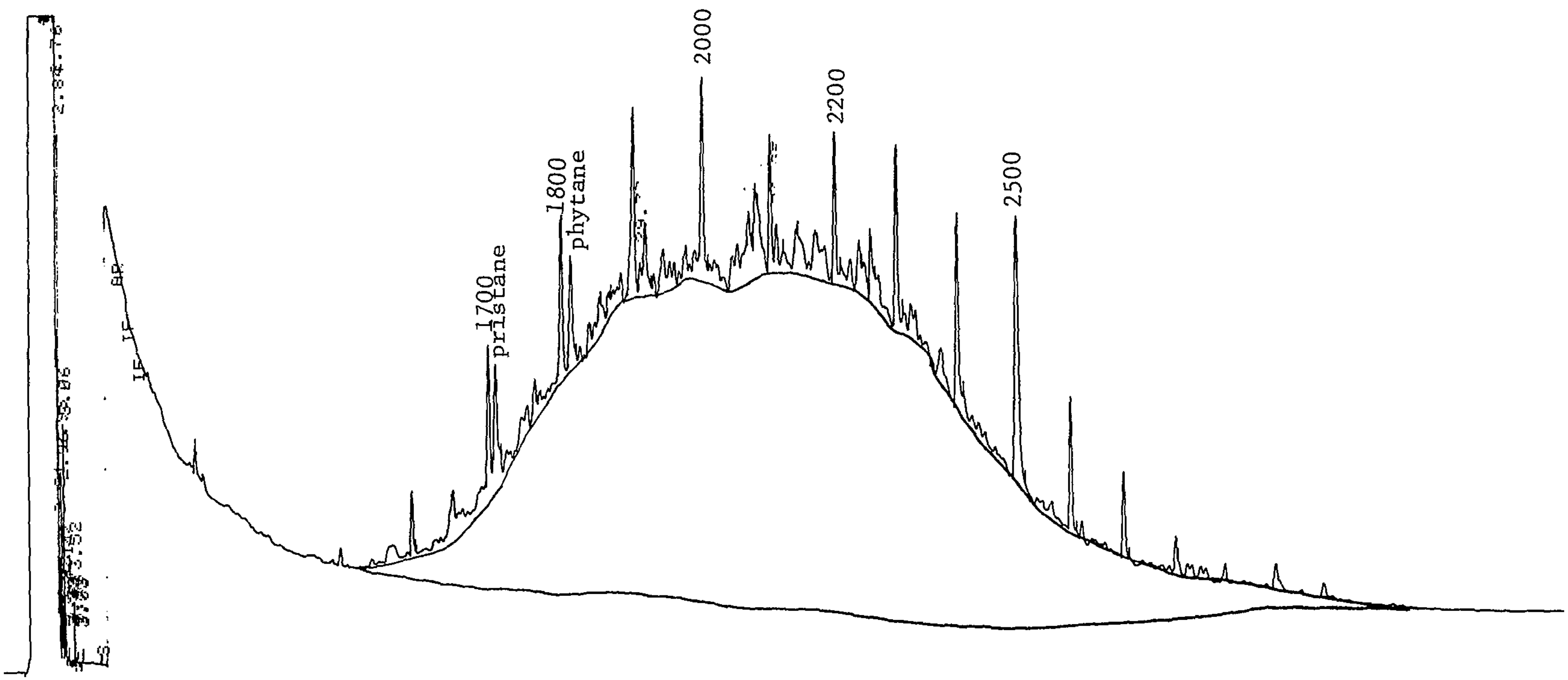


Figure 3.3-39. Chromatographic trace of the hexane fraction of the near-bottom filtered sea water at Station 37, Big Hill.

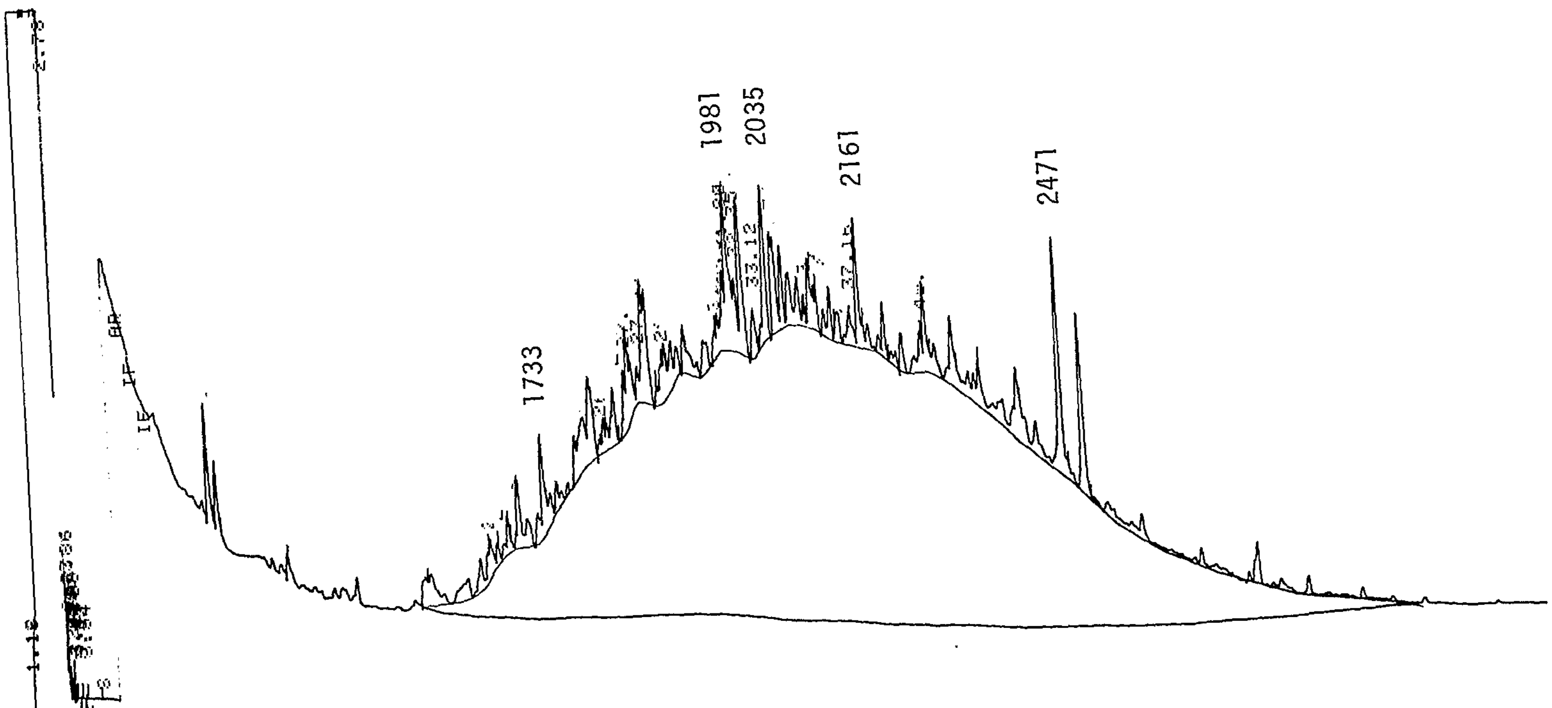


Figure 3.3-40. Chromatographic trace of the benzene fraction of the near-bottom filtered sea water at station 37, Big Hill.

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APPENDIX 3-A. GCMS ANALYSES

APPENDIX 3-A GCMS ANALYSES

Fourteen fractions of the LC hexane and benzene eluates were analyzed by gas chromatography/mass spectrometry (GCMS) using a Finnigan 4000 mass spectrometer and Finnigan/Incos data handling and library system. A glass capillary column (30 meters x 0.25 mm i.d.) coated with a non-polar phase (SP 2100) was used for the analyses in a linear temperature programming mode. All GCMS data were recorded on magnetic tape and will be archived for future use by DOE.

Eight fractions representing anchovy and squid from the Black Bayou site, butterfish and white shrimp from the West Hackberry disposal site were analyzed by GCMS. Four fractions from water filtrate were analyzed, three from the West Hackberry disposal site and one from Big Hill. The two sediment fractions were analyzed from the West Hackberry disposal site.

- Squid (1005), hexane fraction, Black Bayou trawl:

The reconstructed gas chromatogram of the total ionization current is shown in Figure 3-A-1. The composition of this fraction is almost entirely of biogenic hydrocarbons, with the most prominent compound being the C_{19} isoprenoid, pristane (scan 1369). Of secondary abundance are the mono-olefins of the odd carbon n-alkanes (nC_{19}, nC_{21}, nC_{23}; scans 1520, 1675, and 1818, respectively), followed by mono-olefins of the even carbon n-alkanes from nC_{20} to nC_{24} and the low level occurrence of n-alkanes through nC_{31}. Minor amounts of laboratory contaminants were also detected and include dioctyl and butyl phthalate and dioctyl adipate.

- Squid (1005), benzene fraction, Black Bayou trawl:

Other than the slight occurrence of nC_{17} and pristane (scans 1356 and 1365), the major compounds in this fraction consist of poly-olefins, the most prominent of which is squalene, a $C_{30}H_{50}$ triterpene (a precursor for steroid synthesis; Figure 3-A-2, Table 3-A-2). A triplet of C_{25} olefins are of secondary abundance and appear to be of biogenic origin. The compound represented by Scan 1635 is a $C_{21}H_{32}$ poly-olefin with a retention time and mass spectrum similar to heneicosahexane. Since this compound has been detected in diatoms, algae, and water column filtrates, its occurrence in the squid likely indicates a reflection of food source rather than biosynthesis.

- Anchovy (1004), hexane fraction, Black Bayou trawl:

Although data reduction for this sample is not completed, the major components are composed of mono-olefins of nC_{17}, nC_{19}, nC_{21} and nC_{23}. Also pristane and nC_{17} are notable constituents. Although differing in the relative amounts of compounds, the composition is strikingly similar to the hexane fraction of the squid from the same site.

Table 3-A-1. Gas chromatography-mass spectrometry data/or the hexane fraction of a squid sample (1005) from the Black Bayou Trawl.

Scan	Base Peak	Molecular Ion	Compound or Fragments	Formula
1346	55	238	alkene	$C_{17}H_{34}$
1356	57	240	n-C_{17}	$C_{17}H_{36}$
1369	57	268	C_{19} isoprenoid, pristane	$C_{19}H_{40}$
1426	55	252	alkene	$C_{18}H_{36}$
1433	55	252	alkene	$C_{18}H_{36}$
1442	57	254	n-C_{18}	$C_{18}H_{38}$
1453	57	282	C_{20} isoprenoid, phytane	$C_{20}H_{42}$
1473	57	278	unknown; Frag: m/e 68, 82, 95, 123	$C_{20}H_{38}$
1492	57	278	unknown; Frag. as in scan 1473 with m/e 82>68	$C_{20}H_{38}$
1520	55	266	alkene	$C_{19}H_{38}$
1525	57	268	n-C_{19}	$C_{19}H_{40}$
1576	57	282	unknown; Frag: m/e 239, alkane	$C_{20}H_{42}$
1598	55	280	alkene	$C_{20}H_{40}$
1605	57	282	n-C_{20}	$C_{20}H_{42}$
1646	67	292	alkene	$C_{21}H_{40}$
1660	57	294	alkene	$C_{21}H_{42}$
1675	57	294	alkene	$C_{21}H_{42}$
1682	57	296	n-C_{21}	unknown
1703	56	312	butyl ester	$C_{20}H_{40}O_2$
1747	57	308	alkene	$C_{22}H_{44}$
1753	57	310	n-C_{22}	unknown
1818	55, 57	322	alkene	$C_{23}H_{46}$
1823	57	324	n-C_{23}	unknown
1844	56	340	octadecanoic acid, butyl ester	$C_{22}H_{44}O_2$
1872	57	259	bis-(2-ethyl hexyl) adipate	unknown
1882	251	362	phosphoic acid, octyldiphenyl ester	$C_{20}H_{27}O_4P$
1890	57	338	n-C_{24}	unknown
1949	55	350	alkene	$C_{25}H_{50}$
1954	57	352	n-C_{25}	unknown
1960	149	279	dioctyl phthalate	"
2023	?	?	n-C_{26}	"
2105	?	?	n-C_{27}	"
2204	?	?	n-C_{28}	"
2326	?	?	n-C_{29}	"
2478	?	?	n-C_{30}	"
2671	?	?	n-C_{31}	"

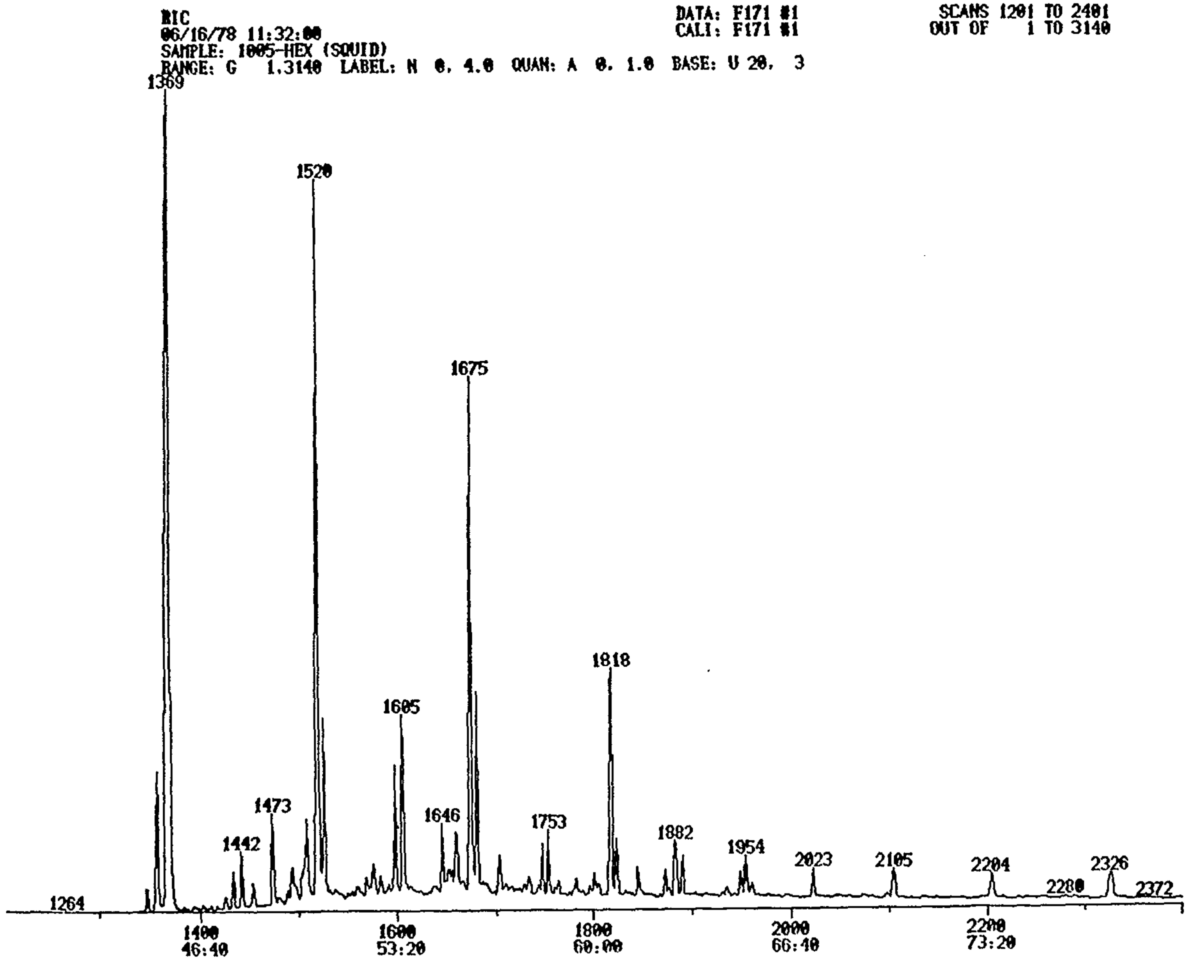

Figure 3-A-1. Reconstructed gas chromatogram of the hexane fraction of a squid (1005) from the Black Bayou trawl.

Table 3-A-2. Gas chromatography-mass spectrometry data for the benzene fraction of a squid sample (1005) from the Black Bayou trawl.

Scan	Base Peak	Molecular Ion	Compound or Fragments	Formula
531	57	156	n-C_{11}	$C_{11}H_{24}$
608	68	136	1-methyl-4-(1-methylethenyl)-,(R)-cyclohexene	$C_{10}H_{16}$
1347	55, 57	238	alkene C_{17}:1	$C_{17}H_{34}$
1356	57	240	n-C_{17} neptadecane	$C_{17}H_{36}$
1365	57	268	C_{19} isoprenoid, pristane	$C_{19}H_{40}$
1635	79	284	heneicosahexaene	$C_{21}H_{32}$
1818	55	346	alkatriene; Frag: m/e 205, 233, 261	$C_{25}H_{46}$
1836	69	346	alkatriene; Frag: m/e 109	$C_{25}H_{46}$
1850	69	344	alkene and/or cyclic alkane; Frag: m/e m-43, m-15, m-71	$C_{25}H_{44}$
1861	69	?	unknown: weak spectra	unknown
2220	69	410	squalene	$C_{30}H_{50}$

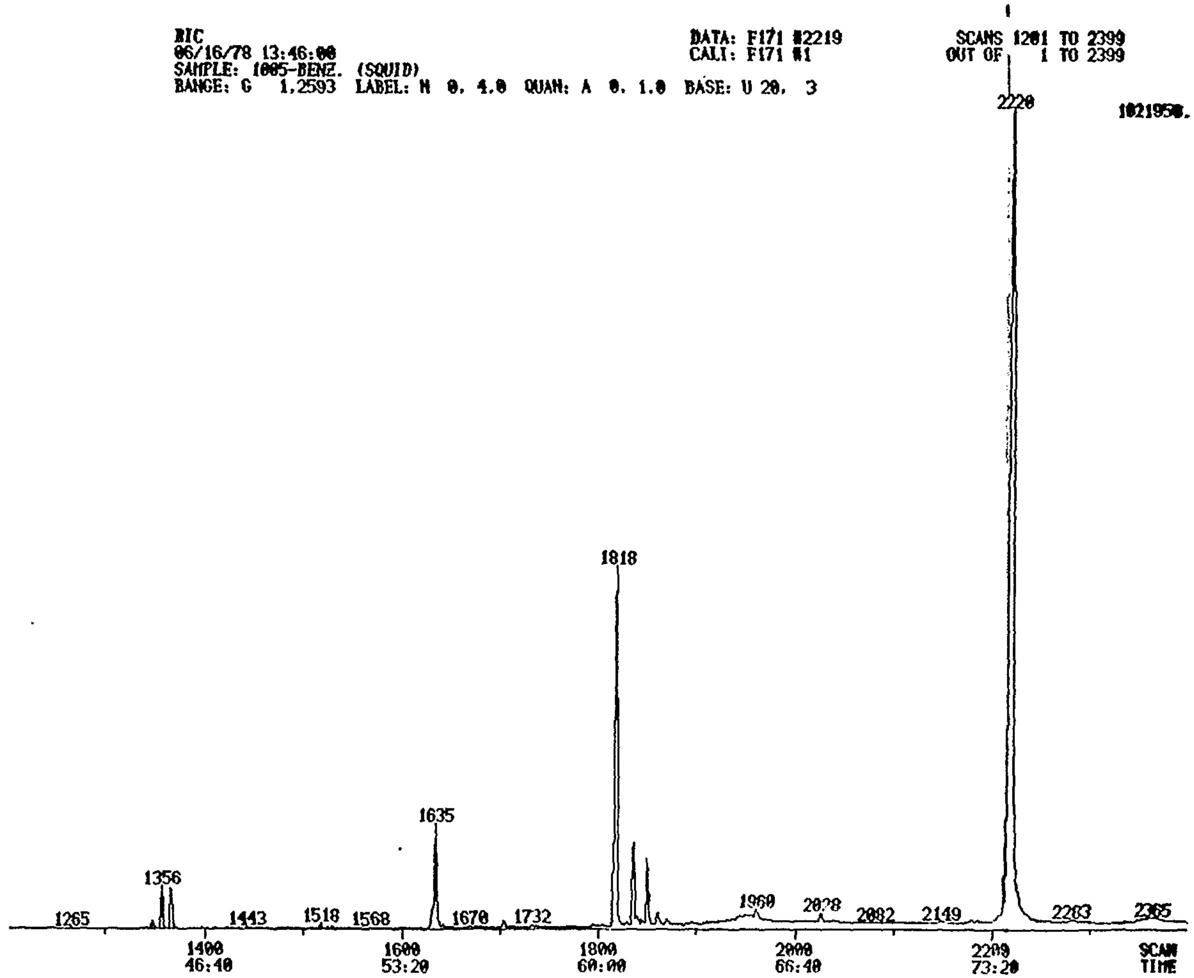

Figure 3-A-2. Reconstructed gas chromatogram of the benzene fraction for squid (1005) from the Black Bayou trawl.

- Anchovy (1004), benzene fraction, Black Bayou trawl:

Preliminary analyses of the data show that the major compounds are the isoprenoid methyl esters (phytanate, pristanate) cholestadiene and cholesterol. Also, elemental sulfur, (ocrahedral) was also present in significant concentrations. A large number of apparent petrogenic and anthropogenic hydrocarbons also occurs, including alkyl- and cycloalkyl benzenes, thiophene, biphenyl, and bromomethyl cyclohexane.

- Butterfish (1011), benzene fraction, West Hackberry Control:

Almost the entire fraction of this sample consists of fatty acid methyl-esters with minor amounts of olefins, cholestadiene, and cholesterol (Table 3-A-3, Figure 3-A-3). Any occurrence of petroleum or anthropogenic aromatics would be masked by these compounds. Their occurrence may be a result of excess fat content in the fish such that complete hydrolysis did not occur during saponification.

- White shrimp (1012), hexane fraction, West Hackberry Control:

This sample contains an homologous series of n-alkanes superimposed upon a moderate unresolved envelope, with the major compound being pristane (scan 1363) (Figure 3-A-4, Table 3-A-4). Also minor abundances of marine unsaturates and diterpanes are also present. The occurance of the moderate UCM and the diterpanes likely reflects sediment hydrocarbons accumulated during feeding.

- White shrimp (1012), benzene fraction, West Hackberry Control:

The benzene fraction of white shrimp contains primarily cholesterol, plus a number of ketones and alcohols. These compounds are natural products and the high concentrations and polar nature is likely a result of LC column overloading. The only anthropogenic compound detected was p,'p'-DDE in trace amounts. (Table 3-A-5, Figure 3-A-5).

- Water Filtrate (2041), benzene fraction, Station 10, West Hackberry Disposal Site:

The major component in this sample is dioctylphthalate, followed by an unidentified alkyl-phenyl (?) (Scan 1975). Squalene (scan 2215) and an homolegous series of n-alkanes are also present. Polynuclear aromatics were also detected in low concentrations (phenanthrene, fluoranthene, pyrene, etc.), indicating a petrogenic source. (Table 3-A-6, Figure 3-A-6).

- Water Filtrate (2034), hexane and benzene fractions, Station 15, West Hackberry Disposal Site:

Preliminary analyses of this sample show a unique distribution of an homologous series of branched alkanes with the three major peaks eluting at KOVAT indices of 1723, 1932 and 2147. Present mass spectra do not show molecular ions for most of these compounds. However, reprocessing the data through various en-

Table 3-A-3. Gas Chromatography/Mass Spectrometry data for the benzene fraction of a butterfish sample (1011) from the West Hackberry control site.

Scan	Base Peak	Molecular Ion	Compound or Fragments	Formula
264	71	100	unknown	unknown
361	72	?	"	"
428	72	?	"	"
555	59	142	"	"
680	95	124	"	"
797	59	?	"	"
1023	84	210	"	"
1172	69	188	"	"
1192	69	200?	unsaturated hydrocarbon	"
1269	74	228	probably C_{13} me ester methyl tridecanoate	$C_{14}H_{26}O_2$
1306	69	214, 218	mixture of unsaturated hydrocarbons	unknown
1364	74	242	C_{14} me ester (methyl myristate)	$C_{15}H_{30}O_2$
1448	74	256	C_{15} me ester (methyl penitadecanoate)	$C_{16}H_{32}O_2$
1487	69	?	unknown: mixture of olefins	unknown
1532	74	270	C_{16} me ester (methyl palmitate)	$C_{17}H_{34}O_2$
1590	88	312	pristanic acid - me ester	$C_{20}H_{40}O_2$
1611	74	284	C_{17} me ester methyl heptadecanoate	$C_{18}H_{36}O_2$
1670	74, 101	326	methyl phytanate	$C_{21}H_{42}O_2$
1689	74	298	C_{18} methyl ester methyl stearate	$C_{19}H_{38}O_2$
1730	56	312	unknown, frag: m/e 257	unknown
1759	74	312	C_{19} me ester methyl nonadecanoate	$C_{20}H_{40}O_2$
1802	149	336	similar to n-butyl phthalate	$C_{18}H_{24}O_6$
1829	74	326	C_{20} me ester methyl anachidate	$C_{21}H_{42}O_2$
1896	74	340	C_{21} me ester methyl heneicosanoate	$C_{22}H_{44}O_2$
1946	69	352	C_{22} me ester unsaturate	$C_{23}H_{44}O_2$
1962	74	354	C_{22} me ester methyl behenate	$C_{23}H_{46}O_2$
2031	74	368	C_{23} me ester methyl tricosanoate	$C_{24}H_{48}O_2$
2095	55	380	C_{24} me ester unsaturate	$C_{25}H_{48}O_2$
2120	74	382	C_{24} me ester methyl lignocerate	$C_{25}H_{50}O_2$
2227	81	396	C_{25} me ester	$C_{26}H_{52}O_2$
2294	81	368	possibly cholesa-3,5-diene	$C_{27}H_{44}$
2312	55	408	C_{26} me ester unsaturate	$C_{27}H_{52}O_2$
2345	74	410	C_{26} me ester methyl cerotate	$C_{27}H_{54}O_2$
2454	69	470?	unknown	unknown
2499	74	424	C_{27} me ester	$C_{28}H_{56}O_2$
2608	57	386	cholesterol (cholest-5-en-3/3-ol)	$C_{27}H_{46}O$
2640	55	?	probably unsaturated me ester	unknown
2657	57	430	unknown	"
2693	74	438	C_{28} me ester	$C_{29}H_{58}O_2$
2750	174	382	cholesta-3,5-diene-7-one	$C_{27}H_{42}O$
3372	57	480	hexadecanoic acid, hexadecyl ester	$C_{32}H_{64}O_2$

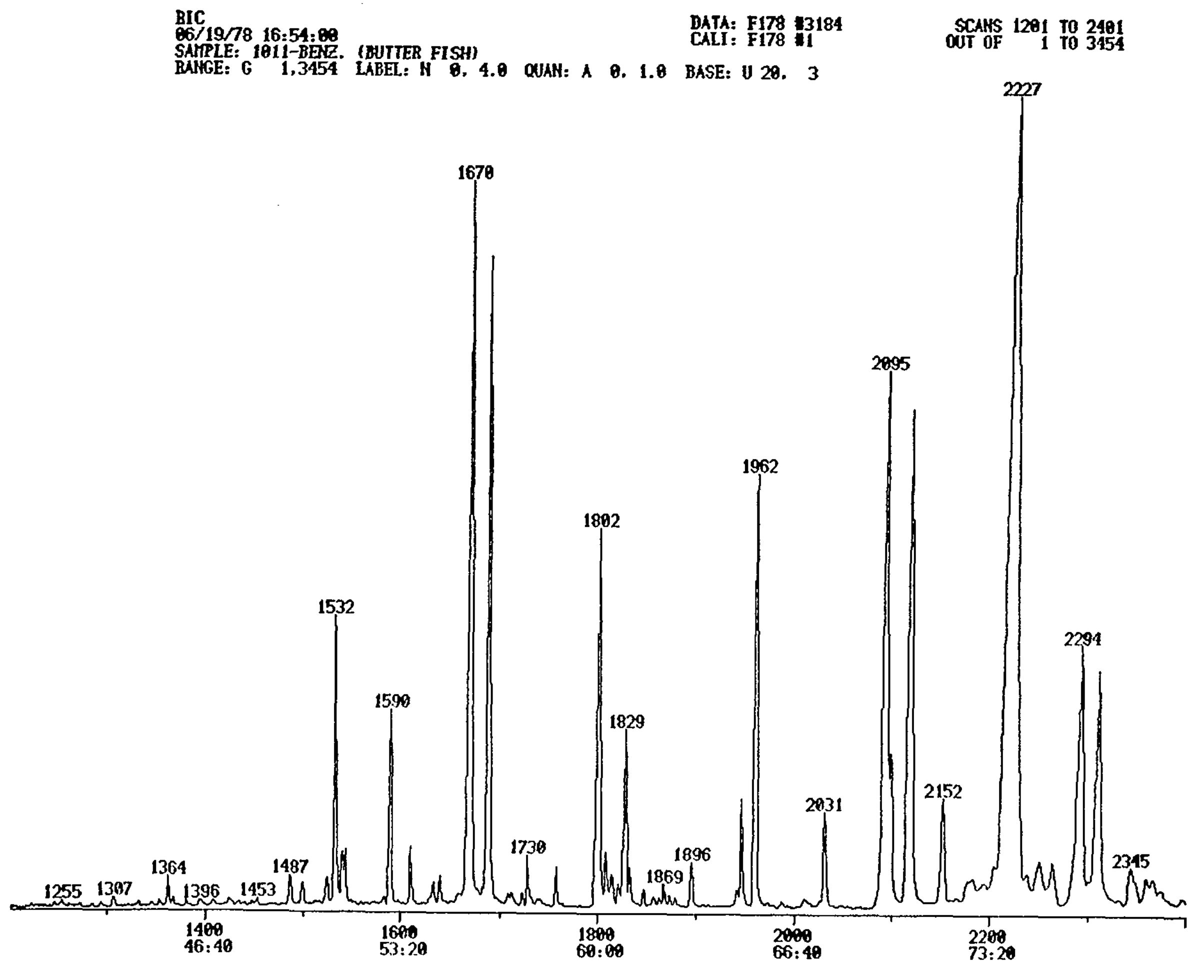

Figure 3-A-3. Reconstructed gas chromatogram for the benzene fraction of a butterfish sample from the West Hackberry control site.

Table 3-A-4. Gas Chromatography/Mass Spectrometry data for the hexane fraction of white shrimp (1012) from the West Hackberry control site.

Scan	Base Peak	Molecular Ion	Compound or Fragments	Formula
842	57	?	probably n-C_{12}	unknown
957	57	?	probably n-C_{13}	"
1065	57	?	probably n-C_{14}	"
1166	57	212	n-C_{15}	"
1263	57	226	n-C_{16}	"
1310	57	?	possibly C_{18} isoprenoid	"
1323	55	236	alkene	$C_{17}H_{32}$
1345	57, 55	238	alkene	$C_{17}H_{34}$
1354	57	240	n-C_{17}	unknown
1363	57	268	C_{19} isoprenoid, pristane	"
1441	57	254	n-C_{18}	"
1452	57	282	C_{20} isoprenoid, phytane	"
1488	57	252	unknown, weak spectra	"
1496	57	264	probably alkene	$C_{19}H_{36}$
1523	57	268	n-C_{19}	unknown
1531	74	270	methyl palmitate	$C_{17}H_{34}O_2$
1602	57	282	n-C_{20}	unknown
1636	57	292	probably unsaturate	$C_{21}H_{40}$
1661	69	288	unknown, unsaturate	$C_{21}H_{36}$
1678	57	296	n-C_{21}	unknown
1701	56	312	unknown, possibly butyl ester	$C_{20}H_{40}O_2$
1616	191	276	C_{20} diterpane	unknown
1684	191	290	C_{21} diterpane	"
1699	97	?	unknown, weak spectra	"
1750	57	310	n-C_{22}	"
1779	57	?	unknown, possibly isoprenoid	"
1820	57	329	n-C_{23}	"
1840	56	340	octadecanoic acid butyl ester	$C_{22}H_{44}O_2$
1886	57	338	n-C_{24}	unknown
1951	57	352	n-C_{25}	"
1956	149	390?	dioctyl or di iso octyl phthalate	"
2018	57	366	n-C_{26}	"
2099	57	380	n-C_{27}	"
2144	57	368	possibly cholesta-3,5-diene	$C_{27}H_{44}$
2196	57	?	probably n-C_{28}	unknown
2208	69	?	unknown, weak spectra	"
2272	81	368	unknown, see scan 2144	"
2316	57	408	n-C_{29}	"
2464	57	422?	n-C_{30}, weak spectra	"
2604	55	386	unknown, probably cholesterol	"

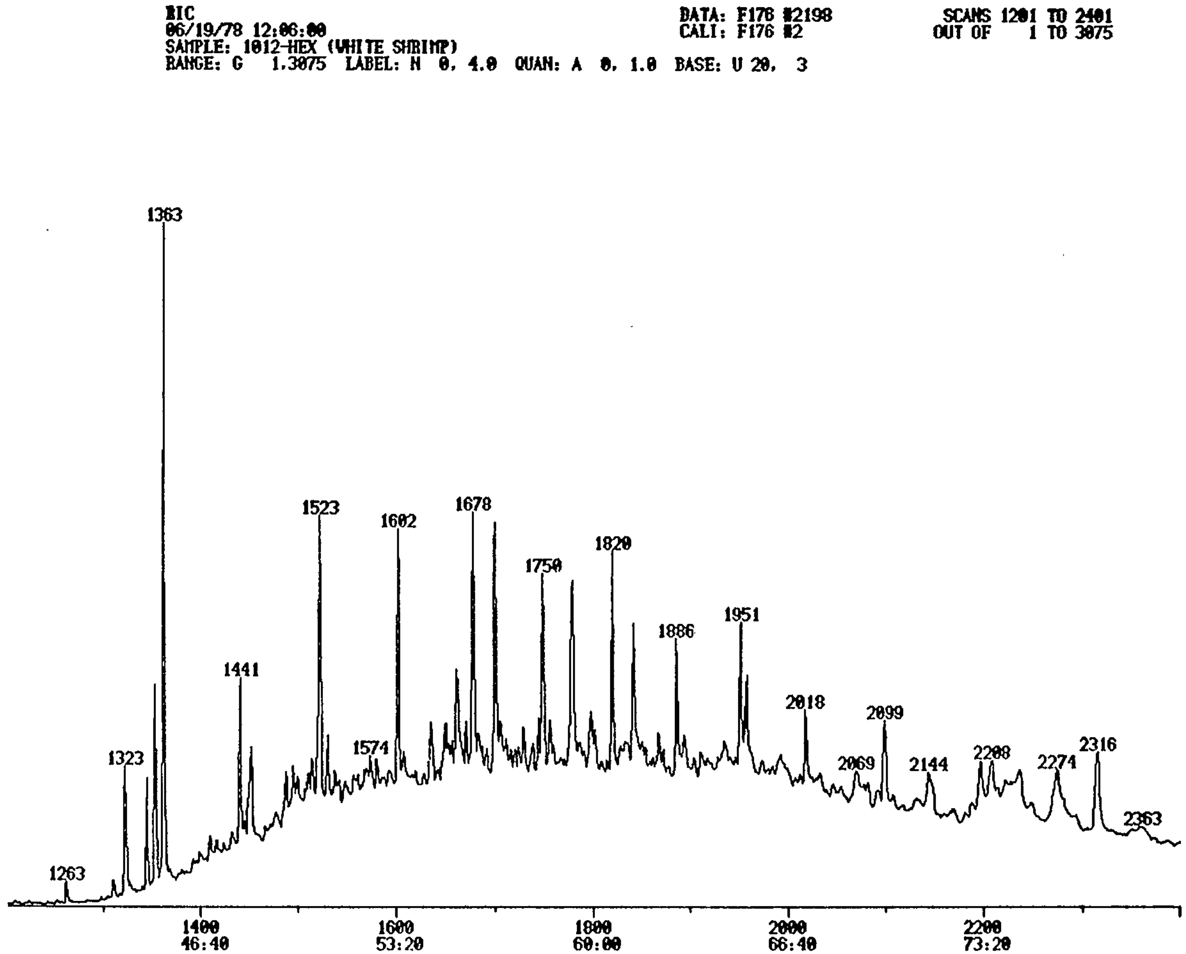

Figure 3-A-4. Reconstructed gas chromatogram for the hexane fraction of white shrimp from the West Hackberry control trawl.

Table 3-A-5. Gas Chromatography/Mass Spectrometry data for the benzene fraction of a white shrimp (1012) from the West Hackberry control trawl.

Scan	Base Peak	Molecular Ion	Compound or Fragments	Formula
987	117	117	1H-indole	C_8H_7N
1094	69	176?	unknown	unknown
1143		198	unknown, ketone?	unknown
1208	79	?	unknown, frag. at m/e 150, 91, 105	"
1223	79	196?	unknown, frag. at 91, 105, 119, 148,	"
1242	58	?	unknown, ketone?	"
1336	58	226?	unknown, probably ketone	"
1363	57	?	possibly isoprenoid (pristane)	"
1381	56	266	possibly unsaturate (branched)	"
1403	55	?	unknown, weak spectra	"
1425	58	240?	unknown	"
1438	57	?	"	"
1466	58	268	6,10,14-trimethyl-2-pentadecanone	$C_{18}H_{36}O$
1511	58	254	unknown, ketone?	unknown
1519	69	262	6,10,14-trimethyl-,(E,E)-5,9,13-pentadecatrien-2-one	$C_{18}H_{36}O$
1531	74	270	C_{16} me ester (methyl palmitate)	$C_{17}H_{32}O_2$
1604	57	250?	unknown	unknown
1664	55	264	"	"
1710	246	31-	P,P'-DDE trace amount	"
1760	55	294	unknown, probably unsaturate	"
1940	57	308	unknown, alcohol, M-18 (homologous series)	"
2010	57	322	unknown, alcohol, M-18 (homologous series)	"
2089	57	336	unknown, alcohol? (homologous series)	"
2146	81	368	unknown, sterene; frag: m/e 145, 213, 247, 255	$C_{27}H_{44}$
2210	69	368	unknown, alkene, sterene?	"
2239	57	368	unknown, sterene, m/e 105, 145, 159, 213, 255, 314	"
2281	81	368	unknown, possibly cholesta-3,5-diene	$C_{27}H_{44}$
2545	55	384	possibly cholesta-5,22-dien-3-ol,(3β)-	$C_{27}H_{44}O$
2670	55, 57	386	cholesterol (cholest-5-en-3β-ol)	$C_{27}H_{46}O$
2684	165	430	2HOl-benzopyran-6-ol,3,4-dihydro-2,5,7,8-tetramethyl-2-(4,8,12-trimethyltridecyl)-,/2R-/2R*(4R*,8R*)//-(9CI)	$C_{29}H_{50}O_2$
2852	124?	384	possibly mixture with methyl cholestene	unknown

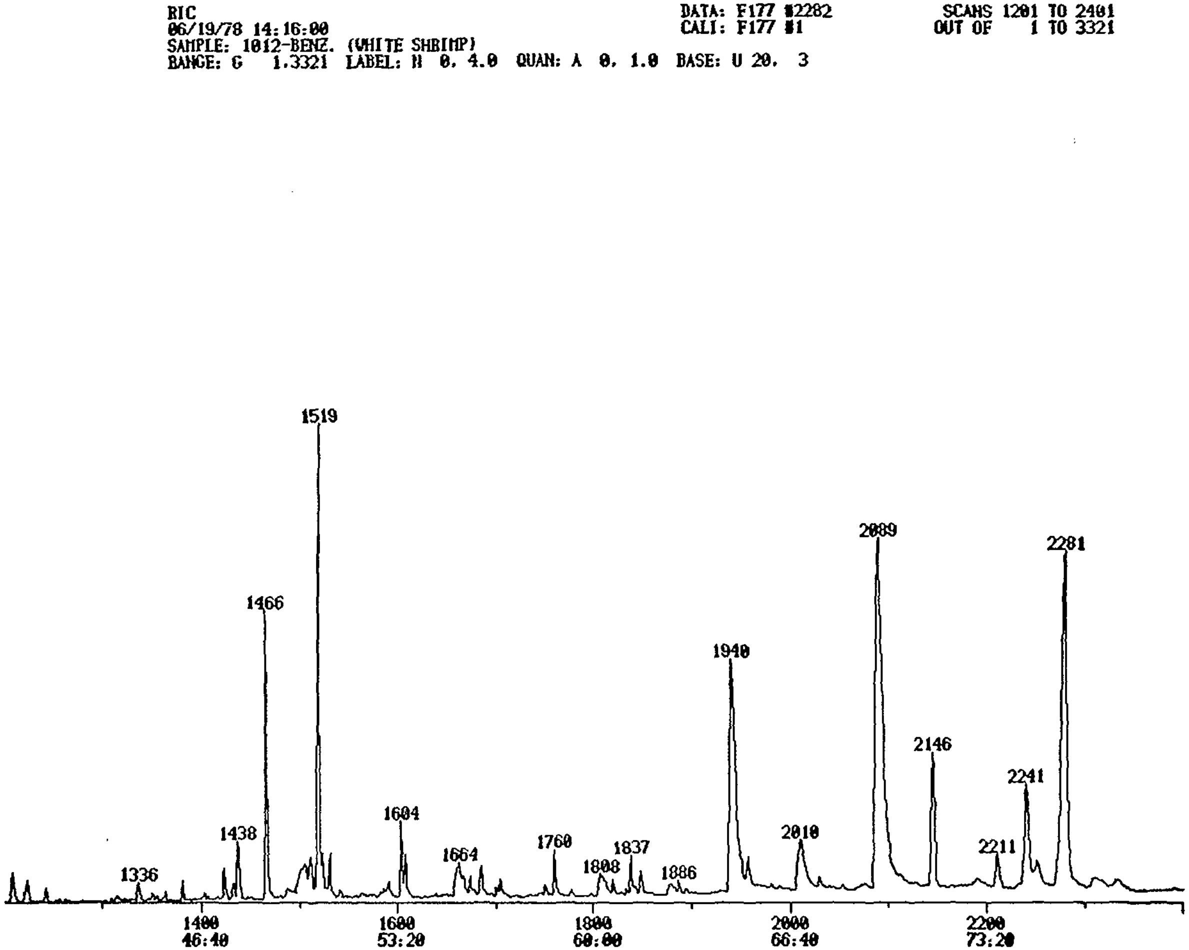

Figure 3-A-5. Reconstructed gas chromatogram of the benzene fraction of white shrimp from the West Hackberry Control trawl.

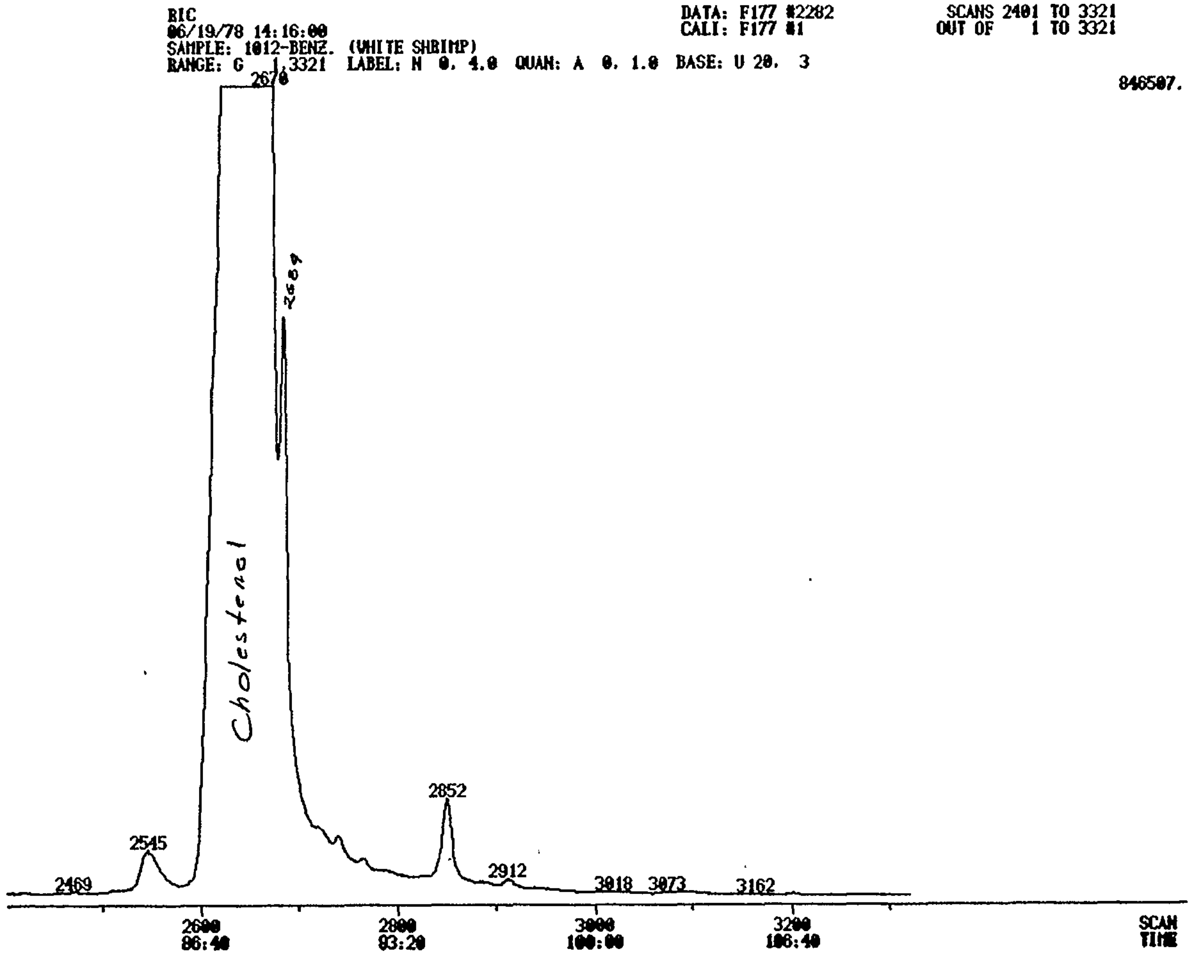

Figure 3-A-5 (cont'd). Reconstructed gas chromatogram of the benzene fraction of white shrimp from the West Hackberry control trawl.

Table 3-A-6. Gas Chromatography/Mass Spectrometry data for the benzene fraction of the bottom water sample from Station 10, West Hackberry intensive.

Scan	Base Peak	Molecular Ion	Compound or Fragments	Formula
1118	177	220	possibly 2,6 Bis (1,1,dimethylethyl)-2,5-cyclo hexadine-1,4-dione	$C_{14}H_{20}O_2$
1165	205	220	possibly BHT (Butylated hydroxy toluene)	$C_{15}H_{24}O$
1401	178	178	phenanthrene/anthracene	$C_{14}H_{10}$
1462	198	198	probably 4,methyl di-benzothiophene	$C_{13}H_{10}S$
1480	198	198	unknown	unknown
1565			"	"
1608	206	206	dimethyl phenanthrene	$C_{16}H_{14}$
1627	202	202	fluoranthene	$C_{16}H_{10}$
1665	202	202	pyrene	$C_{16}H_{10}$
1683	57	276	n-C_{21}	unknown
1756	57	310	n-C_{22}	"
1797	149	278	butyl phthalate	$C_{16}H_{22}O_4$
1825	57	322	n-C_{23}	unknown
1892	57	338	n-C_{24}	"
1907	228	228	Benz [A] anthracene or chrysene	$C_{18}H_{12}$
1960	149	390	dioctyl phthalate	unknown
1975	221	354	phenyl alkyl (?), m/e 91,105,119,	$C_{26}H_{42}$
2008	221	354	isomer of scan 1975	$C_{26}H_{42}$
2023	57	366	n-C_{26}	$C_{26}H_{54}$
2105	57	380	n-C_{27}	$C_{27}H_{56}$
2203	57	394	n-C_{28}	$C_{28}H_{58}$
2215	69	410	squalene	$C_{30}H_{50}$
2284	81	368	mixture with cholesta-3,5-diene	$C_{27}H_{44}$
2324	57	382	n-C_{29}	$C_{29}H_{60}$
2473	57	422	n-C_{30}	$C_{30}H_{62}$
2660	57	436	n-C_{31}	$C_{31}H_{64}$
2896	57	450	n-C_{32}	$C_{32}H_{66}$
3193	57	464	n-C_{33}	$C_{33}H_{68}$

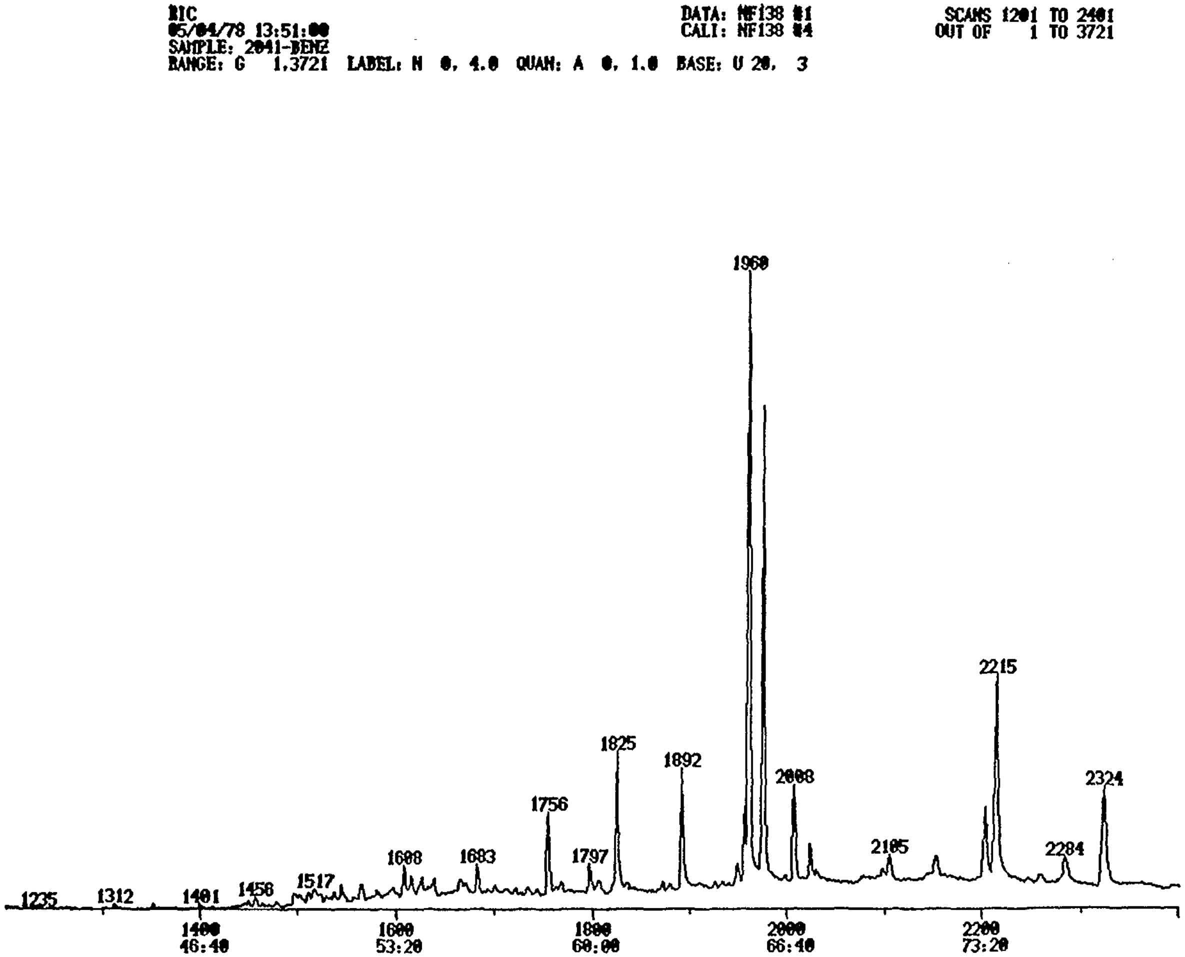

Figure 3-A-6. Reconstructed gas chromatogram for the benzene fraction of a bottom water filtrate at Station 10, West Hackberry Intensive.

hancement techniques may yield the exact molecular weight. This "pattern" has been noted in a number of stations at West Hackberry and in other areas of the nearshore Gulf of Mexico (Shokes, 1978). At the present time their origin is unknown but assumed to be derived from phyto and/or zooplankton. Additionally, the prominent occurrence of n-alkanes from n-C_{23} to nC_{29} are also present. The benzene fractions show the low level presence of aromatic compounds in addition to the prominent occurrence of a C_{21},H_{32} olefin (heneicosahexaene?). In the samples analyzed this olefin is associated with the series of branched alkanes (i.e., KOVAT 1723, 1932, 2147). However, another on-going study suggests that this sample may be composed of two to three independent "populations."

- Water-filtrate (2037), benzene fraction, Station 37, Big Hill site:

Initial data processing indicates that this sample consists of a complex series of aromatic hydrocarbons superimposed on an unresolved envelope.

- Sediment (830), hexane and benzene fraction, Station 19, West Hackberry Disposal Site:

This sample was chosen because of the complexity of the marine poly -olefins eluting between nC_{20} and nC_{22}. The initial analyses show a complex series of predominantly C_{25} poly-olefins with the minor occurrence of C_{19} and C_{21} constituents. Presently, a catalogue of retention indices, mass spectra, and associated sediment textural characteristics is being developed to assess the nature and importance of these marine-derived hydrocarbons. Most of the olefins detected in the water filtrates are reflected in pelagic fauna but have not been detected in the sediments. This observation suggests that the poly-olefins detected in sediments are either diagenetic alterations of those produced in the water column or are indigenous to the sediment (micro-, meio- and macro-infauna). In either case, the distributions of these compounds likely reflect ambient microenvironments near the sediment-water interface, and will serve as a useful tool in assessing any post-disposal effects on the larger scale system.

Section 4.0

Biological Oceanography

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4.0 BIOLOGICAL OCEANOGRAPHY

4.1 Introduction

Beginning September 1977, Science Applications, Inc. (SAI/Oak Ridge) has been conducting a study of the biota at three nearshore primary brine disposal sites and two secondary control sites (Figure 4.1-1) in DOE's SPR program. The primary objective of this study is the characterization of the existing populations and potential production in the vicinity of the future disposal sites. To this end, a monthly sampling program designed to inventory all trophic levels was inaugurated. The present report covers the period from September through December 1977. Specific sampling vectors included: benthic megafauna, benthic meiofauna, phytoplankton, zooplankton, and demersal nekton. Ancillary data collected included: sedimentary grain size distribution, carbonate content, total organic matter, near surface and near bottom chlorophyll a and phaeopigment and vertical salinity, temperature, dissolved oxygen, and pH profiles. To provide an initial characterization of the biota sampling was somewhat more intense in September and October than in November and December. Taking cognizance of what was then known of the regional current regime, the density of sampling stations was skewed to the west on the assumption of a dominant west flowing longshore current. The station array and sampling schedule is shown in Figure 4.1-2 and Table 4.1-1.

4.2 Methodology

Benthic megafauna was sampled with replicate 1/25 m^2 VanVeen grabs. Samples were sieved through a set of precision screens with the greater than 1 mm (megafauna) and greater than .025 mm (meiofauna) fractions isolated. Samples were preserved with 10% buffered formalin and Rose Bengal stain. Rough sorting was performed in white pans under an illuminated magnifying glass, and fine sorting was done under a dissecting microscope. Meiofaunal organisms were floated in ethylene glycol solution in order to separate the animals from debris.

Demersal fishes, larger demersal invertebrates, and larger and more motile benthic anamals were collected with a 14 foot (4.3 meter wide) otter trawl lined with a 2 mm^2 mesh sleeve net. The trawl was towed at a constant speed of 2 knots for 15 minutes in a direction normal to the shoreline. The area covered by the trawl was calculated to be about 3240 m^2. (No corrections have been made to account for variations in trawl distance due to the differences in hydrographic and meteorologic conditions. Since the prevailing currents flow parallel to the shoreline and are relatively weak (1-2 knots) it is thought that this source of error is minimal.) All animals were identified to species and counted. Each individual was measured, although not weighed. Size classes of fish, shrimp and crabs are readily recognizable from these data and show growth rates by months.

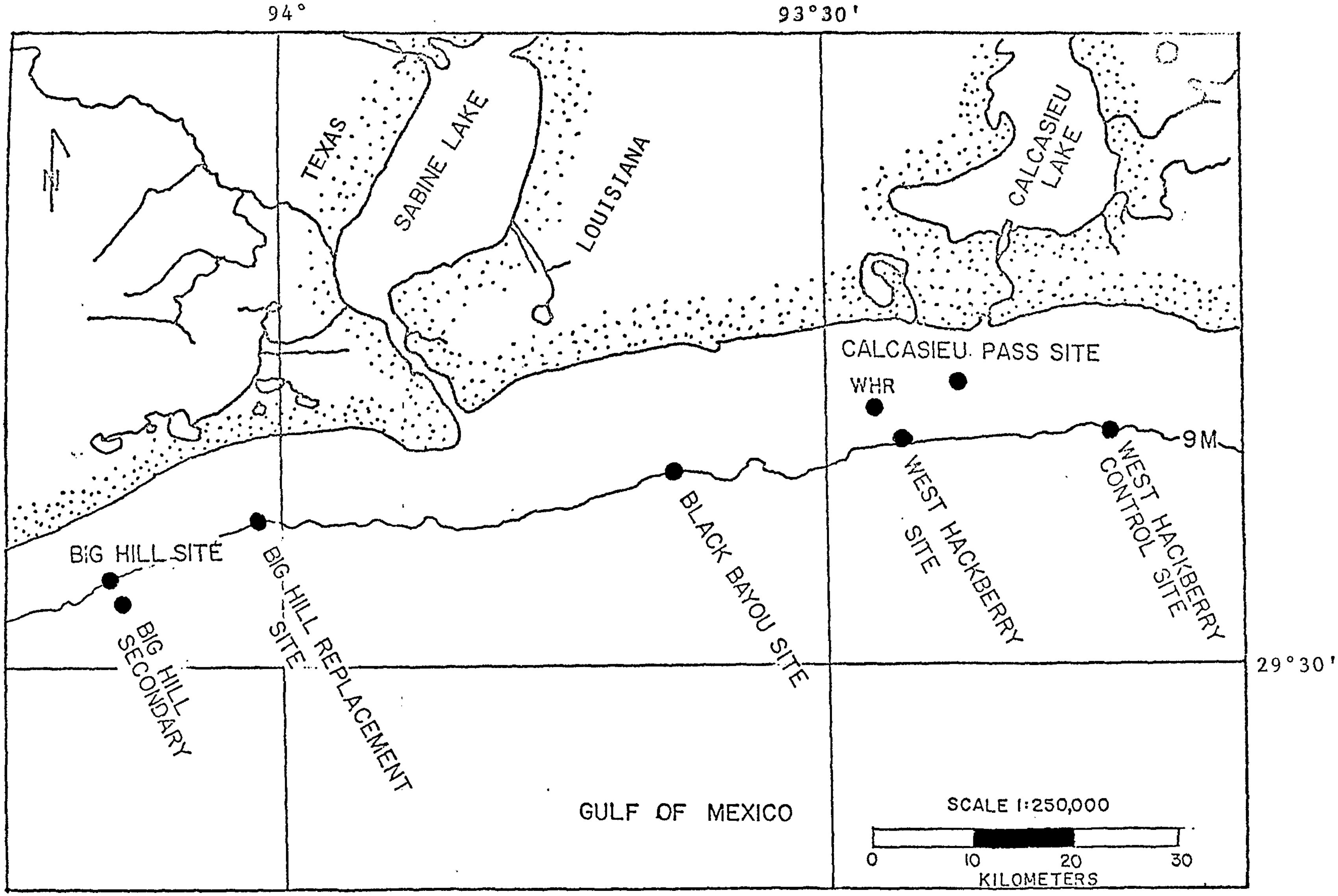


FIGURE 4.1-1. Primary Disposal and Secondary Control Sites in the Texoma Region.

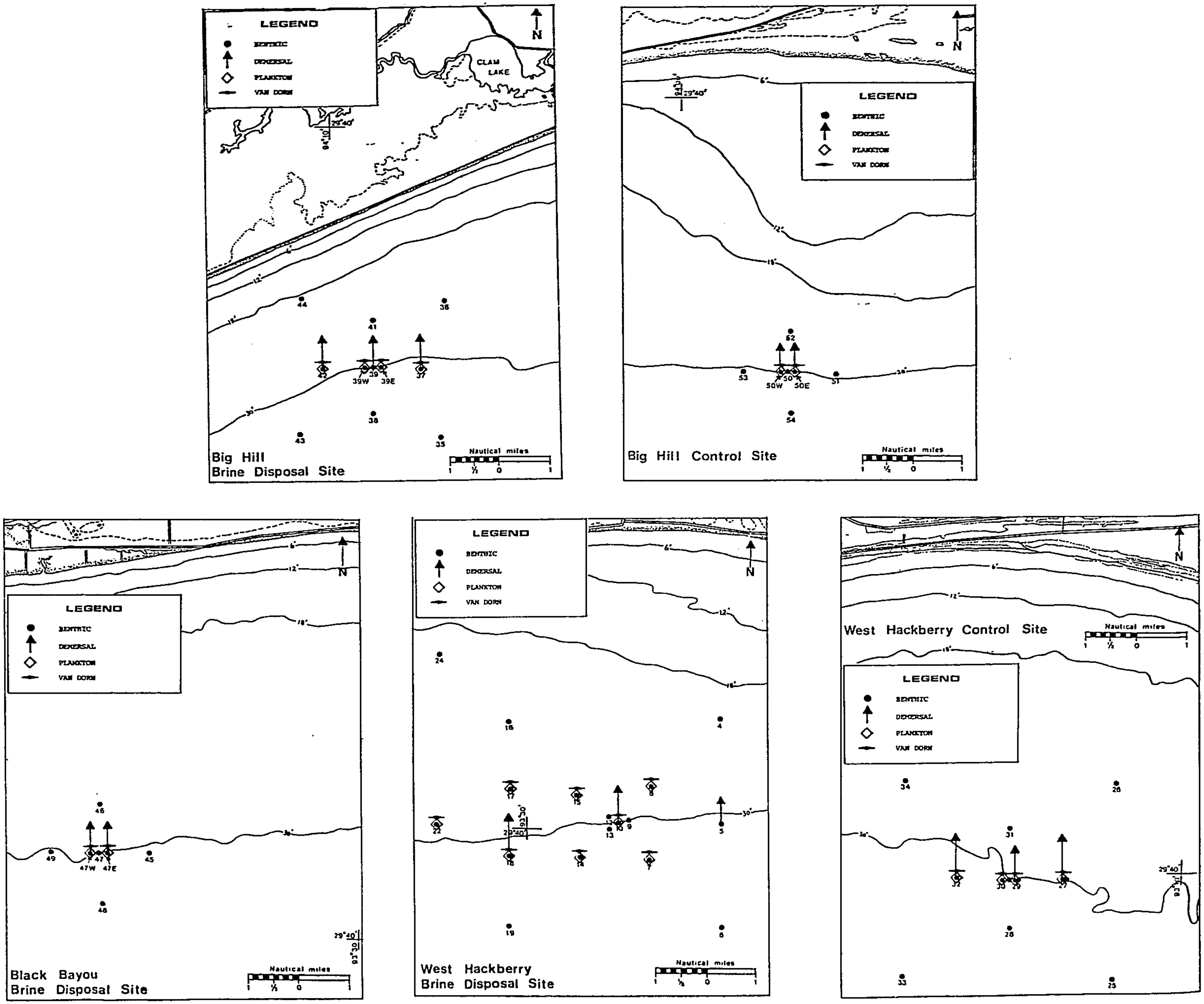


FIGURE 4.1-2. Sampling Scheme Array of the Texoma Study Area.

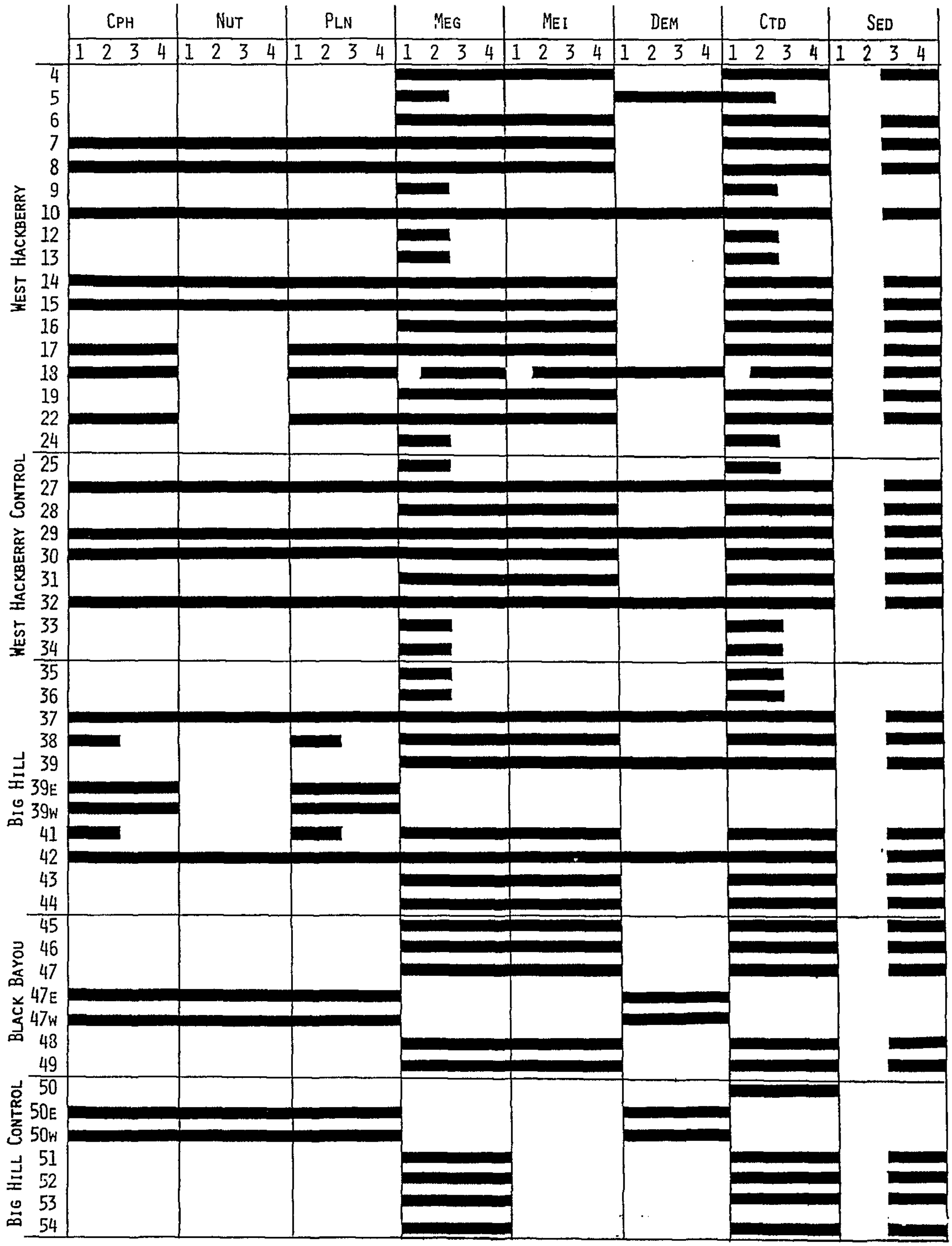


TABLE 4.1-1. Sampling Scheme for the Texoma Region.

NOTE: CPH = CHLOROPHYLL AND LITER PHYTOPLANKTON SAMPLES
NUT = NUTRIENTS
PLN = TOP AND BOTTOM PHYTOPLANKTON AND ZOOPLANKTON
MEG = MEGABENTHOS
MEI = MEIOBENTHOS
DEM = DEMERSAL NEKTON
CTD = CONDUCTIVITY, TEMPERATURE, DEPTH, DISSOLVED OXYGEN, AND PH
SED = SEDIMENT CHARACTERISTICS

Surface and bottom zooplankton and phytoplankton tows were made with a 5" diameter Clark-Bumpus plankton sampler. Zooplankton tows (#10 mesh) were made for 2.5 minutes each (1.5 knots), while phytoplankton tows (#20 mesh) were made for 1.0 minute each. Zooplankton samples were fixed in 5% buffered formalin, stained with Rose Bengal. Enumerations were obtained by the strip-counting method utilizing a Sedgewick Rafter cell. Phytoplankton samples were preserved in 5% buffered formalin with a Methyl Green stain. Enumeration were obtained by strip counting with a Sedgewick-Rafter cell. Phytoplankton counts were reported as "units per liter," where unit refers either to a single cell, or to a group of cells in those species that form colonies or aggregates.

The primary advantage of a Clarke Bumpus sampling procedure, is that it provides integrated samples over large volumes of water, thus tending to obviate some of the sample variability. However, to function effectively, a Clarke Bumpus sampler can employ a net no finer than about a #20 mesh. Such a net does not sample the microflagellate component of the plankton community. To assess the contribution of this group, 1-liter whole water samples (top and bottom) at all plankton stations were obtained with a Van Dorn water sampler. These samples were preserved with a 5% buffered formalin solution, and enumeration with the Sedgewick-Rafter strip-count technique.

In situ oxygen, conductivity, temperature, and pH as a function of depth (1 meter intervals) were taken with a Hydrolab "Surveyor." Conductivities values were converted to salinities, and oxygen values were adjusted for temperature and salinity.

Chlorophyll a and pheophytin determinations were made for near surface and bottom water samples at each plankton station. Two 500 ml aliquots were drawn from top and bottom VanDorn whole water samples, and filtered through millepore (.45μ) filters. These filters were dessicator dried at 4°C, and then frozen until processed. Pigments were extracted with 90% acetone. Spectral absorbancies were determined with a Beckman Model DG Grating spectrophotometer according to procedures outlined in the American Public Health Association (1975) "Standard Methods for the Examination of Water and Wastewater."

Sediment subsamples were obtained from Van Veen grab samples with a 2.5 cm diameter core taken to a depth of about 8.0 centimeters. In the laboratory, the cores were analyzed for sediment-size distribution by sieve and hydrometer procedures described by Folk (1974). Calcium carbonate percentages and total organic matter were calculated using procedures described by Carver (1971).

Statistical analyses utilized in the report included Analysis of Variance (ANOVA) and Pearson correlation coefficient. Both were performed using SAS-76 procedures (Barr et al. 1976).

Another technique utilized to determine patterns in community composition was ordination analysis. The ordination analysis results in a spatial

spatial display of species and/or sample relationships from a data matrix to geometric axis, thereby reducing the complex multidimemsionality of a many species by many sample data matrix to the deimensionality of two or three ordination axes. This should then aid in defining major gradient trends in the data, which can then be related inductively to ecological gradients (Whittaker 1967; Whittaker and Gauch 1973, 1977; Gauch 1977).

Reciprocal averaging ordination was used in this study, having the advantage in that it performs a simultaneous species and sample ordination. Reciprocal averaging ordination was used here to determine species and sample relationships in each of the phytoplankton, demersal, megabenthos and zooplankton data sets.

4.3 Results and Discussion

4.3.1 Phytoplankton

4.3.1.1 General Characterization

A total of 30 diatom and 1 dinoflagellate species were recognized during the course of the study (Table 4.3-1). Both marine and estuarine species were present; the community cannot be characterized as predominately marine or estuarine. The majority of species were ubiquitous, though there were marked changes in rank order from cruise to cruise and some variations from site to site. There were also variations in the numbers of species present at various sites on each of the cruises.

The average standing crop for the October-December period was 102 x 10^3 units/liter, based on whole water samples (Table 4.3-2a), and 119 x 10^3 units/liter based on Clarke Bumpus samples (Table 4.3-2b). These means are based on untransformed data so as to be comparable with reported results at other sites (e.g. Capline). Both seasonal and depth variations were detected for the composite data set, with site-specific differences apparent for some groups. Standing crop at Weeks' Island (DOE 1978) off the Mississippi delta at comparable depths ranged from about 5 to 40 x 10^3 cells/liter during the September-December 1977 period. It is surprising that the standing crop at the Texoma region was so much higher than that off the delta. Primary production in the delta area is generally thought to be higher than westward sites (Riley 1937). The similarity in standing crop estimates from whole water and Clarke Bumpus samples is an indication that present data presumably characterizes the Texoma study region.

Chlorophyll a concentrations ranged from 1.62 mg/m^3 in October to 2.12 mg/l^3 in December. Big Hill Control, West Hackberry control and Black Bayou site had lower means (1.22-1.52 mg/m^3) than West Hackberry and Big Hill (2.02-2.41 mg/m^3). Figure 4.3-1 graphically summarizes these data, while the means (with 95% confidence limits) are presented in Table 4.3-3 and 4.3-4 for chlorophyll and phaeophytin, respectively.

Except for minor reversals at Big Hill Control and West Hackberry control in October, the top samples showed consistently higher means than the bottom samples. Phaeophytin means were lowest (overall) in November

Table 4.3-1

Phytoplankton Species Collected from October to December 1977, based on Whole Water Samples only

Division Bacillariophyta Family	Species	Oct	Nov	Dec
Coscinodiscacaea	Skeletonema sp.			+
	Skeletonema costatum	+	+	+
	Coscinodiscus sp.		+	+
	Coscinodiscus centralis	+	+	+
	Coscinodiscus granii	+		
	Coscinodiscus concinnus	+		
	Coscinodiscus radiatus	+	+	+
	Thalassiosira decipiens	+	+	
Biddulphiacaea	Biddulphia granulata	+	+	
	Biddulphia mobiliensis	+	+	+
	Hemiaulus sp.	+		+
	Eucampia sp.			+
	Lithodesmium undulatum	+	+	
Chaetoceracae	Chaetoceros affine	+	+	
	Chaetoceros currisetum	+	+	+
	Chaetoceros decipiens	+	+	+
Bacteriastracae	Bacteriastrum varians	+		
Leptocylindracaea	Guinardia flaccida	+	+	
Rhizosoleniacae	Rhizosolenia sp.	+	+	+
	Rhizosolenia alata	+		
	Rhizosolenia imbricata	+	+	+
	Rhizosolenia robusta		+	+
	Ditylum sp.	+	+	
	Ditylum brightwelli	+	+	+
Fragilariacae	Asterionella japonica	+	+	+
	Thalassiothrix frauenfeldii	+	+	
	Thalassionema nitzschiodes	+	+	+
Naviculacae	Navicula sp.	+	+	
Bacillariacae	Nitzschia seriata	+	+	+
Surirellacae	Surirella sp.	+		
Division Pyrrophyta Class Dinophyceae	C. tripos	+	+	

Table 4.3-2a

Phytoplankton Standing Crop (units/liter) based on Whole Water Samples based on Untransformed Means of N Samples*

	West Hackberry Control	West Hackberry	Black Bayou	Big Hill Control	Big Hill	Overall
OCT	51,510(12)	122,659(20)	43,969(4)	95,475(4)	113,917(6)	78,893
NOV	91,078(8)	119,029(16)	148,238(4)	96,731(4)	212,306(8)	132,786
DEC	215,447(8)	163,198(16)	184,669(4)	94,219(4)	106,781(8)	157,614
Overall	109,654	134,016	141,642	95,475	147,102	102,049

*Numbers in parentheses (N) indicate number of samples on which mean was based.

Table 4.3-2b

Phytoplankton Standing Crop ($\times 10^4$ Units/Liter) Based on 1 Minute Clarke Bumpus Tows. Samples based on Untransformed Means of N Samples.

	West Hackberry Control	West Hackberry	Black Bayou	Big Hill Control	Big Hill	Overall
OCT	6.66(10)	6.83(20)	7.47(4)	9.21(4)	8.11(6)	7.25(44)
NOV	11.04(8)	11.95(16)	14.68(4)	18.05(4)	18.81(8)	14.04(40)
DEC	11.26(6)	11.26(14)	18.56(4)	21.33(4)	19.97(8)	15.23(36)
Overall	9.43	9.73	13.57	16.21	16.29	11.90

* Numbers in parentheses (N) indicate number of samples on which mean was based.

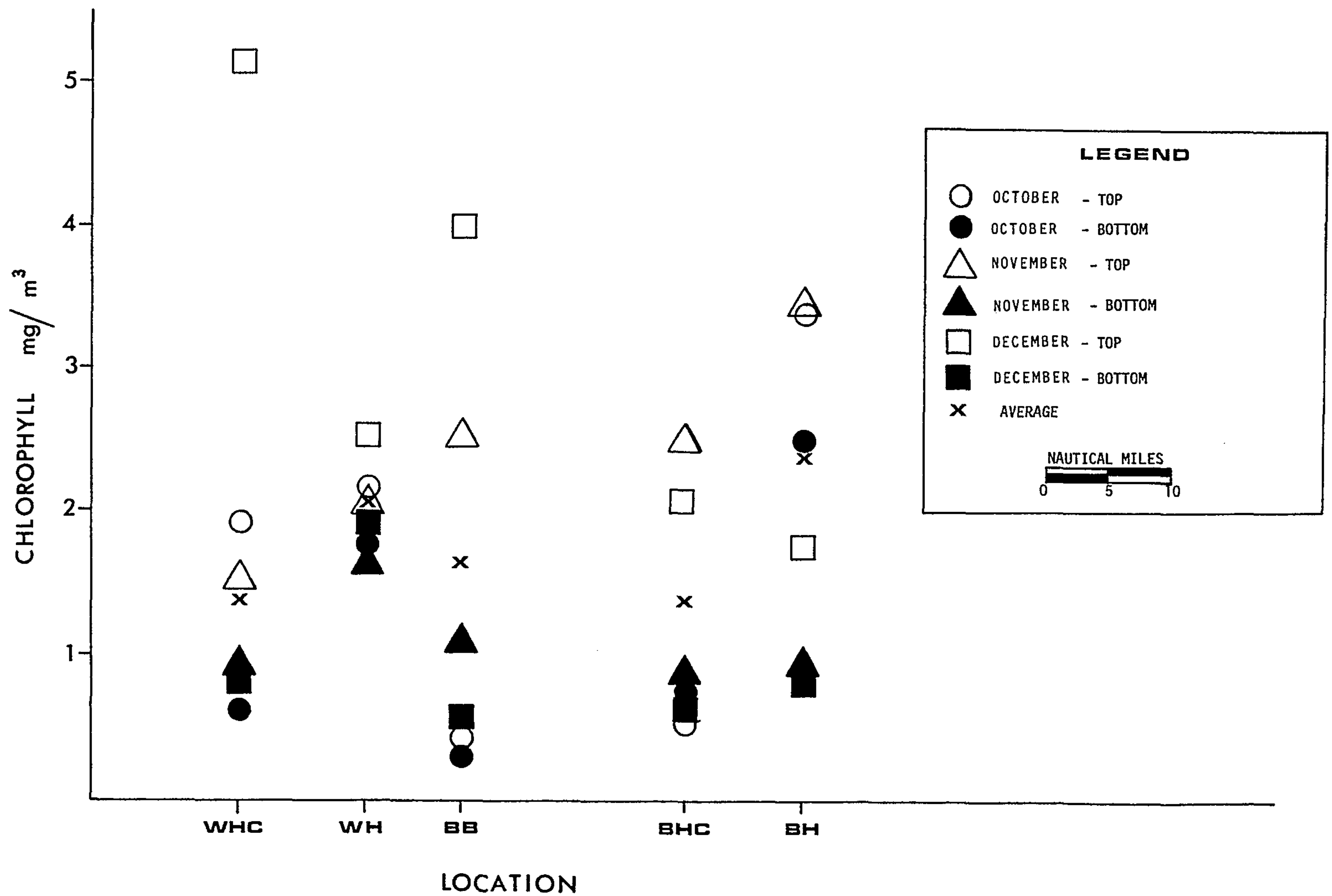


FIGURE 4.3-1 MEAN CHLOROPHYLL VALUES BY DEPTH, SITE AND CRUISE.

Table 4.3-3

Means (Standard Errors) of Chlorophyll Values (mg/m^3) by Depth, Site and Cruise

Cruise		West Hackberry Control	West Hackberry	Black Bayou	Big Hill Control	Big Hill	Overall[a]
October	B	.568(.326)	1.833(.635)	.350(.320)	.785(.705)	2.487(.799)	
	T	.193(.107)	2.183(.802)	.475(.455)	.495(.415)	3.353(1.244)	1.615(.287)
	N	6	10	2	2	6	52
November	B	.925(.615)	1.695(.149)	1.120(.160)	.770(.460)	1.975(.400)	
	T	1.570(.792)	2.043(.317)	2.550(.720)	2.465(1.865)	3.443(.943)	1.884(.195)
	N	4	8	2	2	4	40
December	B	.778(.247)	1.814(.499)	.630(.630)	.735(.225)	.903(.300)	
	T	5.240(1.078)	2.568(.627)	4.010(.420)	2.085(.325)	1.805(.415)	2.122(.284)
	N	4	8	2	2	4	40
Overall		1.379(.372)	2.021(.231)	1.523(.428)	1.223(.347)	2.412(.366)	
		28	52	12	12	28	

B = Bottom, T = Top, N = Number of Samples

[a]Overall mean includes top and bottom samples combined. Overall N equals total number of samples summed over the top and bottom samples.

Table 4.3-4

Mean (Standard Errors) of Phaeopigment Values (mg/m^3) by Depth, Site and Cruise

Cruise		West Hackberry Control	West Hackberry	Black Bayou	Big Hill Control	Big Hill	Overall[a]
2	B	1.026(.440)	2.302(.789)	.455(.045)	.990(.300)	.582(.222)	
	T	1.561(.589)	1.552(.359)	.260(.210)	.545(.015)	.922(.450)	1.30(.206)
	N	6	10	2	2	6	52
3	B	.845(.428)	1.126(.324)	.950(.950)	2.460(1.970)	.672(.573)	
	T	.512(.374)	.801(.284)	.000(.000)	.960(.960)	.527(.304)	.859(.158)
	N	4	8	2	2	4	40
4	B	.087(.017)	1.288(.393)	.790(.790)	.540(.380)	1.620(.393)	
	T	.537(.355)	3.322(1.473)	.000(.000)	.000(.000)	.892(.597)	1.302(.349)
	N	4	8	2	2	4	40
Overall		.837(.192)	1.747(.303)	.409(.189)	.915(.359)	.852(.171)	
		28	52	12	12	28	

[a]Overall mean includes composite of top and bottom samples. Overall N equals top and bottom combined.

B = Bottom, T = Top, N = Number of Samples.

($0.86 mg/m^3$) and about the same ($1.30 mg/m^3$) during October and December West Hackberry had the highest phaeophytin concentration ($1.75 mg/m^3$) and Black Bayou the lowest ($0.41 mg/m^3$) with the other site means similar (0.84-0.92 mg/m3). Depth differences were quite inconsistent.

Table 4.3-1 provides information on the seasonal distribution of the plankton based on combined bottle and tow data. The majority of species were ubiquitous. Nonetheless seasonal changes in community dominance were noted (Table 4.3-5). During October the dominant species were Biddulraphia granulata (11.4%), B. mobilensis (10.6%), Rhizosolenia alata (9.7%), Nitzchia seriata (9.3%), and Coscinodicus centralis (9.1%). In November the community was dominated by Rhizosolenia robusta (16.6%), Skeletonema costatum (14.9%), Chaetoceros decipiens (10.7%), C. currisetum (10.4%) and Coscinodiscus centralis (9.5%). During December the same species continued to dominate the community but in somewhat different order (S. costatum 41.7%, R. robusta 23.1%, C. currisetum 15.1%, C. centralis 5.8% and C. decipiens 4.0%).

Structurally Table 4.3-5 suggests certain changes in community composition from October to December. The total number of species clearly decreases over this time period. Since only slightly fewer tows were taken in November and December, this decrease is unlikely to be due to reduced sampling effort. Also, species evenness decreases markedly over the time period. In October the contributions of the top five species differed by less than three percentage points; in December the top two species differed by almost 20%. These variations are well illustrated in Figure 4.3-2.

The compositions of phytoplankton communities are rather volatile, owing to rapid reproductive rates; the relative abundance of two taxa can change radically over relatively short periods of time. A monthly inventory can at best provide only an indication of the basic features of the community. To the extent that this is so in the present case, it appears that the October and November communities are in a state of transition culminating (?) in the December community. Lines of evidence for this include: 1) decrease in number of species, 2) increase in number of individuals, and 3) decrease in species evenness.

4.3.1.2 Spatial and Temporal Variations

Table 4.3-6 shows the means (retransformed) by cruise, site, and depth for total phytoplankton numbers based on whole water samples. Temporally, the overall values correspond to that seen in the means based on untransformed data (Table 4.3-2), with steadily increasing populations as the study progressed, especially for the top samples. In every case for overall numbers (by site and by cruise), the top samples had higher means, corresponding to the situation seen for chlorophyll a concentrations. Overall means varied from 40658 for Big Hill Control to 91700 for West Hackberry for bottom samples and 82305 for West Hackberry Control to 165278 for Big Hill for top samples. Cruise means varied from 49997 and 60330 for bottom and top, respectively, in October to 70861 and 175476 for bottom and top, respectively, for December. All means are expressed as units/liter.

Table 4.3-5 Seasonal Patterns of Community Dominance.

	OCTOBER			NOVEMBER			DECEMBER		
RANK ORDER	SPECIES	% COMPOSITION	CUMULATIVE % COMPOSITION	SPECIES	% COMPOSITION	CUMULATIVE % COMPOSITION	SPECIES	% COMPOSITION	CUMULATIVE % COMPOSITION
1	B. granulata	11.4	11.4	R. robusta	16.6	16.6	S. costatum	41.7	41.7
2	B. mobiliensis	10.6	22.0	S. costatum	14.9	31.5	R. robusta	23.1	64.8
3	R. alata	9.7	31.7	C. decipiens	10.7	42.2	C. currisetum	15.1	79.9
4	N. seriata	9.3	41.0	C. currisetum	10.4	52.6	C. centralis	5.8	85.7
5	C. centralis	9.1	50.1	C. centralis	9.5	62.1	C. decipiens	4.0	89.7
6	R. imbricata	8.4	58.5	B. mobilensis	7.7	69.8	T. nitzchoides	2.8	92.6
7	C. affine	6.9	65.4	C. affine	7.2	77.8	Eucampia sp.	2.0	94.6
8	S. costatum	5.4	70.8	N. seriata	4.8	81.8	R. imbricata	1.3	95.9
9	D. brightwelli	4.7	75.5	C. tripos	3.5	85.3	A. japonica	1.0	96.9
10	C. tripos	3.5	79.0	C. radiatus	2.6	87.8	Hemiaulus sp	1.0	97.9
11	Rhizosolenia sp.	3.4	82.4	D. brightwelli	2.5	90.4	C. radiatus	0.7	98.6
12	T. nitzchoides	2.8	85.2	R. imbricata	2.1	92.5	N. seriata	0.6	99.2
13	G. flaccida	2.1	87.3	A. japonica	1.5	94.0	Rhizosolenia sp.	0.3	99.5
14	A. japonica	1.4	88.7	Navicula sp.	1.2	95.2	D. brightwelli	0.2	99.7
15	Navicula sp.	1.4	90.1	Coscinodiscus sp.	1.1	96.3	B. mobilensis	0.1	99.8
16	T. decipiens	1.4	91.5	T. frauenfeldii	1.0	97.3	Coscinodiscus sp.	0.1	99.9
17	C. concinnus	1.3	92.8	Rhizosolenia sp.	0.9	98.2	Skeletonema sp.	0.1	100.0
18	Surirella sp.	1.3	94.1	T. decipiens	0.9	99.1			
19	L. undulatum	1.2	95.3	B. granulata	0.2	99.3			
20	B. varians	0.8	96.1	C. radiatus	0.2	99.5			
21	C. decipiens	0.8	96.9	L. undulatum	0.2	99.7			
22	Hemiaulus sp.	0.7	98.4	G. flaccida	0.1	99.8			
23	C. granii	0.5	98.9	T. nitzschoides	0.1	99.9			
24	Ditylum sp.	0.5	99.4						
25	T. frauenfeldii	0.5	99.0						
26	C. radiatus	0.2	100.0						
27	C. currisetum	0.2	100.0						

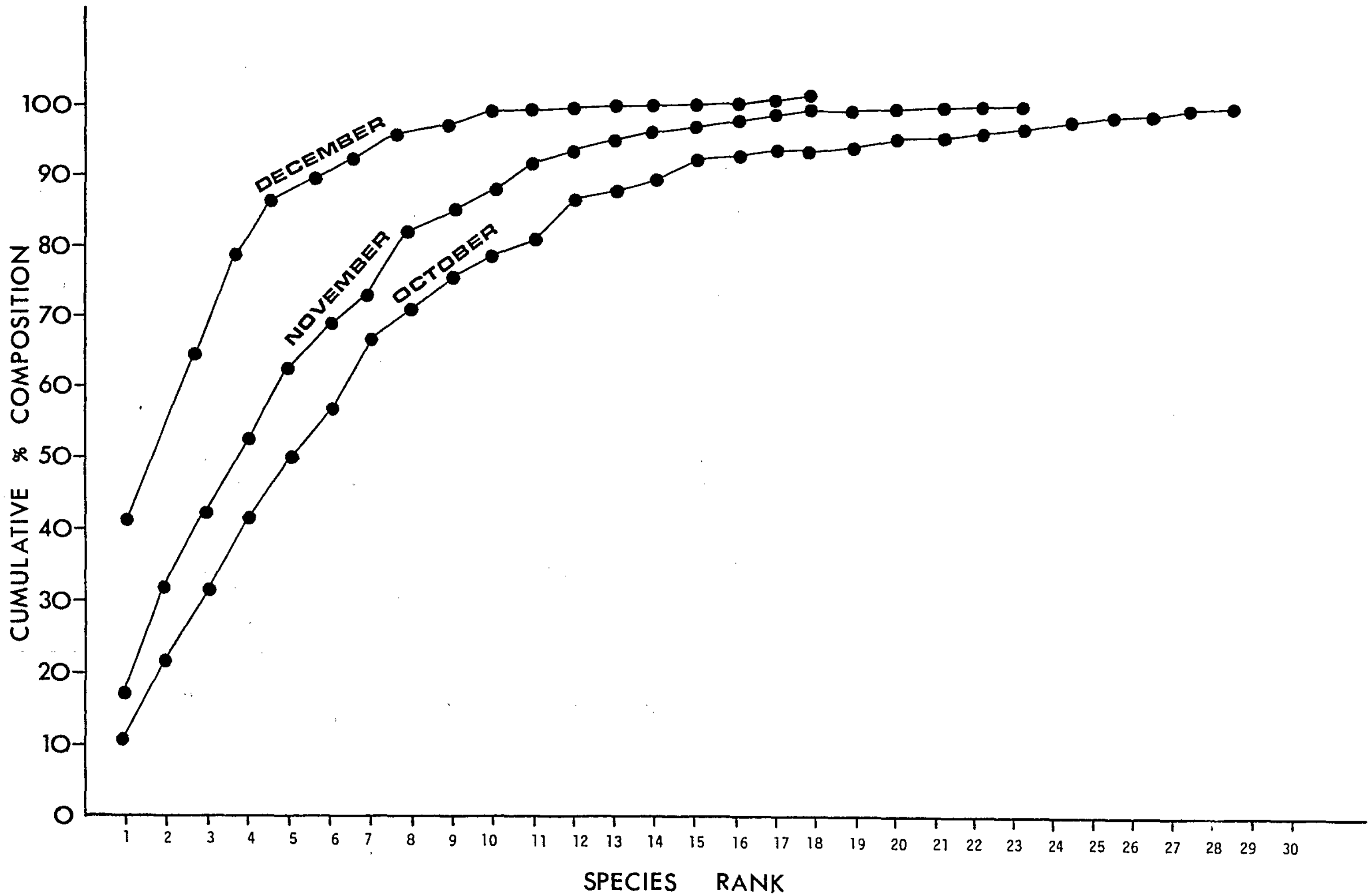


FIGURE 4.3-2. CUMULATIVE PERCENT COMPOSITION OF THE PHYTOPLANKTON COMMUNITY BY MONTH.

Table 4.3-6

Mean Number of Phytoplankton Individuals with Confidence Limits Per Sample by Month, Site and Depth (units/liter) (All Species)

SITE		OCTOBER		NOVEMBER		DECEMBER		OVERALL	
		Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top
Black Bayou	L_1[a]	1424414	1432461	199684	338644	5794835	455832	130501	468144
	γ	39900(2)[b]	20598(2)	75997(2)	217441(2)	28307(2)	312863(2)	44488(6)	116890(6)
	L_2	-3611.86	-4568	27043	138982	-4833	214245	13064	26387
Big Hill	L_1	1085388	685269	161071	668685	159093	273272	123009	263338
	γ	29915(3)	115389(3)	95649(4)	253968(4)	60640(4)	128726(4)	64578(11)	165278(11)
	L_2	-3905	15958	55994	94539	21248	59255	27547	96765
Big Hill Control	L_1	48378878	4618488	543949	3573514	49910	200245	129248	252596
	γ	44696(2)	39355(2)	39920(2)	107337(2)	37614(2)	150425(2)	40648(6)	86840(6)
	L_2	4973.9	-4599	-1345	-1496	28069	112697	10517	27733
West Hackberry Control	L_1	47214	67369	267251	277271	174581	494724	79892	167206
	γ	41904(6)	25439(6)	36289(4)	80693(4)	49206(4)	362071(4)	47160(14)	82305(14)
	L_2	37134	7048	1244	21002	11349	264629	21166	34307
West Hackberry	L_1	149541	172458	150451	214909	228249	266172	124795	147549
	γ	68685(10)	89908(10)	90745(8)	103599(8)	110335(8)	118439(8)	91700(26)	107269(26)
	L_2	30125	45752	53967	48574	52027	51183	59748	70391
Overall	L_1	86698	90711	102927	192276	102970	247906		
	γ	49997(23)	60330(23)	69522(20)	127825(20)	70861(20)	175476(20)		
	L_2	27980	32993	46453	84429	41469	116716		

[a] L_1 and L_2 equals the lower and upper confidence limits respectively (after Sokal and Rohlf, 1969)

γ equals the mean

[b] number of samples

Analysis of Variance

Results of the three-way ANOVA(Table 4.3-7) for individual phytoplankton species and total numbers showed the greatest tendency was for cruise to cruise variations in population means, with site differences (p = 0.05) important for only five species (Chaetocerus currisetum, Rhizosolenia alata, R. sp., Coscinodiscus centralis, and Biddulphia granualta), with the trend being strong (.001) only for B. granulata. Of all species tested (also all species combined) only Rhizosolenia sp. and Coscinodiscus centralis showed no significant cruise variations. Significant depth differences were apparent for only four species and for all species combined. Three of the species showing significant depth differences were of the same genus (Chaetoceros).

The trend shown for all species combined, with significant cruise and depth differences with levels $>$.001 and no significant site differences results from the interaction of a number of trends. Insignificant site differences resulted from only a few species showing marginally significant differences, with the majority of species showing no site differences.

Overall significant depth differences were due to the relative importance of the species showing these depth differences (all dominant species) along with the consistently higher numbers in the top samples for all these species. The fact that the overall significance level was less than that for most individual species is indicative of rapidly overturning communities, with different dominant forms from cruise to cruise.

For those species (and all species combined) that showed significant cruise differences in the three-way ANOVA's with no confounding interaction, multiple means tests of all possible pairwise combinations of cruise means were performed, and the results summarized in Table 4.3-8 . As can be seen, results of the multiple means tests clearly show the temporal transition of authority in the community. The overall similarity in the total community and Skeletonema costatum is due at least partially to the great numerical importance of S. costatum in the December samples, where it was essentially 40% of the total community, having increased from approximately 5% of the community in October and 15% in November. Other species with significant cruise differences and showing the same trend for overall lowest mean in October and greatest in December included Chaetoceros currisetum and Rhizosolenia robusta. Table 4.3-8 shows that in direct contrast to this trend was the one shown by Ditylum brightwelli, Nitzschia seriata and Rhizosolenia imbracata, with highest means in October and lowest in December. Other species showing similar trends were B. mobiliensis, R. alata, and B. granulata, with the latter two not present at all in December.

A third group, including Ceratium tripos, Chaetoceros affinis, and Chaetoceros decipiens, showed November with the highest means, being significantly higher than the means for either October or December. Both C. tripos and C. affinis showed no presence in December. Cocinodiscus centralis, which had significant cruise differences, also had highest mean in November.

Table 4.3-7

Levels of significance resulting from the ANOVA of selected phytoplankton species and total species

	EFFECT						
Species	Cruise	Site	Depth	Cruise Site	Cruise Depth	Site Depth	Cruise Site Depth
Biddulphia granulata	.0001*	.0001*	.196	.0001*	.399	.762	.912
B. mobiliensis	.0001*	.109	.200	.854	.002*	.731	.919
Ceratium tripos	.0001*	.110	.484	.440	.187	.876	.954
Chaetoceros affinis	.0001*	.271	.040*	.181	.111	.169	.733
C. currisetum	.0001*	.010*	.0001*	.615	.006*	.058	.042*
C. decipiens	.0001*	.157	.005*	.278	.288	.739	.071
Coscinodiscus centralis	.260	.035*	.130	.048*	.139	.503	.160
Ditylum brightwelli	.003*	.125	.107	.783	.460	.724	.964
Nitzschia seriata	.0001*	.303	.095	.534	.250	.390	.890
Rhizosolenia sp.	.406	.036*	.586	.768	.949	.942	.999
R. alata	.0001*	.017*	.593	.004*	.779	.571	.621
R. imbricata	.004*	.990	.070	.686	.349	.479	.913
R. robusta	.0001*	.595	.002*	.014*	.014*	.118	.097
Skeletonema costatum	.0001*	.672	.209	.395	.054	.200	.303
TOTAL	.003*	.245	.003	.413	.134	.529	.267

*significant at p = 0.05

Table 4.3-8

Summary of Multiple Means
Tests for all Possible Pairwise Comparisons of Cruise Means

Phytoplankton (whole water samples)

Taxonomic Group	Dependent Variable	Cruise Means (Highest		Lowest)
Total	log N	December	November	October
Ceratium tripos	log N	November	October	December
Chaetoceros affine	log N	November	October	December
Chaetoceros decipiens	log N	November	December	October
Ditylum brightwelli	log N	October	November	December
Nitzschia seriata	log N	October	November	December
Rhizosolenia sp	log N	October	November	December
Skeletonema costatum	log N	December	November	October

Tukey's t = 2.57

Indications that the November population was in a transition phase can be seen in the fact that the two species with the highest percent composition in November (R. robusta and S. costatum, with 16.6 and 14.9%, respectively) had significantly higher means in December.

Results of the multiple means tests for site differences (Table 4.3-9) shows the only apparent trend is for higher populations of some species at West Hackberry, but this is only clearcut for Rhizosolenia sp. Other species with significant site effects and highest overall means at West Hackberry include B. granulata, R. alata, and C. centralis. Thus the overall lack of significant site differences for all species combined is due to the fact that the major species for October (B. granulata and B. mobiliensis) showed highest means at different sites along with the lack of significant site differences for the dominant species (R. robusta and S. costatum) for the November and December samples.

Results of the ANOVA's for pigments are shown in Table 4.3-10 for chlorophyll, depth was the only significant main effect. Although there was some variation during the October sample, there were consistent depth differences for the November and December cruises, with the top samples having by far the higher concentrations. The range of overall means for the five sites was only 1.22 to 2.41 mg/m^3. No one site was consistently high from cruise to cruise, indicating that pigment distribution is not site specific. Much of the variation in the data can be explained by the clumped distribution of plankton populations. The results showing depth effects correspond to the significantly greater overall numbers of phytoplankters found in the surface samples via the ANOVA.

For phaeopigments, there were significant site differences (P = .05). Highest phaeopigment values were found at West Hackberry (1.747 ± .303 mg/m^3) (Table 4.3-4) while lowest values were found at Black Bayou (.409 ± .189 mg/m^3). Since phaeopigment is a breakdown product of chlorophyll a it is possible that West Hackberry is subjected to higher cell mortalities than other sites. Given the high cell numbers at West Hackberry it is likely that the high phaeopigment values are simply a reflection of high standing crop.

Correlations between Phytoplankton Species Numbers

Results of the correlation analyses are presented in Table 4.3-11. In general the presence of significant correlations seems most related to the temporal incidence of occurrence of the particular species. For example, the group with highest means in December (in all three cases December>November>October), S. costatum, C. currisetum, and R. robusta showed correlation coefficients of from 0.61 to 0.76, and they generally represent the most highly correlated group in the overall community. Table 4.3-12 summarizes the relationships between this December group and the group with highest means in October (in all cases October>November> December). No positive correlations exist, with all relationships being

Table 4.3-9

Summary of Multiple Means
Tests for all Possible Pairwise Comparisons of Site Means

Phytoplankton (whole water samples)

Taxonomic Group	Variable	Site Means (Highest				Lowest)
Biddulphia mobiliensis	log N	BHC	BH	WHC	WH	BB
Chaeteceros currisetum	log N	WH	BB	WHC	BHC	BH
Rhizosolenia sp.	log N	WH	BB	BH	WHC	BHC

Tukey's t = 2.735

WH = West Hackberry
WHC = West Hackberry Control
BB = Black Bayou
BH = Big Hill
BHC = Big Hill Control

Table 4.3-10 Results of ANOVA's for Pigments

Effect	Chlorophyll a	Phaeopigments
Cruise	0.32	0.35
Site	0.07	0.02
Depth	0.001*	0.98
Cruise/Site	0.017*	0.42
Cruise/Depth	0.06	0.29
Site/Depth	0.71	0.76
Cruise/Site/Depth	0.35	0.63

* Significant at 0.05 level.

Table 4.3-11 Results of the Analyses of Simple Correlations For the Major Phytoplankton Species

	S. costatum	R. robusta	R. imbricata	R. alata	Rhizosolenia sp.	N. seriata	D. brightwelli	C. centralis	C. decipiens	C. currisetum	C. affine	C. tripos	B. mobiliensis
B. granulata	-.33[a]	-.43	.37	.81	.23	.46	.38	NS	-.27	-.41	.23	.22	.34
B. mobiliensis	-.18	-.22	.37	.36	NS	.51	.50	.29	NS	-.22	.59	.45	
C. tripos	NS[b]	NS	.23	.21	NS	.45	.53	.24	.25	NS	.53		
C. affine	NS	NS	.34	.32	NS	.59	.45	.34	.30	NS			
C. currisetum	.61	.69	NS	-.37	NS	NS	NS	.41	.65				
C. decipiens	.35	.52	NS	-.19	NS	.25	NS	.45					
C. centralis	.26	.23	.23	NS	NS	.36	.33						
D. brightwelli	NS	NS	.37	.42	.26	.60							
N. seriata	NS	NS	.47	.50	.31								
Rhizosolenia sp.	NS	NS	NS	.21									
R. alata	NS	-.34	.37										
R. imbricata	NS	NS											
R. robusta	.76												

[a]Correlation coefficients significant at $p = .05$.

[b]NS = Not Significant.

Table 4.3-12. Correlation matrix for comparison of species with highest means in October and December.

Species with Rank of Means October>November>December	Species with Rank of Means December>November>October: *S. costatum*	*C. currisetum*	*R. robusta*
D. brightwelli	NS[a]	NS	NS
N. seriata	NS	NS	NS
R. imbricata	NS	NS	NS
B. mobiliensis	-.18[b]	-.22	-.22
R. alata	NS	-.37	-.34
B. granulata	-.33	-.41	-.43

[a]NS = not significant

[b]correlation coefficients significant at $p = 0.05$

either not significant or with a significant negative correlation. Clearly these are two distinct groups. All members of the group with the October high mean were positively correlated with each other, with the strongest relationship exhibited by R. alata and B. granulata (r = 0.81).

The middle group, with highest means in November (C. tripos, C. affinis, C. centralis, and C. decipiens) had all species showing positive significant correlations with each other, and behaved as a transition group relative to the other groups. C. tripos and C. affinis (both with November>October>December) were not at all related to the members of the December high group, with no significant relationship apparent. They were, however, rather closely related to the October high group, with significant positive correlations between each species of each group. C. centralis, on the other hand, also had November>October>December means, but it was correlated with members of both the October and December group, being positively correlated with all members of the latter and all but two (R. alata and B. granulata) of the former. C. decipiens (which had rank of means November>December>October) was more closely related to the species with December high means, being positively correlated with all three (C. costatum, C. currisetum, and R. robusta) , with the highest correlation with C. currisetum (r = 0.65). C. decipiens was positively correlated with N. seriata of the October high mean group, but was negatively correlated with B. granulata and R. alata. It was not significantly correlated with the other three species (D. brightwelli, R. imbricata, and D. mobiliensis).

The results indicate a trend for change in community composition from October through December, with the October and December communities being quantitatively distinct and the November community representing a transition group with some members with affinities to either the October or December groups and others with affinities to both.

Correlations between Phytoplankton Numbers and Pigments

Results of the correlation analyses for total number of phytoplankton and plant pigments are shown in Table 4.3-13. Over all cruises and sites, chlorophyll a was positively correlated with plankton numbers (r = 0.70, p = 0.0001). For phaeopigment, there was a significant negative correlation (r = -0.21), but in this case much less of the variation in the two variables was coincident.

For data sorted by cruise, results for chlorophyll a were very consistent, with r = 0.58, 0.76, and 0.78 for October, November, and December, respectively. Only during Cruise 3 were phaeopigments significantly correlated (negatively) with plant populations (r = 0.36).

For data sorted by site, Black Bayou showed the best correlation (r = 0.87) between plant population and chlorophyll a concentration. Big Hill data did not show a significant correlation between the two variables, with the other sites (West Hackberry, West Hackberry Control and Big Hill Control)

Table 4.3-13.

Results of Correlation Analyses for Total Phytoplankton and Pigments

Data Set	Chlorophyll a		Phaeopigments	
	r	Pr>	r	Pr>T
All Cruises/All Sites	0.70	0.0001	-0.20	0.02
October/All Sites	0.58	0.0001	ns	
November/All Sites	0.76	0.0001	-0.36	0.02
December/All Sites	0.78	0.0001	ns	
All Cruises/Black Bayou	0.87	0.0001	ns	
All Cruises/Big Hill	0.38	0.0821	ns	
All Cruises/Big Hill Control	0.79	0.002	ns	
All Cruises/W. Hackberry	0.65	0.0001	-0.34	0.01
All Cruises/W. H. Control	0.82	0.0001	ns	

Note: ns = not significant.

showing correlation coefficients of 0.65-0.82. Only at West Hackberry was there a significant (negative) correlation between phaeopigments and plant numbers. The low correlation between chlorophyll a concentration and plant population at Big Hill is not easily explained. Otherwise, when the fact that there are significant differences in cell size and pigment quotas among phytoplankton species is taken into account, the r values for correlation of total phytoplankton and chlorophyll are quite good.

Ordination Results

Figures 4.3-3 through 4.3-5 depict the results of reciprocal averaging ordinations of the phytoplankton data, as sampled by the Van Dorn whole water and/or the Clarke Bumpus methods. Species occurring five times or fewer were dropped. The distribution along axes 1 and 2, only, of sample and species space have been shown. These axes account for 29% of the variance in the whole water samples, and 25% of the variance in the Clarke Bumpus samples. Figure 4.3-3 shows the whole water samples distinguished according to site of collection. No site specific trend is apparent, as was shown by both the chlorophyll and total number ANOVA's and the correlation analyses. The same result is obtained for the Clarke Bumpus data (not shown). Figures 4.3-4 and 4.3-5 show the distribution of whole water and Clarke Bumpus samples with date of collection distinguished. This coincides with the seasonal changes in population structure inferred from the ANOVA's and correlation analyses. This is a clear substantiation of the view that community composition varied primarily as a seasonal function. It should also be pointed out that the spread in sample distribution along axis 2 decreases from the October to the December samples. This is an indication of the increasing constancy of composition over this time period. It is a reflection of the fact that in October the contribution of various species was more evenly distributed over a number of species, whereas in December the community was overwhelmingly dominated by *S. costatum* and *R. robusta*. The overall shift in community composition is shown well in Figure 4.3-6, representing an ordination of the samples in species space. The position of *Biddulphia granulata* on the extreme right corresponds to the relative position of the October samples in sample space. Likewise, the positions of *R. robusta* and *S. costatum* on the extreme left correspond to the same relative position of the December samples. The reader should compare this figure with Table 4.3-11 to fully appreciate the importance of the seasonal factor in phytoplankton spatial and temporal distribution.

4.3.2 Zooplankton

The analysis and interpretation of zooplankton abundance in relation to temporal and spatial variation in other environmental factors are presented in this section. Analysis has been implemented with graphical and tabular presentations and discussions of abundance, number of zooplankton groups (species and others), number of zooplankton groups with low numbers, percentage occurrence of major larval forms, sampling effectiveness, zooplankton group diversity index values, statistical

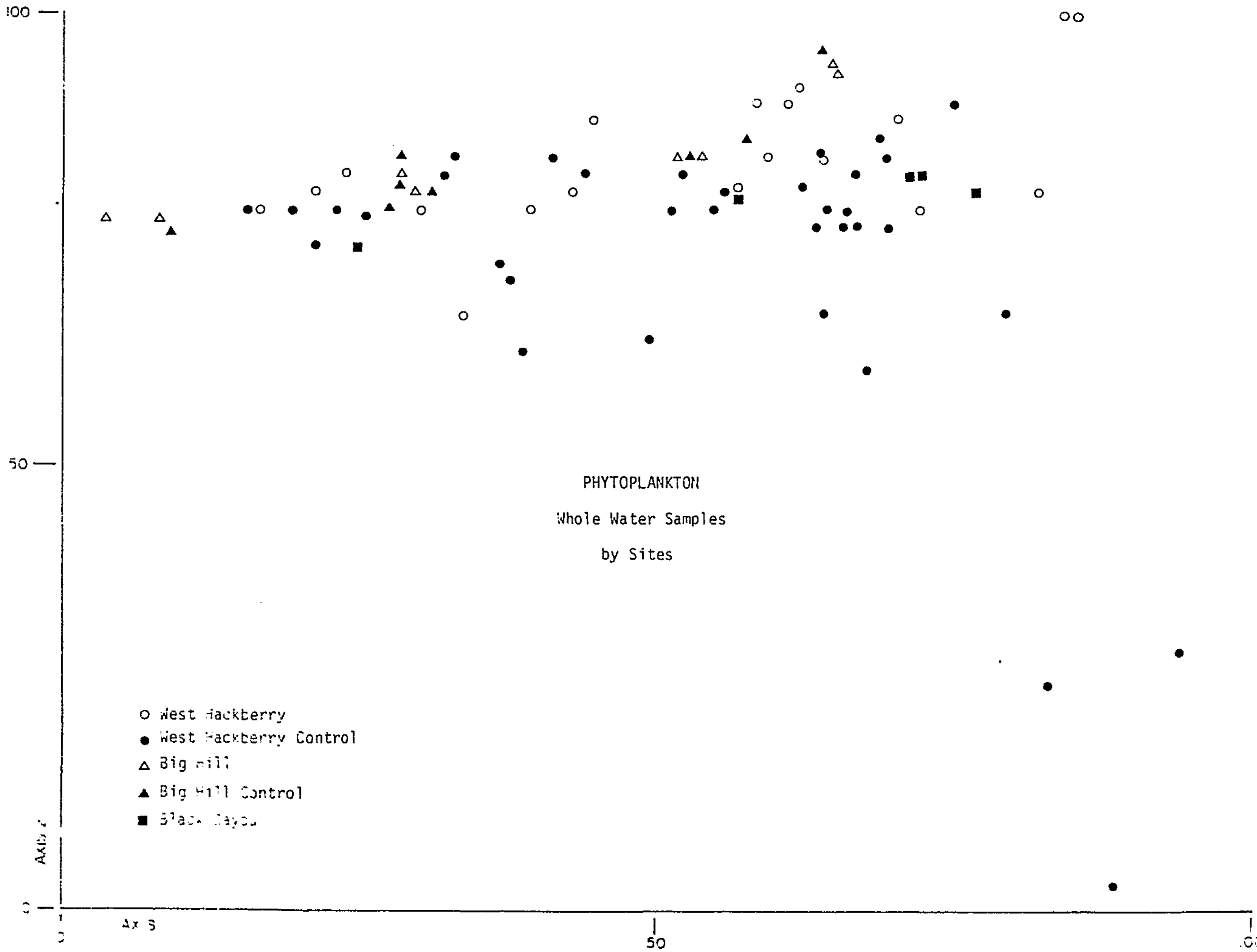


Figure 4.3-3 Reciprocal Averaging Ordination For Phytoplankton (Whole Water), Shown in Sample Space, Sample Sites Indicated

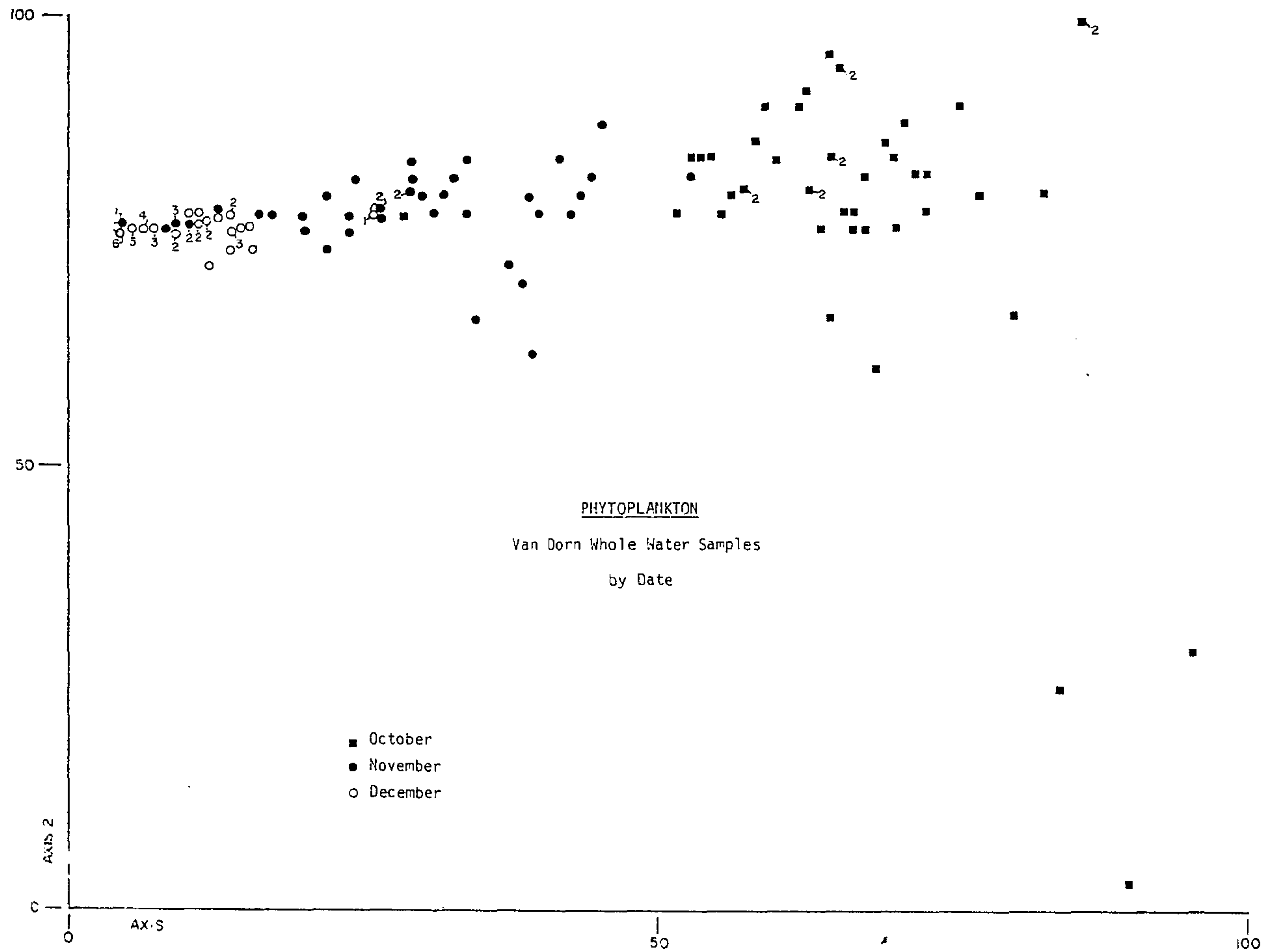


Figure 4.3-4 Reciprocal Averaging Ordination For Phytoplankton (Whole Water), Shown in Sample Space, Sample Dates Indicated

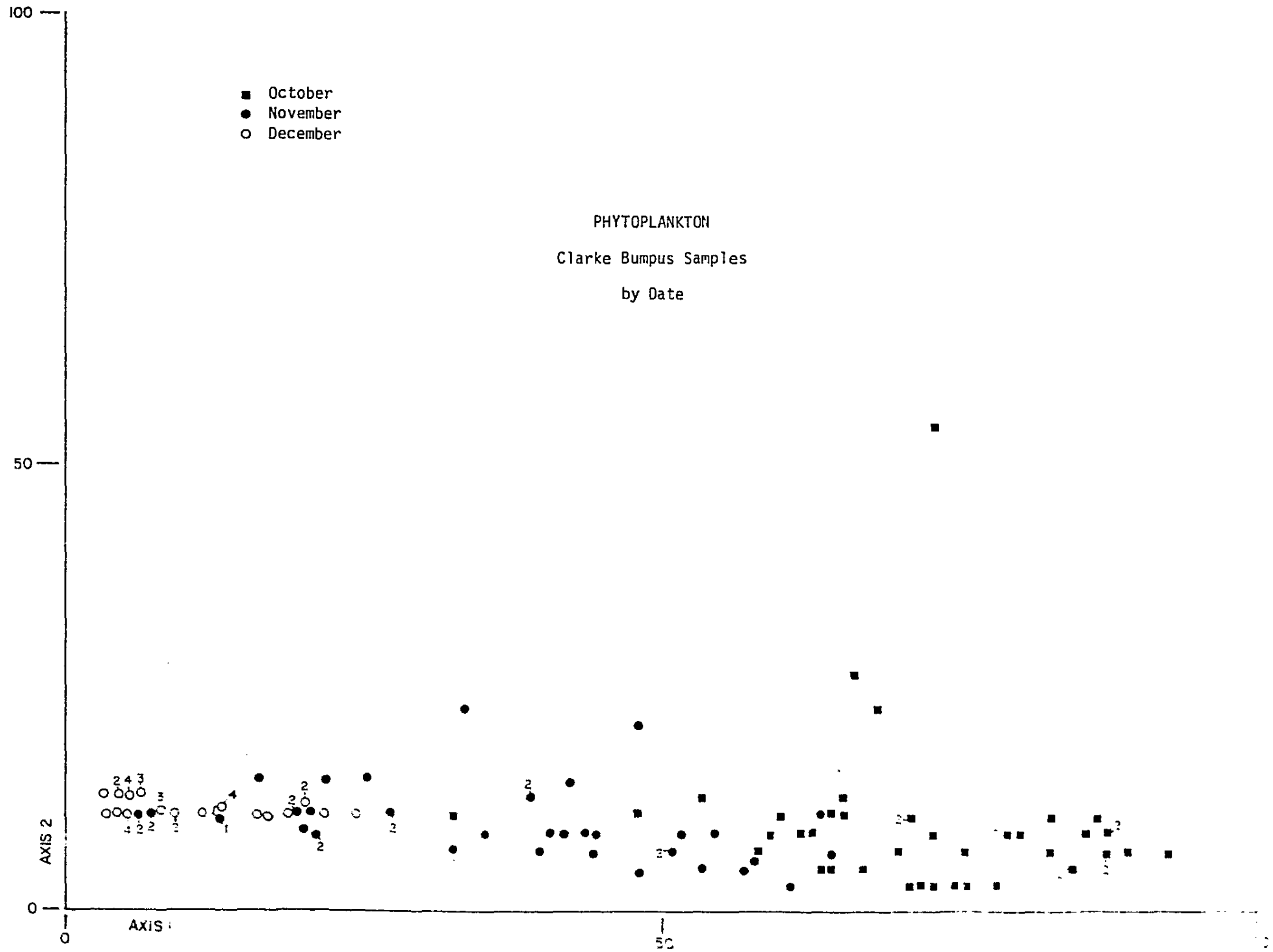


Figure 4.3-5 Reciprocal Averaging Ordination For Phytoplankton (Clarke Bumpus), Shown in Sample Spaces, Sample Dates Indicated

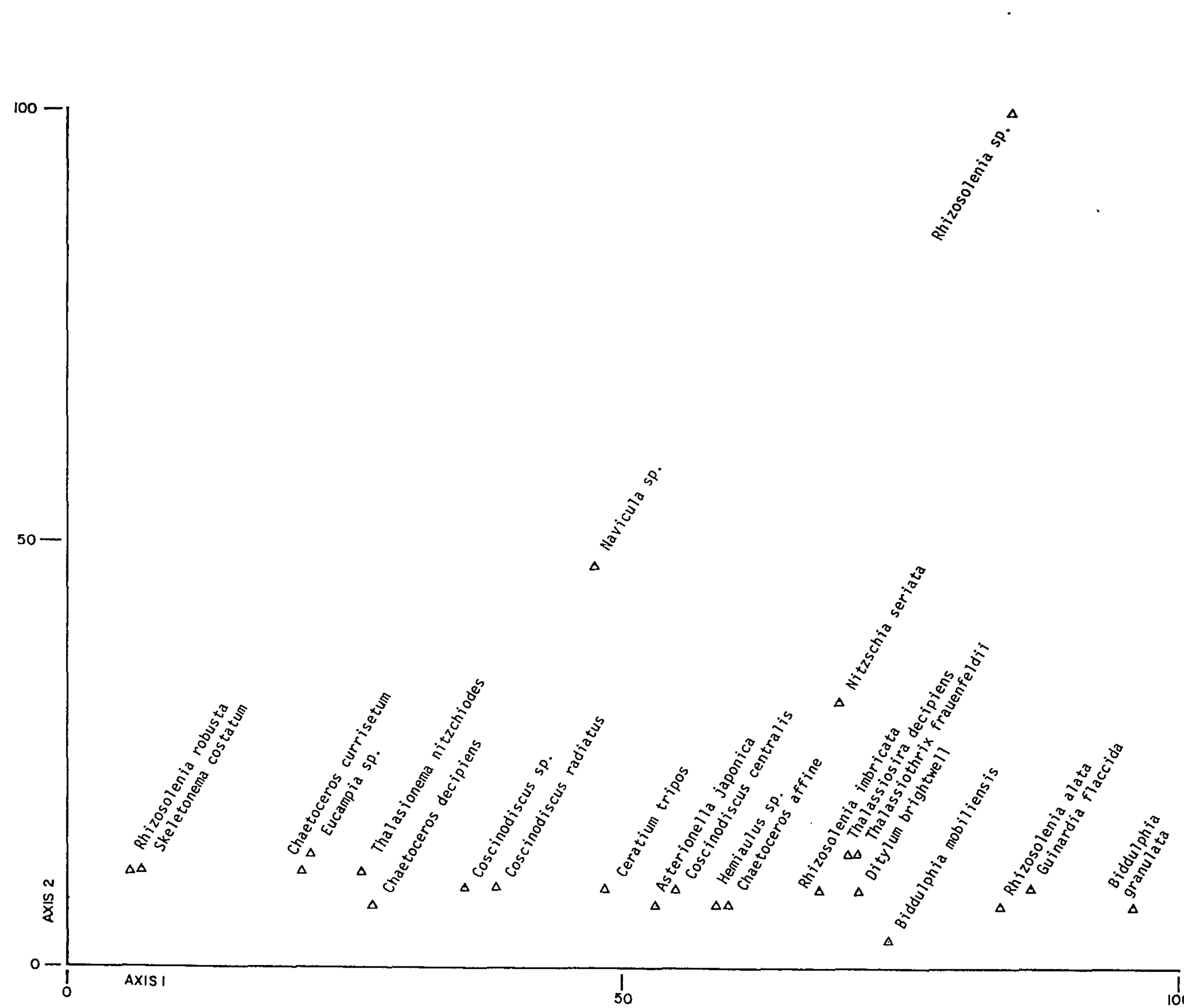


Figure 4.3-6 Reciprocal Averaging Ordination For phytoplankton, Shown in Species Space

analysis of variation of the numerically most important groups, statistical correlation between important groups, and ordination (by reciprocal averaging) of groups and samples in relation to axes accounting for maximum differences in the overall data set.

4.3.2.1 General Characterization

Some 102 zooplankton groups were discrimminated during the study period. These are listed in Table 4.3-14. Most of these groups are discrete species and do not overlap with the other groups. The specific name was not determined for all species discriminated. The maximum total number of groups obtained at any one of the study sites on any of the months of the study was 54. The zooplankton were dominated by several species, mostly copepods and the tunicate, *Oikopleura*. No more than five adult forms were dominant during any month at any study site. Larval forms were least abundant in September.

Combined zooplankton average densities for combinations of study site, months and depth ranged between over 30,000 individuals/m^3 and approximately 240 individuals/m^3. A consistent trend in combined average densities was evident. Abundance (density) was greatest during September, declined by over two to over ten times at the different study sites by October, fell somewhat lower during November, and returned to the levels of October by December. Average group densities over the entire study period reached the order of magnitude of 1000 individuals/m^3. Average group (e.g., species) densities at any study site on any month reached a maximum of over 4,500 individuals/m^3. Although there was often a large difference between top and bottom sample densities at different stations, such differences did not occur in any consistent pattern. The differences presumably reflect the influence of vertical migration.

Diversity was highest during October and November, lowest in December, and next to lowest in September. It was broadly but not completely related to combined zooplankton abundance: when abundance was high, diversity was lower and vice versa. The community was apparently a mixed type which contained both typical coastal and typically estuarine forms.

Zooplankton combined abundances were at high levels at all the study sites. The abundances were on the order of 100-fold greater than densities of estuarine zooplankton in the same region reported in the *Cooperative Gulf of Mexico Estuarine Inventory and Study, Louisiana*. The species list in the inshore area has only about one-third the species recorded in the present study. Combined zooplankton abundances ascertained in the present study ran slightly higher than were obtained in long-term studies of the South Texas Outer Continental Shelf by NOAA. The peak average densities exceeded those in the NOAA work by a factor of about five. Abundance and the number of species obtained for the same time period as in the present study in the Capline Group baseline studies off the east-central Louisiana coast were both at the low end of the ranges for the present study.

Table 4.3-14 List of Zooplankton Groups

Acartia lilljeborgii
Acartia tonsa
Acetes americanus
Amphuira filiformis
Anchoa mitchelli eggs
Anchoa mitchelli larvae
Anomura larvae
Anthomedusae
Barnacle nauplii
Bolinopsis infundibulum
Brachyuran larvae
Brachyuran megalops
Brevoortia sp. larvae
Centropages furcatus
Conchoecia sp.
Conchoecia elegans
Copepoda nauplii
Corycaeus amazonicus
Crustacea nauplii
Ctenophora
Cypris stage of a barnacle
Decapoda zoea
Doliolum sp.
Ectoprocta cyphonautes
Eggs
Ensis minor
Euterpina acutifrons
Ertemocaris larva
Eucalanus pileatus
Euphausiacea larvae
Fritillaria sp.
Galathea sp. larvae
Globigerina sp.
Globigerina inflata
Halocypris brevirostris
Harpacticoida copepod
Hyperia sp.
Janthina exigua
Jaxea nocturna
Labidocera aestiva
Labidocera nauplii
Labidocera scotti
Leptomedusae
Leptosynapta inhaerens larvae
Litiopa melanostoma
Lucifer faxoni
Macrosetella gracilis
Macrura larvae
Meganyctiphanes norvegica
Membranipora sp.
Miracia efferata
Mnemiopsis sp.
Muggiaea sp.
Mysidacea
Nereis nectochaete larvae
Noctiluca sp.
Obelia sp.
Oikopleura sp.
Oithona nana
Oncaea mediterranea
Ophiuroidea larvae
Opisthobranchiata
Osteichthyes eggs
Osteichthyes larvae
Ostracoda
Paguridea zoea
Panopeus herbstii
Paracalanus crassirostris
Penaeus sp.
Penilia avirostris
Phoronis sp.
Pleurobrachia sp.
Podon sp.
Polychaeta larvae
Porcellanid crab larvae
Portunus sp.
Portunus sp. zoea
Prosobranchia larvae
Radiolaria
Sagitta sp.
Salpidae
Scapholebris sp.
Serpulidae trochophore
Siphonophora
Squilla sp.
Stellifer sp. larvae
Synchaeta sp.
Temora turbinata
Tintinnidae
Tompteris septendrionalis
Tornaria larvae
Tortanus setacacidata
Unidentified calanoid copepod #1
Unidentified calanoid copepod #2
Unidentified calanoid copepod #3
Unidentified calanoid copepod #4
Unidentified calanoid copepod #5
Unidentified Calanoida copepods
Unidentified copepod (cyclcpoid?)
Unidentified Cyclopoida copepod
Turritopsis nutricula
Veneridae larvae

4.3.2.2 Detailed Results and Interpretation

Abundances of dominant zooplankton are presented graphically by study area and month in Figure 4.3-7 as the average numbers which were encountered per meter on a single line which passed through the column of water filtered by the Clarke-Bumpus Sampler. These numbers are the cube roots of the numbers per cubic meters measure used to express abundance in the general characterization. This device compresses the volumetric densities, dampening the legendary imprecision in plankton sampling. Strickland (1972) reported studies indicating that individual abundance estimates from paired tows typically had to be greater than double or less than half of the other value to be significantly different (.05 level).

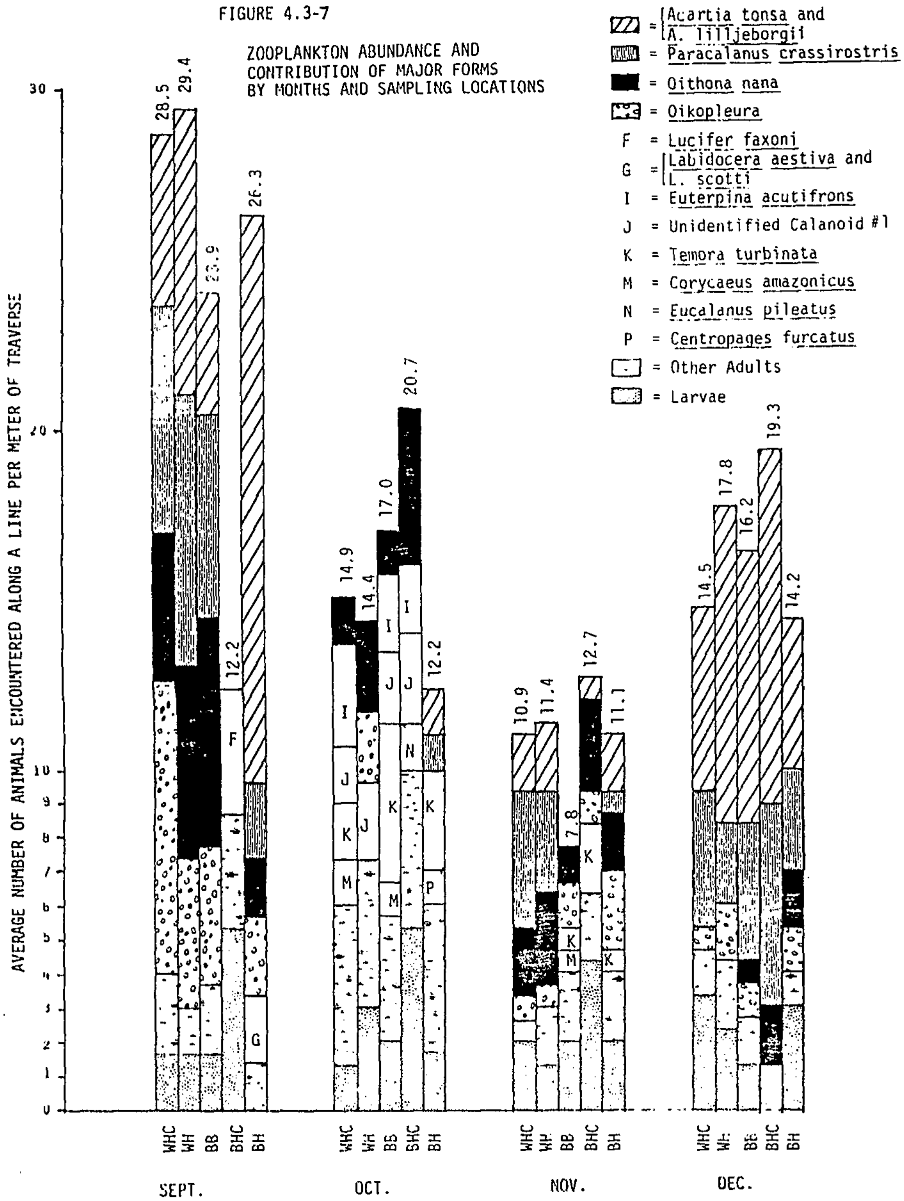
Figure 4.3-8 shows another aspect of this variability. This figure relates the number of species (groups) collected to the number of samples obtained. There was not a pronounced difference in pattern from month to month although there was a change in species composition. Most of the species were obtained in similarly low numbers. Individual species characteristics do not seem to have produced a pronounced bias and the densities of species presumably are reliable in proportion to the number of species obtained, up to the point where the number of species becomes asymptotic. The pattern is relatively smooth across sites (individual points) among months except for the October points, so that the sampling appears reasonably representative across the study area. According to this reasoning, the sites at which low numbers of samples were obtained: Black Bayou, Big Hill Control and to some extent, Big Hill, are not as reliably represented by their species lists and corresponding densities as West Hackberry and West Hackberry Control.

Turning back to Figure 4.3-7, three calanoid copepod species (Acartia tonsa, A. lilljeborgii, and Paracalanus crassirostris), a cyclopoid copepod species, (Oithona nana) and a tunicate (Oikopleura) dominated the zooplankton community in September except at Big Hill Control. Labidocera species became abundant at Big Hill. These species have been identified as L. aestiva and L. scotti. The single sample at Big Hill Control was dominated by cypris barnacle larvae and the crustacean, Lucifer faxoni. Only five other species were present in the sample. The categories of other adults and larvae were prominant in this first month. Other adults were typically comprised of a large number of species (Table 4.3-15) while the larvae were difficult to characterize since the species of most of the copepod nauplii (Table 4.3-16) could not be distinguished.

The result that phytoplankton steadily increased from October through December suggests that the zooplankters Acartia tonsa, A. lilljeborgii, and Paracalanus crassirostris, which lose most of their prominance during October and directly return to prominance during November and December, were directly dependent upon phytoplankton. These species are known to be phytoplankton feeders, although Acartia has also been reported to use animal food and it has been suggested that it also can use detritus. Oikopleura, a tunicate which was prominant except in.

FIGURE 4.3-7

ZOOPLANKTON ABUNDANCE AND CONTRIBUTION OF MAJOR FORMS BY MONTHS AND SAMPLING LOCATIONS



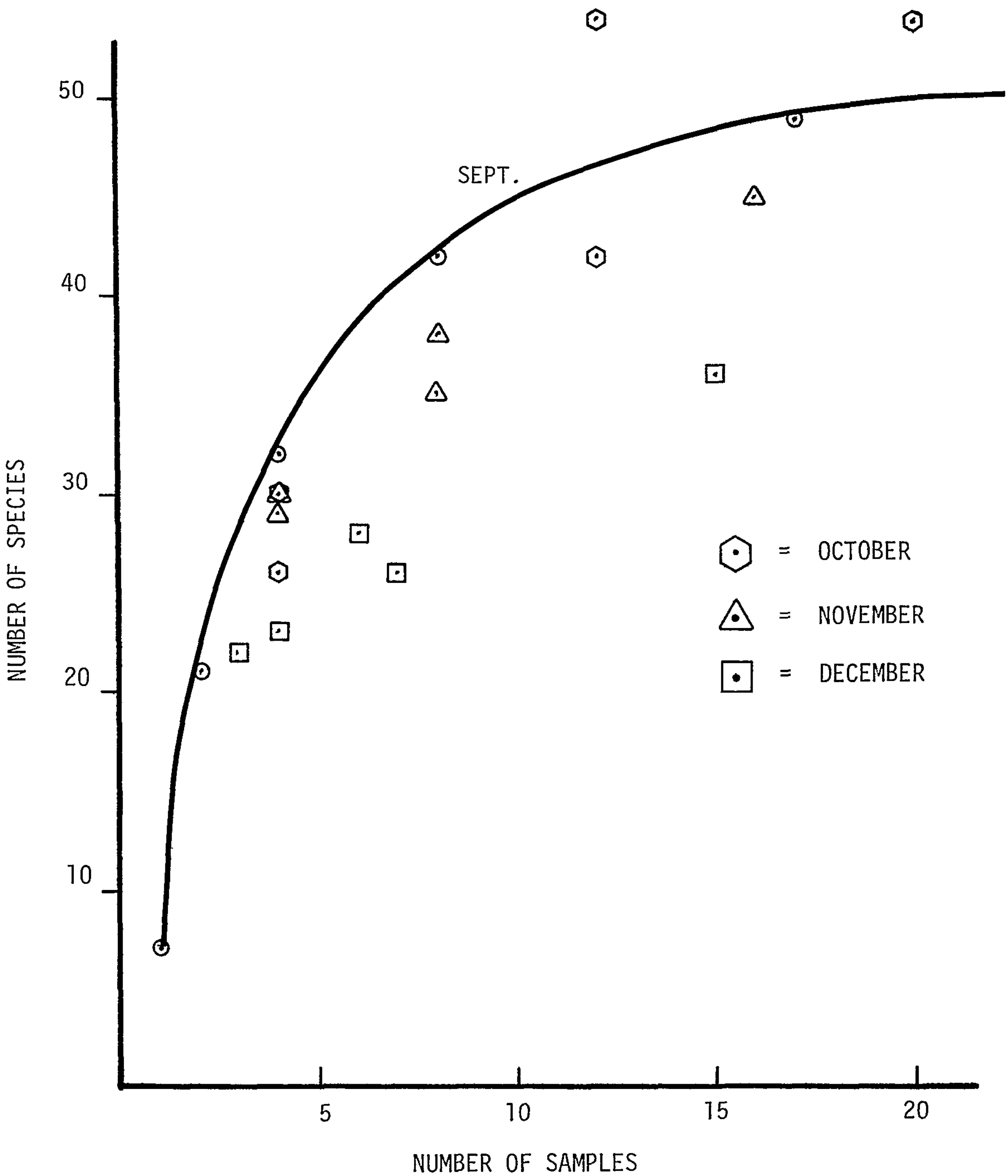


FIGURE 4.3-8

NUMBER OF ZOOPLANKTON GROUPS IDENTIFIED PLOTTED AGAINST NUMBER OF SAMPLES PER SITE BY MONTH.

Table 4.3-15

Total Numbers of Species by Month and Site and Number of Species in "Other Adults", Figure 4.3-5

Month	Site	Number Samples	Number of Species	Number of Species in "Other Adults"
SEPTEMBER	West Hackberry Control	8	42	36
	West Hackberry	17	50	44
	Black Bayou	2	21	15
	Big Hill Control	1	7	4
	Big Hill	4	32	27
OCTOBER	West Hackberry Control	12	54	47
	West Hackberry	20	54	48
	Black Bayou	4	30	23
	Big Hill Control	4	26	20
	Big Hill	12	42	35
NOVEMBER	West Hackberry	8	38	30
	West Hackberry	16	45	36
	Black Bayou	4	29	22
	Big Hill Control	4	30	22
	Big Hill	8	35	28
DECEMBER	West Hackberry Control	7	26	21
	West Hackberry	15	36	32
	Black Bayou	4	23	18
	Big Hill Control	3	22	18
	Big Hill	6	28	22

Table 4.3-16

Major Larval Forms and Their Percentage Abundances by Month and Site

MONTH	SITE	LARVAL GROUP: <u>Labidocera</u> [Calanoid copepod] Nauplii	Other Copepod Nauplii	Stellifer [Star Drum] Larvae	Poly-chaete Larvae	Ophiuroidea [Brittle Star] Larvae	Veneridae [Bivalve] Larvae	Prosobranchia [Gastropod] Larvae	Barnacle Larvae	Membranipora [Calcareous Bryozoan] Larvae	TOTAL
Sept.	West Hackberry Control	2	2	---	---	---	2	---	---	---	6
	West Hackberry	2	3	---	---	---	---	---	---	---	5
	Black Bayou	---	5	---	---	---	2	---	---	---	7
	Big Hill Control	---	---	6	---	---	---	---	37	---	43
	Big Hill	---	---	---	---	---	---	---	---	---	---
Oct.	West Hackberry Control	---	8	---	1+	---	---	---	---	---	9
	West Hackberry	---	17	2	2	---	---	---	---	---	21
	Black Bayou	---	9	---	3	---	---	---	---	---	12
	Big Hill Control	---	24	---	2	---	---	---	---	---	26
	Big Hill	---	11	---	1+	---	---	---	1+	---	13
Nov.	West Hackberry Control	11	2	---	2	---	---	---	---	2	17
	West Hackberry	1+	5	---	---	---	---	1+	4	1+	12
	Black Bayou	1+	18	---	4	---	---	---	---	---	23
	Big Hill Control	---	14	---	12	4	5	---	---	---	35
	Big Hill	3	16	---	---	---	---	---	---	---	19
Dec.	West Hackberry Control	21	---	---	---	---	---	---	2	---	23
	West Hackberry	13	2	---	---	---	---	---	2	---	17
	Black Bayou	5	---	---	---	---	---	---	3	---	3
	Big Hill Control	2	---	---	---	---	---	---	---	---	2
	Big Hill	19	2	---	---	---	---	---	---	---	21

October, is known to feed on small plankton. High numbers of copepods larvae in October and November seem to relate to higher numbers of adult copepods in November and December. Oithona nana, a cyclopoid copepod which is largely prominant through November, and on into December at more westerly stations is a presumative nanoplankton feeder. Labidocera species are thought to be mainly predatory.

Euterpina acutifrons, a harpacticoid copepod; Temora turbinata, Eucalanus pileatus, Centropagas furcatus, calanoid copepods; unidentified calanoid copepod species 1; and Corycaeus amazonicus, a cyclopoid copepod, became prevalent at one or more study sites during October. Centropages and Temora are considered to graze heavily on phytoplankton and also to use animal food. Sagitta, a relatively large predatory form (an arrowworm), although not numerous enough to be singled out from the other adults category, were obtained everywhere except at the West Hackberry study site during October also. Sagitta made up two to four percent of total numbers. Copepod and polychaete larvae were consistently present at all study sites (Table 4.3-16). October was a month of great transition.

During November, species which were dominating during September became relatively numerous again, overshadowing the species which were most important during October. The top species from September (Acartia spp. and Paracalanus crassirostris) continued to increase into December. The total number of species generally hit its lowest ebb during this last month of the study period. No species in the "other adults" category reached 1 percent of the overall mean for any site in December, except for Euterpina acutifrons which reached slightly more than 1 percent at West Hackberry Control.

There was an increase in the variety of larvae during November (Table 4.3-16). Copepod larvae were important during November as during October, and polychaete larvae were above 1 percent at all except Big Hill and West Hackberry. Brittle star and gastropod larvae were relatively abundant at Big Hill Control and bivalve, barnacle, and bryozoan larvae were noted at West Hackberry. Barnacle larvae continued to be important in the eastern sites into December. Copepod larvae were predominantly in one genus (Labidocera) in December.

The extensive estuarine areas adjacent to the study area (coastal) appear to show a certain seasonal correspondence with it. The highest numbers in the inshore estuarine reaches reported in the Cooperative Gulf of Mexico Estuarine Study and Inventory, Louisiana, occur during fall. The dominant form is Acartia, the number of copepod species increases and there is transition in main forms in fall also.

The eastern Gulf of Mexico presents a decline in zooplankton volume during fall and winter, with the decline beginning after September, according to NOAA studies reported by Houde and Chitty (1976). This pattern parallels that for densities observed in the present study.

Acartia is reportedly a generalist feeder able to utilize a wide variety of phytoplankton and other food types--but is wasteful in the process compared to more specialized feeders. Additionally, Acartia has a high food intake requirement (approaching 30 percent of its weight daily) and cannot tolerate starvation conditions for more than a few days (Dagg, 1977). Members of this genus can therefore be expected to reflect changes in food availability. The dilution of food or a decline in it resulting from biological causes are reasonable explanations for the changes observed in Acartia and, since its pattern of abundance and dependence on herbivory are similar, probably Paracalanus also. Miller et al. (1977) notes that Acartia tonsa mortality from predators is very high in the older stages in the life cycle. This seems to be compensated for by shortening of the duration of the later stages in the life cycle. Acartia produces resting eggs as an efficient means to survive unfavorable conditions. Thus, this and similar forms can increase with great rapidity when conditions are good and can leave the pelagic habitat completely when they are bad. Many other species can pass through adverse conditions in a state of arrested growth as late copepodites (preadult larvae). Presumably, the replacing copepod species which became dominant during October in the present study are more likely to possess this capability.

Raymont (1963) noted a tendency for temperate neritic zooplankton to show an extreme summer peak but for production to be spread out in tropical areas. In a Florida coastal area, there was no spring maximum, summer abundance was low, and the peak was in October. Walsh et al. (1978) were able to distinguish distinct zooplankton, phytoplankton, and bacteria communities at different distances from shore over the continental shelf of the New York Bight area. The copepod composition of the nearshore and offshore areas was very different. Nearshore copepods were at highest levels during stratified conditions while the offshore grouping was stimulated by strong mixing during spring. Dagg (1977) suggests that the migratory orientation of copepods to the vertical dimension is more likely to lead to success in locating food concentration than a horizontal orientation would be. It is plausible that some degree of stratification, along with other favorable conditions is related to the high September zooplankton abundance seen in the present study.

Shannon-Weaver diversity (Table 4.3-17) is sensitive to both the number of species in an assemblage and the number of individuals in those species. The general community structure becomes clearer when diversity index values are compared with information in Figure 4.3-9, Table 4.3-10, and Table 4.3-11. Diversity was lowest in December when both overall numbers and the number of species were down. Diversity was next lowest in September when the number of species was fairly high and overall abundance was the highest. The abundance was largely a function of a limited number of species; most of the other species had relatively low numbers. Diversity was high during the October and November period of transition, with an increased number of species present in fairly similar numbers although total abundances were at low ebb. Many larval forms were fairly abundant during November, which compensated for a decline in the overall number of adult species when compared to October.

Table 4.3-17

Average Shannon-Weaver Diversity Index for Zooplankton by Month and Site

Month	Site	Average Diversity ± Standard Deviation
SEPTEMBER	West Hackberry Control	.771 ± .051
	West Hackberry	.751 ± .152
	Black Bayou	-
	Big Hill Control	-
	Big Hill	.821 ± .366
OCTOBER	West Hackberry Control	1.079 ± .090
	West Hackberry	.996 ± .086
	Black Bayou	1.074 ± .117
	Big Hill Control	1.008 ± .120
	Big Hill	1.036 ± .059
NOVEMBER	West Hackberry Control	.959 ± .084
	West Hackberry	.952 ± .067
	Black Bayou	1.095 ± .023
	Big Hill Control	1.074 ± .030
	Big Hill	.947 ± .069
DECEMBER	West Hackberry Control	.668 ± .132
	West Hackberry	.624 ± .124
	Black Bayou	.720 ± .066
	Big Hill Control	.648 ± .172
	Big Hill	.762 ± .123

Analysis of Variance

The cruise and site means, based on retransformed data, are presented in Table4.3-18, along with the 95% confidence limits. Overall, no great variation is seen in site means, with the range from 1138-2232 units/m^3. Temporal differences are apparent, with the overall mean for September being an order of magnitude greater than that for October and December, and with November having the lowest means. Generally, similar trends were seen for each site over time. Three-way analysis of variance of the numerically most important zooplankton groups with months, sites, and depths as factors showed months to be a consistently high significant influence (Table 4.3-19). For the other main effects (site and depth) the trends were relatively weak with only five species or species groups showing significant site differences and in no case was the trend as strong as the weakest trend for monthly differences. In only one group (Acartia spp.) was site significant, with $p < 0.01$, and in this case, site differences could be attributable to the fact that more than one species was in the group. In general, site was not an important factor in zooplankton distribution, as shown for the total data set. Similarly, depth differences were few in number, with only Sagitta, Oithona nana and Eucalanus pileatus showing strong trends. All three had significantly higher means for the bottom samples, with the trend for Eucalanus pileatus not consistent from site to site. Overall, temporal differences dominated the dynamics of the zooplankton community.

Results of multiple means tests for those zooplankton species or species groups showing significant cruise differences with no confounding interaction are presented in Table 4.3-20. As can be seen, the species fall into several groups, with highest means in either September (Veneridae larvae), October (unidentified calanoid, Euterpina acutifrons, Centropages furcatus, Corycaeus amazonicus, and Eucalanus pileatus), or December (Barnacle larvae and Labidocera nauplii). The fact that only one group had highest mean during the same month (September) as did the total community is due to the fact that most species with highest means during September had significant interaction and could not be analyzed by multiple means procedures. These included a number of the major forms, such as Oikopleura, Oithona nana, Acartia spp., Sagitta, and Paracalanus. In a similar vein, other species showing significant temporal effects in the ANOVA's (with interaction) and having highest mean in October included Temora, Polychaete larvae, and copepod nauplii. No major species or species group had highest mean in November.

Correlation Analysis

Significant simple linear correlations within months and within month-site combinations for September and October are summarized in Table 4.3-21. Correlations are considered significant at the 0.05 probability level or lower. It is evident from the table that positive correlations are overwhelming compared to negative correlations. The strengths of significant correlations (not presented) range much higher in the within month and site data sets than in the correlations within months, as is

Table 4.3-18 Mean number of zooplankton individuals with confidence bounds by site and month. (units/m^3)

Site		Month: September	October	November	December	Overall
Black Bayou	L_1[a]	865.02	62.36	273.86	130.65	482.30
	$\bar{Y}$	11537.59(2)[b]	968.89(4)	458.05(4)	1462.56(4)	1253.83(14)
	L_2	15388.70	14846.80	765.65	16269.70	3256.99
Big Hill	L_1	209.48	379.94	203.52	910.87	662.17
	$\bar{Y}$	4573.81(4)	806.27(12)	591.99(8)	2141.61(6)	1137.97(30)
	L_2	99867.31	1709.73	1547.21	5033.48	1955.15
Big Hill Control	L_1		181.74	99.95	7.66	445.21
	$\bar{Y}$	1810.99(1)	2646.43(4)	790.25(4)	1051.81(3)	1360.84(12)
	L_2		38353.40	6200.93	127984.70	4155.38
West Hackberry Control	L_1	13654.90	612.73	190.19	212.60	1016.36
	$\bar{Y}$	20670.19(8)	1419.35(12)	491.99(8)	950.76(7)	1898.57(35)
	L_2	31289.62	3286.15	1265.11	4239.96	3538.34
West Hackberry	L_1	18077.47	560.03	253.00	872.27	1413.31
	$\bar{Y}$	23171.20(17)	1044.65(20)	510.49(16)	2084.68(15)	2231.81(68)
	L_2	29700.22	1947.91	1029.01	4980.30	3526.50
Overall	L_1	11063.19	769.22	368.11	950.27	
	$\bar{Y}$	16252.32(32)	1127.94(52)	539.20(40)	1621.10(35)	
	L_2	23875.16	1653.73	789.59	2765.01	

[a] L_1 and L_2 equal the lower and upper confidence bounds respectively (after Sokal and Rohlf, 1969).
$\bar{Y}$ Mean number of individuals.

[b] Number of samples.

TABLE: 4.3-19. Three-way Analysis Of Variance Interpretation: The Probabilities Of Variation Attributable To The Factors Months, Sites, Depths And Their Interactions Occurring By Chance Are Presented With Respect To 16 Important Zooplankton Groups And The Totals Of All Zooplankton Species.[1]

	MONTHS	SITES	DEPTHS	M X S	M X D	S X D	M X S X D
Unidentified Calanoid Copepod #1	.0001**	.52	.08	.82	.42	.43	.42
Barnacle Larvae	.0001**	.22	.38	.71	.75	.88	.78
Acartia spp. (*tonsa* and *lilljeborgii*)	.0001**	.0052**	.61	.01**	.08	.27	.30
Paracalanus crassirostris[2]	.0001**	.03*	.30	.001**	.004**	.71	.37
	.0001**	.03*	.33	.03*	.67	.10	.08
Centropages furcatus	.0001**	.02*	.04*	.48	.56	.007**	.15
Copepod Nauplii (except *Labidocera*)	.0001**	.92	.33	.13	.007**	.37	.92
Corycaeus amazonicus	.0001**	.08	.32	.05[b]	.89	.44	.52
Euterpina acutifrons	.0001**	.40	.01**	.33	.55	.50	.43
Eucalanus pileatus	.0001**	.21	.002**	.17	.30	.03*	.03*
Labidocera Nauplii	.0001**	.29	.59	.06	.33	.23	.81
Oikopleura	.0001**	.58	.36	.03*	.14	.17	.51
Oithona nana	.0001**	.70	.005**	.0001**	.25	.06	.91
Polychaete Larvae	.0001**	.30	.80	.051[b]	.02*	.02*	.26
Sagitta	.0001**	.08	.0001**	.14	.58	.15	.32
Temora turbinata	.0001**	.03*	.18	.03*	.46	.65	.31
Veneridae (Bivalve) Larvae	.0004**	.44	.93	.11	.41	.03*	.20
Totals	.0001**	.77	.09	.39	.29	.009**	.30

[1]The Analysis Of Variance Was Carried Out On Log-transformed Data.

[2]The Second Of The Two Lines Of Values Which Are Presented Corresponds To An Earlier Misidentification Of A Small Part Of This Species During September.

*Significantly Low Probability Of Factor-Associated Variation Resulting From Chance Events.

**Highly Significantly Low Probability Of Factor-associated Variation Resulting From Chance Events.

[b]Borderline Of Significance (.05 Level).

Table 4.3-20. Results of Multiple Means Tests for Zooplankton by Cruise

Taxonomic Group	Cruise Means Highest			Lowest
Total	September	December	October	November
Veneridae larvae	September	November	October	December
Unidentified calanoid copepod	October	September	November	December
Euterpina acutifrons	October	September	November	December
Centrophages furcatus	October	November	September	December
Corycaeus amazonicus	October	November	December	September
Eucalanus pileatus	October	November	September	December
Barnacle larvae	December	November	September	October
Labidocera nauplii	December	September	November	October

Tukey's $t_{0.05} = 2.57$

Zooplankton Groups

Zooplankton Groups	Month	Barnacle Larvae	S	O	Acartia spp. (tonsa and lilljeborgii)	S	O	Paracalanus crassirostris	S	O	Centropages furcatus	S	O	Copepod Nauplii (except Labidocera)	S	O
Unidentified Calanoid Copepod #1	S		1				[1]			[1]						
	O	-			-		[2]	-		[2]	+			+		
	N						[3]			[3]			3			3
	D						[5]			[5]			5			
Barnacle Larvae	S						1			1						
	O				+		2	+		2						
	N				+			+						+		
	D				+		5	+								
Acartia spp. (tonsa and lilljeborgii)	S							+		1						
	O							+		2						
	N							+		4			[3]	+		[3]
	D							+		5				+		
Paracalanus crassirostris	S															
	O															
	N															[3]
	D													+		
Centropages furcatus	S															1
	O													+		2
	N													+		3
	D															5

Zooplankton Groups	Month	Corycaeus amazonicus	S	O	Euterpina acutifrons	S	O	Eucalanus pileatus	S	O	Labidocera Nauplii	S	O	Oikopleura	S	O
Unidentified Calanoid Copepod #1	S									1						
	O	+						+			+					
	N															
	D			5			5			5						
Barnacle Larvae	S	+														
	O		2											+		
	N				+						+		3	+		
	D															5
Acartia spp. (tonsa and lilljeborgii)	S															
	O															
	N	+		[3]			[3]			[3]	+			+		
	D				+		5				+			+		
Paracalanus crassirostris	S						2						[2]			[2]
	O															
	N	+		[3]	+		[3]				+			+		[3]
	D				+		5							+		
Centropages furcatus	S		1	1			1									
	O	+		2	+		2	+		2				+		2
	N	+		3	+		3	+		3	+			+		
	D						4			4, 5						4, 5
Copepod Nauplii (except Labidocera)	S			1	+		1			1						
	O	+		2	+		2	+		2				+		2
	N	+		3	+		3	+		3	+			+		
	D	+		5						5				+		5
Corycaeus amazonicus	S						1			1						
	O				+		2	+		2				+		2
	N				+		3	+			+			+		
	D						5			5						5
Euterpina acutifrons	S									1				+		
	O							+		2				+	2	2
	N							+						+		3
	D									4				+		
Eucalanus pileatus	S															
	O													+		2
	N															
	D															5
Labidocera Nauplii	S															
	O															
	N													+		
	D															

Zooplankton Groups	Month	Oithona nana	S	O	Polychaete Larvae	S	O	Sagitta	S	O	Temora turbinata	S	O	Veneridae (Bivalve) Larvae	S	O
Unidentified Calanoid Copepod #1	S															
	O	+			+	2		+			+				2	
	N			3			3			3			3			
	D			5			4, 5			4			4, 5			
Barnacle Larvae	S															
	O	+												+		
	N	+														
	D	+									+		5			5
Acartia spp. (tonsa and lilljeborgii)	S	+														
	O															
	N	+			+			+					[3]	+		
	D	+						+		5	+					5
Paracalanus crassirostris	S	+							1					+	1	
	O															2
	N	+		[3]				+		[3]			[3]			
	D	+						+			+					5
Centropages furcatus	S			1						1			1			
	O	+		2	+		2	+		2	+		2	+		2
	N	+		3	+			+			+		3	+		
	D			5						5						
Copepod Nauplii (except Labidocera)	S	+		1			1		1				1	+		
	O	+	2	2	+		2	+		2			2	+		2
	N	+		3	+		3	+		3	+		3	+		
	D	+		5			5	+		5			5			
Corycaeus amazonicus	S			1			1			1			1			
	O	+		2	+		2	+		2	+		2	+		2
	N	+		3, 4	+		3, 4	+		3	+		3, 4	+		
	D			5			5			4			5			
Euterpina acutifrons	S			1			1			1			1			
	O	+		2	+		2	+		2	+		2	+		2
	N	+		3	+			+		3	+		3	+		
	D	+		4	+	5	4	+					5	+		
Eucalanus pileatus	S						1		1	1			1			
	O	+		2	+		2	+		2	+			+		2
	N	+		4	+		4	+		4	+			+		
	D			5									5			
Labidocera Nauplii	S													+		
	O															
	N	+			+			+						+		
	D															
Oikopleura	S															1
	O	+		2	+		2	+		2	+		2			2
	N	+			+			+		3	+		3	+		
	D			5			5	+			+					
Oithona nana	S									1			1	+		
	O						2	+		2	+		2	+		2
	N				+		3	+			+		3	+		
	D						4, 5	+		4, 5	+		4, 5			
Polychaete Larvae	S							-		1			1	+		
	O							+		2	+		2	+	2	2
	N							+		3	+			+		
	D									4			4, 5			
Sagitta	S												1			
	O										+		2	+		2
	N										+		3	+		
	D												4			
Temora turbinata	S															
	O													+	2	2
	N													+		
	D															

SYMBOLS

+ = Significant Positive Correlation
- = Significant Negative Correlation
1 = West Hackberry Control
2 = West Hackberry
3 = Black Bayou
4 = Big Hill Control
5 = Big Hill
□ = Significant Negative Correlation

Table 4.3.21

Matrix Showing Distribution of Significant Simple Correlations for Selected Zooplankton Groups by Month (Columns With + or -) and by Site Within the Months September and October (Shaded Columns With Numbers) to be expected.

September and October were selected for more detailed analysis (within month and site correlations) because the greatest change in numbers and species composition occurred between these months.

Main trends in Table 4.3-21 are presented below by species. In general, the number of signficant correlations is lowest in September, highest in October in November, and next to lowest in December. Relatively few significant correlations at given sites are evident for September compared to October. This pattern conforms to that for diversity in a general way.

Unidentified calanoid copepod number 1 shows a number significant positive correlations by months in October and was significantly negatively correlated with Acartia spp and Paracalanus crassirostris during the same month. October is the only month when this form is important. Signficant negative correlations in October are present across sites whereas significant positive correlations occur at western sites.

Barnacle larvae show significant positive correlations by months but no significant negative ones. The significant correlations occur in October and subsequent months for the most part. Barnacle larvae are especially correlated during October to the main herbivores Acartia spp., Paracalanus crassirostris, and Oikopleura and to venerid (bivalve) larvae.

Acartia species are significant linked to Paracalanus crassirostris on each month and are significantly postively correlated with this species in October at all sites but Black Bayou. Acartia species are also negatively correlated with unidentified calanoid copepod number 1 in October and with several other copopod species and nauplii at Black Bayou during October--although not negatively correlated during October with these forms over all sites. All monthly significant correlations without consideration of site were positive except for the one case noted above. Most monthly signnificant correlations with Acartia species occur in November and December.

Paracalanus crassirostris shows a pattern generally similar to that of Acartia species. Both Paracalanus and Acartia are significantly postively correlated with Oithona nana during September, November, and December. Paracalanus is significantly negatively correlated with copepod larvae and Oikopleura at West Hackberry during October.

Centropages furcatus shows monthly significant positive correlations during October and November and a significant negative correlation with Poracalanus crassirastris during October at one site, Black Bayou. As with most other species, a number of month-site signficant positive correlations were spread among sites.

Copepod nauplii except those of Labidocera show signficant positive correlations with a number of species. However, there are significant negative correlations with Acartia species and Paracalanus crassirostris during October. Significant positive month-site correlations are scattered across the sites and, typically, associated mainly with October.

Corycaeus amazonicus shows significant positive correlations with a number of species over October, November, and December--especially Oithona nana. During October, significant positive correlations of this species are scattered among sites and significant negative correlations with Acartia species and Paracalanus crassirostris are present at Black Bayou.

Euterpina acutifrons behaves similarly to Corycaeus amazonicus. It is also especially strongly linked to Oithona nana and significantly negative correlated with Acartia and Paracalanus at Black Bayou during October.

Eucalanus pileatus shows a number of significant monthly positive correlations in October and November and a significant negative October correlation at Black Bayou.

Labidocera nauplii are significantly positively correlated with nearly all other species in November and did not show significant month-site correlations.

Oikopleura shows numberous signficant postiive correlations for the months of October and November. It is significantly postively correlated with Euterpina acutifrons during each month of the study. It is significantly positively correlated with Corycaeus amazonicus, Euterpina acutifrons, Sagitta, and Temora turbinata during October, November, and December. Significant correlations within sites during October were common but do consistently occur at specific sites. All but one of these correlations are positive--Oikopleura is significantly negatively correlated with Paracalanus crassirostris at Black Bayou during October and at West Hackberry during September.

Oithona nana shows significant positive correlations at individual sites in October and a significant negative correlation with Paracalanus crassirostris at Black Bayou. Within month significant positive correlations were most prominant during November, followed by October. However, barnacle larvae, Acartia species, Paracalanus, Sagitta, and Temora turbinate were significantly positively correlated with Oithona in December; copepod nauplii were significantly positively correlated during all four study months; and Acartia spp. Paracalanus and venerid larvae were significantly postively correlated in September.

Polychaete larvae show many significant within month positive correlations and one negative one. These correlations generally involve October. The negative correlation is with Sagitta in September, however. A number of positive correlations were also significant in November. There are many within site significant correlations in October, but there is no particularly consistent link to given sites.

Sagitta shows numerous significant within months positive correlations

TABLE 4.3-22

INVENTORY OF SIGNIFICANT SIMPLE CORRELATIONS BY SITES FOR ZOOPLANKTERS WITH SIGNIFICANT VARIATION ATTRIBUTABLE TO SITES[1]

Site	ZOOPLANKTER NAME	Unidentified Calanoid Copepod #1	Barnacle Larvae	Acartia spp. (tonsa and lilljeborgii)	Paracalanus crassirostris	Centropages furcatus	Copepod Nauplii (except Labidocera)	Corycacus amazonicus	Euterpina acutifrons	Eucalanus pileatus	Labidocera Nauplii	Oikopleura	Oithona nana	Polychaete Larvae	Sagitta	Temora turbinata	Veneridae (Bivalve) Larvae
West Hackberry Control	Acartia spp. (tonsa and lilljeborgii)		-		+	-		-		-	+	+	+	-			
	Paracalanus crassirostris	-		+						-		+	+	-	+		
	Centropages furcatus			-			+	+	+	+	-			+	+	+	-
	Temora turbinata					+	+	+	+	+	-			+	+		+
West Hackberry	Acartia spp. (tonsa and lilljeborgii)	-	+		+	-				-	+	+	+				+
	Paracalanus crassirostris	-		+					+	-	+	+	+				+
	Centropages furcatus	+		-			+	+	+	+			+	+	+	+	+
	Temora turbinata	+				+	+		+	+	-	+	+	+	+		+
Black Bayou	Acartia spp. (tonsa and lilljeborgii)		+		+	-		-		-		+		-			
	Paracalanus crassirostris			+		-		-		-		+	+	-			
	Centropages furcatus	+		-	-					+				+		+	
	Temora turbinata	+				+		+		+				+			
Big Hill Control	Acartia spp. (tonsa and lilljeborgii)	-	+		+						+						
	Paracalanus crassirostris	-	+	+							+						
	Centropages furcatus	+						+	+	+		+		+	+	+	
	Temora turbinata		-			+	+	+	+	+			+	+			+
Big Hill	Acartia spp. (tonsa and lilljeborgii)	-	+		+				-		+	+	+		+		
	Paracalanus crassirostris	-	+	+								+	+				
	Centropages furcatus	+					+	+	+	+				+		+	+
	Temora turbinata	+			-	+	+	+	+	+	-			+			

[1]The Species Which are Repeated by Site at the Left Hand Side of the Table Showed Significant Site Effects in Table 4.3-8b.

+ = Significant Positive Correlation
- = Significant Negative Correlation

in October, November, and December and a significant negative correlation in September with polychaete larvae, as pointed out above. Significant month-site correlations are numerous during October, are all positive, and are not consistently linked to given sites.

Temora turbinata is significantly positively correlated during one or more of the last three months with every entry in Table 4.3-21 except Labidocera nauplii. The concentration is in October and November, but Temora is significantly positively correlated with Ocirofleura and Oithona nana into December. Numerous month-site correlations are significant in October. Only two of these are negative.

Venerid larvae are significantly positively correlated with other species during various of the first three months of the study: September, October, and November. Within month and site significant correlations in October are not as common as with the majority of forms. They are all positive and are predominantly linked to West Hackberry.

Significant correlations by sites and irrespective of other factors are presented in Table 4.3-22 for the species which show significant site variation (Acartia, Paracalanus, Centropages, and Temora) in Table 4.3-19.

If just significant positive correlations are followed and the sites from which the fewest samples are involved, Black Bayou and Big Hill Control, are discounted, there is a general similarity across sites except for Sagitta, venerid larvae, Oithona, and perhaps Euterpina and Oikopleura. Significant negative correlations are somewhat more prevalent at the eastern sites. Except for the above forms, species can be grouped in relation to correlations with Acartia and Paracalanus or Centropages and Temora. It appears that at least 11 main species respond to the conditions which influence the two alternatives of Acartia/Paracalanus or Centropages/Temora. These data suggest that there is a tendency to two alternative compositions of zooplankton community dominants in which the numbers of certain few species are occasionally disproportionally high or low at certain sites.

Ordination Analysis

A reciprocal averaging ordination was performed for the zooplankton community. Species occurring five or fewer times were dropped from the data set. Figures 4.3-9 to 4.3-11 show the distribution of data along the 1st and 2nd axes of sample and species space. Figure 4.3-9 depicts the distribution in sample space with collection site distinguished. No site specific trend is apparent. Figure 4.3-10 also shows the distribution in sample space but with date of collection distinguished. Evidence of seasonal changes is clear, with the October and November samples pulling out to the left and September and December pulling out to the right. Considerable overlap is present in between--especially between November and September. This suggests a cyclical change in community composition. The September community is replaced by another community in October, with a return to the original community in November, and a shift to yet a third community in December.

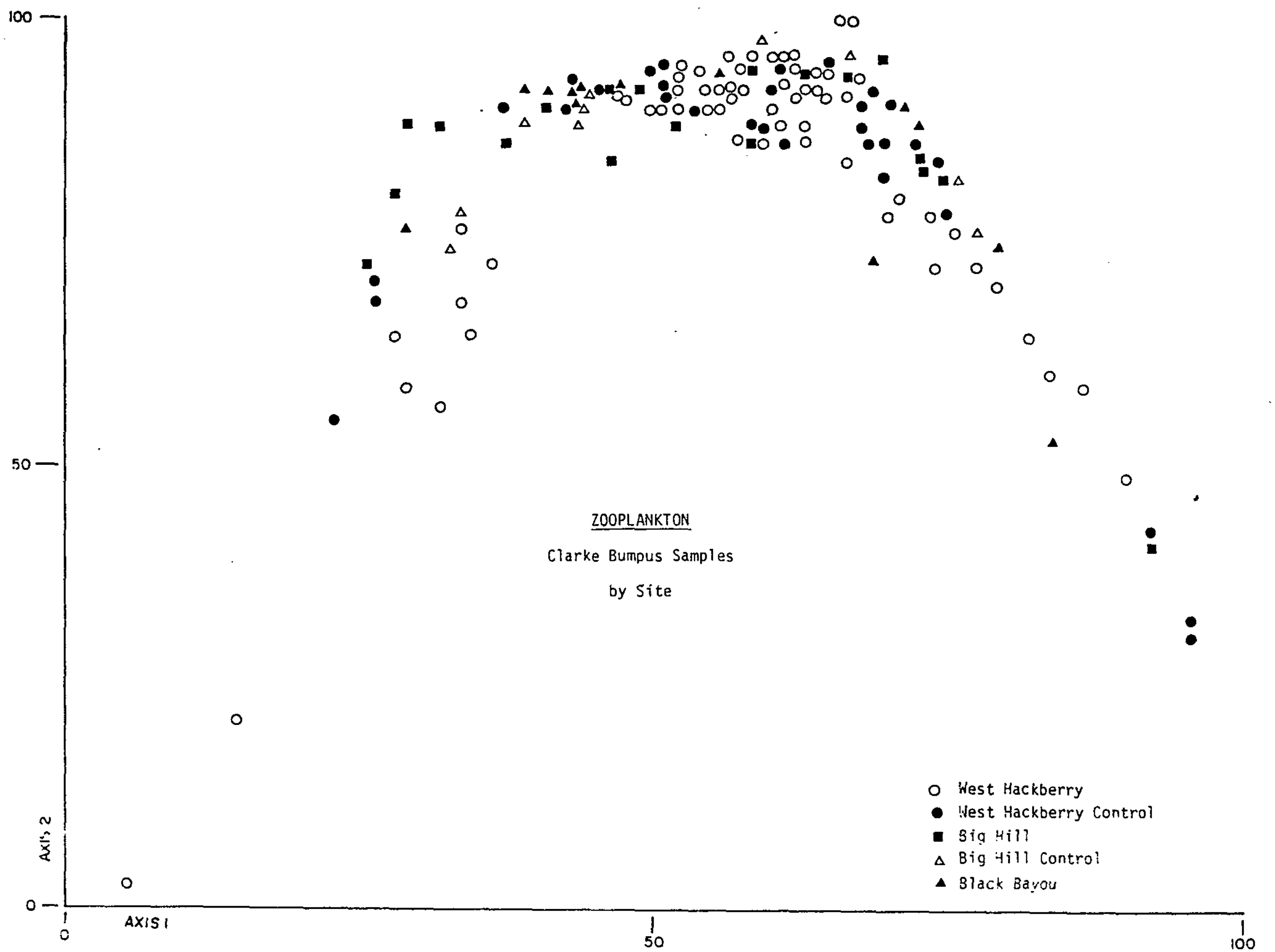


Figure 4.3-9 Reciprocal Averaging Ordination For Zooplankton, Shown in Sample Space, Sample Sites Indicated

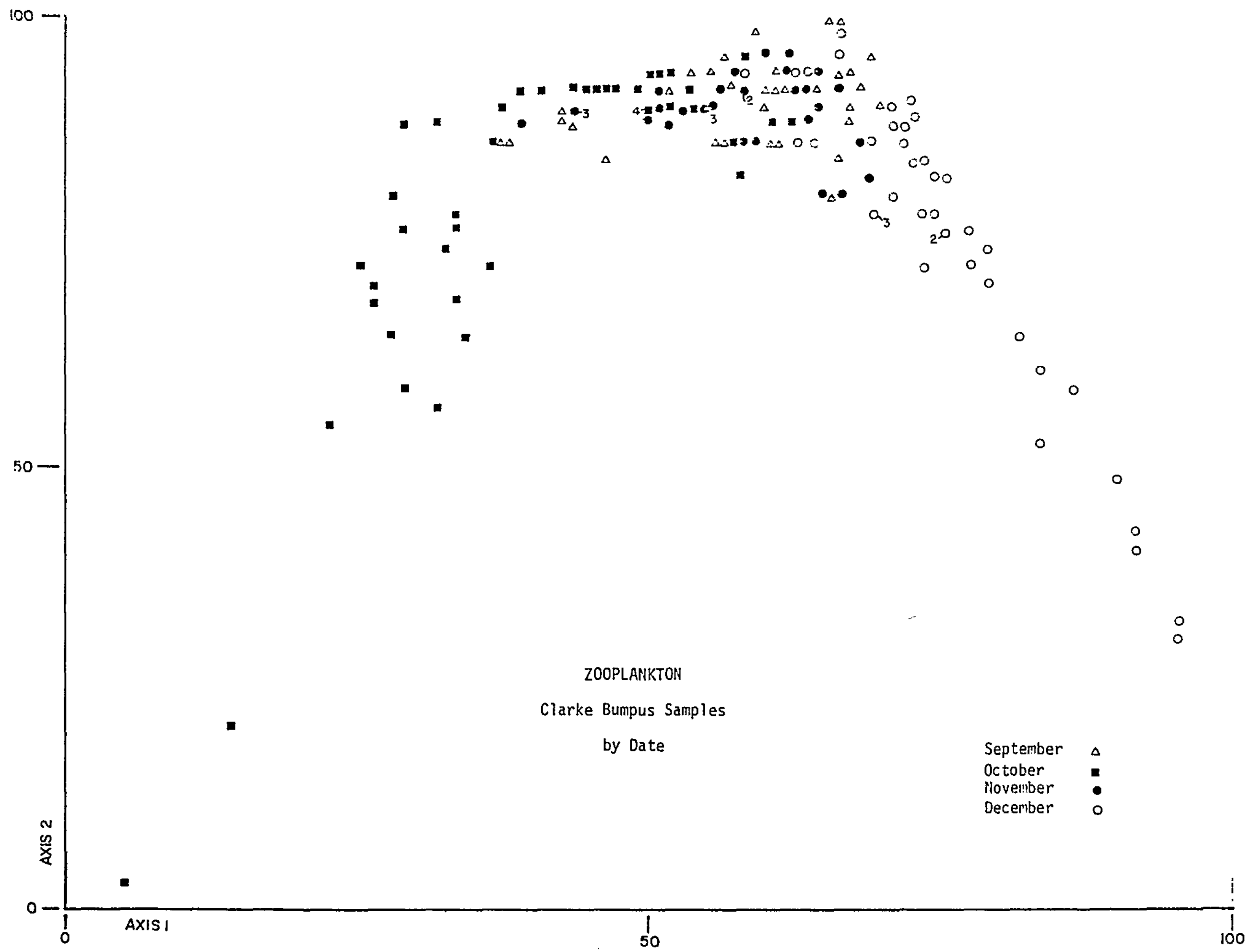


Figure 4.3-10 Reciprocal Averaging Ordination For Zooplankton, Shown in Sample Space, Sample Dates Indicated. Numbers Indicate Superimposed Samples.

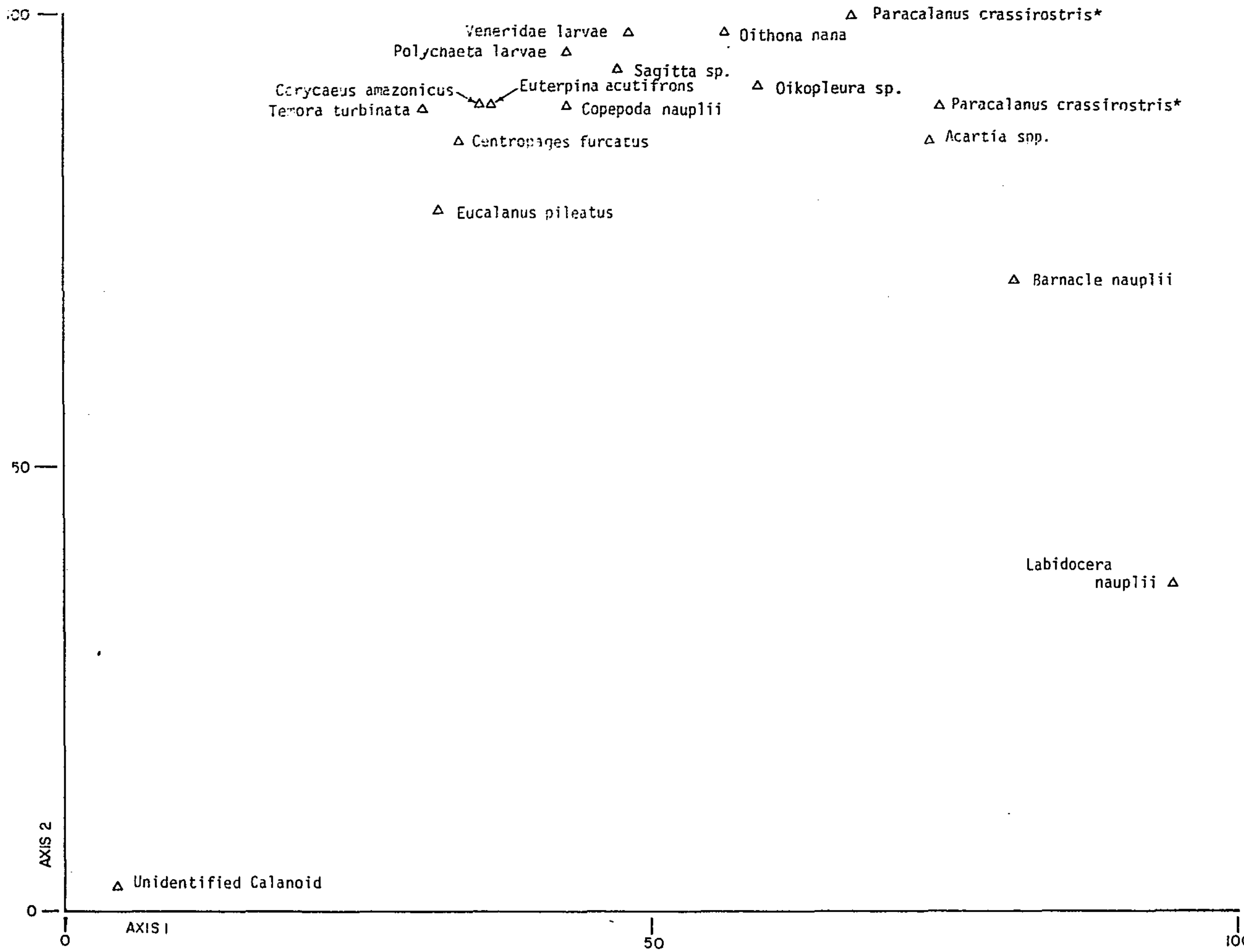


Figure 4.3-11 Reciprocal Averaging Ordination For Zooplankton, Shown in Species Space
*The Two Entries For P. crassirostris Reflect the Correction of an Earlier Misinterpretation, in Which This Species Was Listed as Two Separate Taxa.

Figure 4.3-11 displays the affinities of the main species of zooplankton. Groups which vary similarly, such as Oithona and Oikopleura, Paracalanus and Acartia spp, and Temora and Centropages, are close together on the graph. The divergent calanoid number 1 is widely separated from other species on the graph by contrast.

Summary

The various analyses performed (ANOVA, correlation, and ordination) all point to the same variable, time, as the main factor associated with changes in community composition. As discussed in the ANOVA section, the multiple means tests and ranks of means distinguish three main groups. The first, with highest means in September, include Veneridae larvae, Oikopleura, Oithona nana, Acartia spp., Sagitta, and Paracalanus. This September group was also characterized by relatively high values in November (see Table , Veneridae larvae). The October group, including unidentified calanoid number 1, Euterpina acutifrons, Centrophages furcatus, Corycaeus amazonicus, and Eucalanus pileatus, along with Temora, Polychaete larvae, and copepod nauplii. The December group was not as diverse, with barnacle larvae and Labidocera nauplii as principle members. The correlation analyses indicated that most significant correlations involved members within each group, with inter-group correlations relatively rare. The ordination analyses, in addition to confirming the ANOVA results of no significant site differences and significant cruise differences (with September and November similar) also showed, in the species display, that species that occurred together temporally formed groups on the display. Since the study was conducted during a period of environmental transition (summer to winter), such a temporal pattern could be expected.

4.3.3 Benthos

4.3.3.1 General Characterization

A total of 126 megafaunal taxa were taken from the benthic grab samples (Table 4.3-23). Of these, 113 taxa were enumerated; the remainder included organisms such as hydrozoans where the number of individuals is meaningless and/or difficult to ascertain, or taxa which could not be readily distinguished for enumeration purposes and were lumped together. Overall there were 6 coelenterates, 10 Aschelminthes, 1 siponculid, 42 polychaetes, 3 oligochaetes, 16 gastropods, 15 peleycepods, 1 cephalopod, 24 crustacea, 6 echinoderms, and 2 vertebrates (Table 4.3-23). In terms of both numbers of species (41), and numbers of individuals (69% of the total) the polychaetes were the dominant benthic taxa. Community dominance by polychaetes appears to be characteristic of coastal bottom communities in the northern Gulf of Mexico (Ragan 1975, NOAA 1977, TAMU 1978, FEA 1978). In other studies of the coastal Gulf Coast pericarideans (isopods, amphipods, etc) have also been found and

Table 4.3-23

List of Megafaunal Taxa taken in 1/25 m^2
Van Veen Grabs and Retained on 1.00 mm screens

COELENTERATES

Bunodactis texaensis
Bunodosoma cavernata
Calliactis tricolor
Paranthus rapiformis
Strobila stage of jellyfish
Hydrozoan

LOWER INVERTEBRATE GROUPS

Aschelminthes

Carinoma tremaphoros
Cerebratulus sp.
Dolichardorus heterocephalus
Nematoda
Nematomorpha
Nemertea
Paleonemertea cf.
Phascolion strombi
Polycladia
Turbellaria

Miscellaneous

Sipunculidea

ANNELIDS

Polychaeta

Aglaophamus verrilli
Ancistrosyllis sp.
Aricidea jeffreysi
Chaetopterus variopedatus
Cistenides gouldi
Clymenella torquata
Cossura delta
Dinophylidae
Diopatra cuprea
Drilonereis longa
Eteone heteropoda
Eunicidae
Glycera sp.
Glycera americana
Glycera dibranchiata
Goniada maculata
Harmothe aculeata
Lepidonotus squamatus
Lumbrineris sp.
Lumbrineris tenuis
Magelona sp.
Maldane sarsi
Neanthes succinea
Onuphis sp.
Owenia fusiformis
Paraprionospio pinnata
Phylochaetopterus sp.
Pilargidae
Pilargis pacifica
Serpulidae
Streblospio benedicti
Sigambra tentaculata
sp. #1
sp. #2
sp. #3
sp. #4
sp. #5
sp. #6
sp. #7
sp. #15
sp. #31

MOLLUSKS

Gastropoda

Anachis obesa
Cantharus cancellarius
Circulus trilix
Cyclostremiscus jeannae
Epitonium angulatum
Eulima bifasciata
Litiopa melanostoma
Melanella bilineata
Nassarius actus
Polinices hepaticus
Sinum perspectivum
Tectonatica pusilla
Terebra protexta
Turbonilla interrupta
Volvuella oxytata
Tectibranchia

Table 4.3-23, Continued

Pelecypoda
- *Abra aequalis*
- *Anadara ovalis*
- *Anadara transversa*
- *Atrina serrata*
- *Callocardia texasiana*
- *Chione intepurpurea*
- *Corbula contracta*
- *Ensis minor*
- *Macoma brevifrons*
- *Mulinia lateralis*
- *Mysella planulata*
- *Nuculana acuta*
- *Nuculana concentrica*
- *Pandora trilineata*
- *Tellina versicolor*

Cephalopoda
- *Lolliguncula brevis*

ARTHROPODS

Crustacea
- *Acetes americanus*
- *Ampelisca* sp.
- Amphipoda
- *Balanus nivius*
- *Callianassa*, sp.
- *Callianassa atlantica*
- *Callianassa rathbunae*
- Copepoda
- Corophiidae
- *Corophium* sp.
- *Euceramus praelongus*
- Gammaridae
- *Lysiosquilla empusa*
- *Neopanope texana sayi*
- *Pagurus pollicaris*
- *Panopeus herbstii*
- *Persephona punctata aquilonaris*
- *Pinnixa chaetopterana*
- *Pinnixa cristata*
- *Pinnixa sayana*
- Pinnotheridae
- *Porcellana sayana*
- *Portunus gibbessi*
- *Polyonyx* sp.
- Spionidae cf.

ECHINODERMS

Asteroidea

Ophiuroidea
- *Amphipholis squamata*
- *Hemipholis elongata*
- *Micropholis atra*

Holothuroidea
- *Thyone briareus*
- *Thyonella gemmata*

VERTEBRATES

- Fish Larvae
- *Stellifer lancaeolatus*

characteristic organisms; their nearly complete absence at the Texoma sites is therefore remarkable.

Just 12 taxa (Table 4.3-24) comprised 83% of the 3,848 individuals taken in the study. The remaining taxa were found infrequently (less than 10% of the grabs, Figure 4.3-12) and in low numbers (typically one or two individuals). Functionally, community metabolism was based on deposit feeding. Of the dominant taxa almost 90% were deposit feeders (Table 4.3-25).

With certain exceptions as discussed below, the benthic community was dominated by Magelona sp., a deposit feeding polychaete. Other important taxa included Lumbrineris spp., Mulinia lateralis, Diopatra cuprea, Micropholis atra, and Clymenella torquata. These taxa were generally no more than half as abundant as Magelona and are probably best considered as sub-dominants. While of consistent high importance in the community the rank order of the sub-dominants varied irregularly from cruise to cruise and site to site. This probably reflects a sampling "noise" problem, rather than a real world pattern.

The average density of individuals of all taxa was $291/m^2$. This is lower than densities reported elsewhere in the northern Gulf of Mexico under comparable conditions. Population densities of from 5000 to 7000 individuals/m^2 were reported for the Buccaneer Platform site off Galveston (NOAA 1977). Average density for the September-December period at the Bryan Mound inshore brine diffuser site (TAMU 1978) was 2105 individuals/m^2. Ragan (1975) reported a mean density of $860/m^2$ in a Louisiana coastal study. Mean monthly densities at the Weeks Island and Chacahoula brine disposal sites (DOE 1978) ranged from $530/m^2$ to $700/m^2$.

4.3.3.2 Spatial and Temporal Variations

Overall population density varied with both site and month of collection (Table 4.3-26). These variations were significant (ANOVA P = .0001) without significant interaction (P = .63). Seasonally the population density fell from September to October, and rose from October to December. This is comparable to the pattern reported elsewhere in northwestern Gulf Coast waters (e.g., TAMU 1978). This may be a climatic phenomenon.

The Big Hill site was marked by very low densities of organisms, relative to the other sites. This appears to be correlated with sediment grain size. Fine grained coastal sediments have been associated with depressed population densities elsewhere along the northwestern Gulf Coast (TAMU 1978); the sediments at Big Hill are predominantly silty clays, in contrast to the sandier sediments at the other four sites.

Analysis of Variance

Results of the 2-way ANOVA's for benthos numbers for the various important groups are shown in Table 4.3-27. Significant temporal and spatial variations are evident, with the differences in total number of

TABLE 4.3-24. Benthic dominants.

Species	Number of Individuals	Percent Composition	Feeding Type *	Taxonomic Affinity **
Magelona sp.	1,056	27.44	Df	Poly
Lumbrineris sp.	376	9.77	Df	Poly
Mulina lateralis	353	9.17	Df	Pele
Diopatra cuprea	324	8.42	Df	Poly
Clymenella torquata	237	6.16	Su	Poly
Micropholis atra	154	4.00	Df	Echi
Nuculana concentrica	147	3.82	Df	Pele
Neanthes succinea	133	3.45	Pr	Poly
Ancistrosyllis sp	109	2.83	Df	Poly
Lumbrineris tennis	102	2.65	Df	Poly
Cossura delta	87	2.26	Df	Poly
Owenia fusiformis	66	1.72	Df	Poly
Acetes americanus	54	1.40	Una	Crt
Total Dominants	3,198	83.10		
All Others	650	16.89		
Grand Total	3,848	99.99		

*Df Deposit feeder
Su Suspension feeder
Pr Predator
Una Unassigned

**Poly Polychaete
Pele Pelecypod
Echi Echinoderm
Crt Crustacean

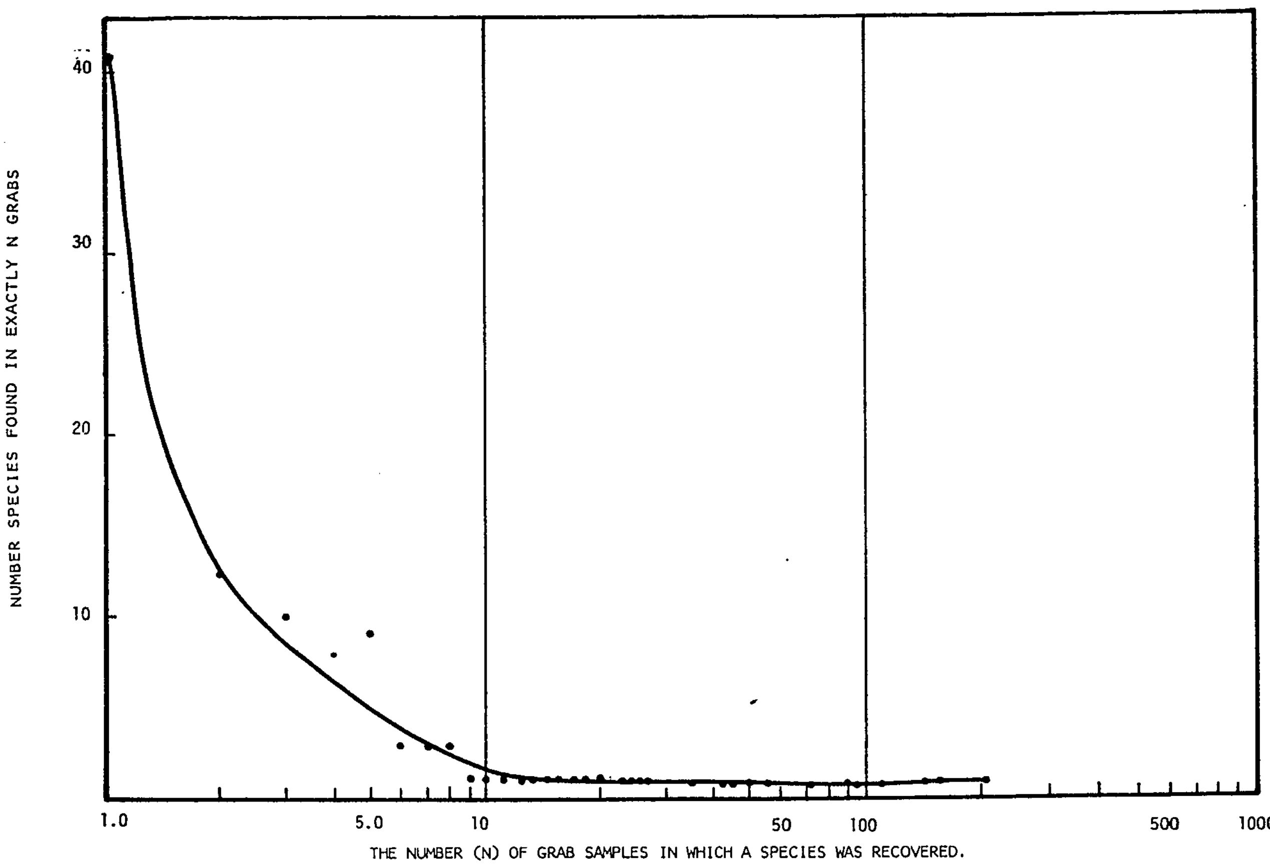


FIGURE 4.3-12 FREQUENCY OF SPECIES OCCURRENCE IN GRAB SAMPLES.

THE NUMBER OF MEGAFAUNAL SPECIES WHICH WERE RECOVERED IN EXACTLY N GRABS SAMPLES. THE MAJORITY (42) OF SPECIES WERE FOUND ONLY ONCE.

Table 4.3-25

Feeding Patterns of Dominant Species of Benthic Megafauna

Feeding Pattern	Number Dominant Species	Number Individuals	% Total Dominants
Deposit feeders	10	2,774	86.7
Suspension feeders	1	237	7.4
Predators	1	133	4.2
Unassigned	1	54	1.7

Table 4.3-26. Mean number of individuals with confidence limits, per 1/25 m^2 grab sample[a] by site and month.

Site		Month: September	October	November	December	Overall
Black Bayou	L_1[b]	1.64	3.60	10.51	13.23	6.53
	$\bar{Y}$	3.84 (5)[c]	7.80 (5)	11.82 (5)	19.02 (5)	9.22 (20)
	L_2	7.86	15.85	13.27	27.15	12.89
Big Hill	L_1	1.42	1.48	3.48	2.87	2.88
	$\bar{Y}$	2.97 (9)	2.60 (9)	5.96 (7)	5.24 (7)	3.82 (32)
	L_2	5.52	4.22	9.83	9.06	4.98
Big Hill Control	L_1	4.10	1.51	7.68	13.56	7.30
	$\bar{Y}$	6.36 (5)	7.56 (5)	13.05 (5)	18.14 (5)	10.41 (20)
	L_2	9.60	28.25	21.75	24.16	14.68
West Hackberry Control	L_1	7.54	4.55	8.03	9.56	7.96
	$\bar{Y}$	9.68 (10)	6.38 (10)	11.54 (6)	14.20 (6)	9.48 (32)
	L_2	12.36	8.83	16.41	20.88	11.26
West Hackberry	L_1	3.32	7.23	7.89	11.79	8.02
	$\bar{Y}$	7.96 (16)	8.88 (17)	11.24 (12)	15.73 (12)	10.23 (57)
	L_2	17.58	10.86	15.85	20.89	12.99
Overall	L^1	4.42	5.14	8.57	10.61	
	$\bar{Y}$	6.23 (45)	6.40 (46)	10.27 (35)	13.13 (35)	
	L_2	8.66	7.92	12.28	16.21	

[a] Each sample is the mean of replicates at each station.

[b] L_1 and L_2 equals the lower and upper confidence limits respectively (after Sokal & Rohlf, 1969) $\bar{Y}$ equals the mean.

[c] Number of samples.

Table 4.3-27 Results of Analysis of Variance for Important Benthic Megafaunal Groups

Taxonomic Group	Cruise	Main Effect Site	Interaction Cruise* Site
Diopatra	.42	.0001	.75
Neanthes	.01	.0001	.09
Clymenella	.004	.0001	.15
Lumbrinereis tenuis	.001	.021	.21
Nuculana concentrica	.01	.27	.04
Ancistrosyllis	.0001	.06	.008
Cossura	.0001	.02	.02
Lumbrinereis sp.	.0001	.0001	.08
Micropholis	.94	.0001	.92
Total Benthos	.0001	.0001	.73
Mulinia	.0001	.0001	.51
Total minus *Mulinia*	.0001	.16	.45

benthic animals being significant for both main effects, and no significant interaction. Virtually every species showed significant cruise differences (with the exceptions of Diopatra and Micropholis) and all except Nuculana and Ancistrosyllis showed significant site differences. The general lack of significant interaction indicates that trends for the different sites were similar over time.

As expected, Mulinia showed only significant cruise differences, being present in appreciable numbers only in September. When Mulinia is removed from the data set, however, very significant site and cruise effects for the total data set remain, indicating that groups other than Mulinia contributed to the overall site and cruise differences.

Analysis of variance results for Magelona showed significant cruise and site differences in mean numbers, with the interaction term also significant. This latter point indicated that during some months the sites were behaving divergently. Generally, over all sites, the mean number of individuals increased through the course of the study from the September low. The only major exception, and the incident responsible for a large portion of the interaction, was for West Hackberry control, where the October mean was about one-half that for September. Also, at West Hackberry the November population of Magelona was slightly lower than that for October. During all months, Big Hill had the lowest populations, with Big Hill control samples generally with highest or near highest means.

For all sites, highest populations were found during December. The low populations during September were coincident with high populations of Mulinia with the latter decreasing dramatically in subsequent months as Magelona increased in abundance.

From results of the multiple means tests (Table 4.3-28) for cruise effects, the trend for the majority of the other important groups also showed a late fall or early winter maximum, with highest populations in November and December. For the most part the November and December means were significantly higher than those for September and October.

The general increase in species' numbers could represent either a recovery of the benthic population from an environmental stress or a normal fall to winter transition in community structure.

The site differences (Table 4.3-29) seen in the multiple means tests following ANOVA are clearcut, with Big Hill consistently having the lowest means. In no case was the mean for Big Hill not significantly lower than that for West Hackberry or West Hackberry control. For one group of species (Diopatra, Neanthes, Clymenella and Micropholis) Big Hill Control had the lowest means, while for another group (Lumbrineris tenuis, Lumbrineris spp., total numbers, and total numbers minus Mulinia.

Big Hill control had the highest means, but they were not significantly higher than those at any of the other sites except Big Hill. In general it was the data at Big Hill which yielded the significant site differences.

Table 4.3-28

Summary of Multiple Means
Tests for all Possible Pairwise Comparisons of Cruise Means

Taxonomic Group	Dependent Variable	Cruise Means (Highest			Lowest)
Mulinia	log N	September	October	December	November
Neanthes	log N	December	November	September	October
Clymenella	log N	November	December	October	September
Lumbrineris spp.	log N	November	December	October	September
Lumbrineris tenius	log N	October	December	September	October
Total benthos	log N	December	November	October	September
Total benthos minus *Mulinia*	log N	December	November	October	September

Tukey's t = 2.57

Table 4.3-29

Summary of Multiple Means
Tests for all Possible Pairwise Comparisons of Site Means

Taxonomic Group	Variable	(Highest				Lowest)
Diopatra	log N	WH	WHC	BB	BHC	BH
Neanthes	log N	WH	WHC	BB	BHC	BH
Clymenella	log N	BB	WH	WHC	BHC	BH
Lumbrineris tenius	log N	BHC	WHC	WH	BB	BH
Lumbrineris spp.	log N	BHC	BB	WH	WHC	BH
Total benthos	log N	BHC	WH	WHC	BB	BH
Total benthos minus Mulinia	log N	BHC	WH	WHC	BB	BH
Micropholis	log N	WHC	BB	WH	BHC	BH

Tukey's t = 2.735

WH = West Hackberry
WHC = West Hackberry Control
BB = Black Bayou
BH = Big Hill
BHC = Big Hill Control

Results of these analyses coincide with the ordination results. The September community was clearly distinct, while the October through December sampling revealed the same dominants and subdominants present throughout the three month period.

4.3.3.3 Benthos - Substrate Relationships

For the total data set (all species combined) for cruises three and four, results of the correlation analysis showed a significant negative correlation with percent clays (r = -0.33, p = 0.001), percent fines (r = -0.31, p = 0.003) and organic matter (r = -0.19, p = 0.02). These results relate to the fact that Big Hill, highest in percent fines, clays, and organic matter, had by far the lowest populations of benthic organisms. There was also a significant negative correlation between total benthos and percent calcium carbonate (r = 0.22, p = 0.006), possibly indicating a substrate preference. Since percent carbonate was not significantly correlated with sediment texture or organic content, the correlations between percent carbonate and total benthos could indicate the source of some of the site to site variability in the data.

Groups most highly correlated (-) with organic matter included Clymenella (r=-0.26, p = 0.0009), and Micropholis (r = 0.23, p = 0.004), while total benthos and total minus Mulinia had r values of -0.19 and -0.20, respectively. Groups most highly correlated with carbonate content included Lumbrinereis sp. (r = -0.23, p = 0.0005), total benthos (r = -0.22, p = 0.006), and total minus Mulinia (r = -0.23, p = 0.004).

For percent fines, Micropholis had the highest (negative) correlation (r = -0.52, p = 0.0001), while Clymenella had an r value of -0.45 (p=0.0001). Other groups with significant negative correlations with percent fines included Lumbrinereis sp. (r = -0.43, p = o.0001), total minus Mulinia (r = -0.37, p = 0.0003), Neanthes (r = -0.31, p = 0.03). Virtually identical results were found for the correlations between these same benthic groups and percent clays.

The overall indication, therefore, is that the significantly lower populations at Big Hill, combined with the significantly higher content of fines and organic matter in the sediments, yielded generally negative correlations. Whether this negative correlation is due to specific sediment-organism relationships, or to a common sausal factor is not known.

4.3.3.4 Community Composition

Table 4.3-30 shows the community composition for each site on each cruise, in rank order. With certain exceptions the community composition is surprizingly stable from site to site and cruise to cruise. Magelona sp is the consistent top dominant, and is generally twice as abundant as the next ranking species at a given site or cruise.

TABLE 4.3-30. Benthic Community Composition by Month and Site.

	West Hackberry Control		West Hackberry		Black Bayou		Big Hill Control		Big Hill	
SEPTEMBER	Magelona	26.1	Mulinia	42.7	Mulinia	33.3	Magelona	14.3	Mulinia	20.6
	Lumbrineris sp.	13.1	N. concentricia	8.3	Magelona	16.7	Diopatra	13.0	N. concentrica	16.5
	Diopatra	10.8	Diopatra	6.4	Diopatra	9.1	N. concentrica	11.7	Aglaophamus	15.5
	Micropholis	8.1	Neanthes	4.6	Micropholis	7.6	Lumbrincris sp.	11.7	Diopatra	11.3
	Owenia	6.3	Clymenella	3.5	Owenia	6.1	L. tenuis	10.4	Nassarius	8.2
	Mulinia	5.0					Mulinia	10.4		
OCTOBER	Magelona	17.4	Magelona	35.3	Magelona	23.3	Magelona	45.0	Magelona	24.1
	Diopatra	15.3	Clymenella	14.1	Clymenella	20.0	Lumbrineris	15.3	Diopatra	20.7
	Micropholis	11.8	Diopatra	13.5	Lumbrineris sp.	10.0	Nematoda	8.4	N. concentrica	15.5
	Lumbrineris sp.	9.7	Lumbrineris sp.	8.0	Micropholis	10.0	Diapatra	7.6	Ancistrocyllis	15.5
	L. tenuis	5.6	L. tenuis	6.0	Diopatra	6.7	L. tenuis	7.6	Lumbrineris sp.	5.2
NOVEMBER	Magelona	39.7	Magelona	24.8	Magelona	28.9	Magelona	60.0	Paraprionospio	29.1
	Lumbrineris sp.	13.9	Lumbrineris sp.	19.0	L. tenuis	19.0	L. tenuis	11.0	Magelona	28.2
	Diopatra	9.3	Clymenella	11.0	Clymenella	14.0	Cossura	4.8	Diopatra	5.8
	Cossura	6.6	Diopatra	8.3	Diopatra	8.3	Ancistrocyllis	4.1	Ancistrocyllis	3.9
	Micropholis	6.0	Neanthes	6.1	Micropholis	5.8	Nematoda	3.4	Lumbrineris sp.	3.9
DECEMBER	Magelona	30.0	Magelona	33.8	Magelona	34.8	Magelona	50.8	Magelona	43.2
	Acetes	13.5	Diopatra	9.6	Clymenella	16.5	Lumbrineris sp.	12.8	N. concentrica	10.2
	Lumbrineris sp.	9.2	L. tenuis	8.2	Lumbrineris sp.	12.5	Cossura	6.2	Diopatra	6.8
	Diopatra	7.2	Clymenella	6.3	Ancistrocyllis	7.1	Diopatra	4.1	Lumbrineris sp.	6.8
	Neanthes	7.2	Ancistrocyllis	5.4	Diopatra	4.0	Ancistrocyllis	4.1	Dolichadarus	4.5

Below Magelona in order of abundance are Diopatra cuprea, and Lumbrineris spp. Clymenella torquata and Micropholis atra were also occasionally of high importance. With the exception of Magelona the rank order of the dominant species varied more or less randomly between sites and cruises.

Only in September was there any significant difference in community composition. At that time Mulinia lateralis, and to a lesser extent Nuculana concentrica, essentially replaced Magelona as the dominant species at West Hackberry, Big Hill and Black Bayou. While Magelona continued as the top dominant at Big Hill Control, Mulinia and Nuculana were fairly important (each comprising about 10% of the community, versus 14% for Magelona). Even at West Hackberry Control Mulinia comprised 5% of the community, whereas at other sites, at other times it seldom exceeded 1% of the community, if at all present. The shift from a Mulinia dominated community to one dominated by Magelona may be a seasonal phenomenon. However the presence of Mulinia has been considered by some (R. Parker personal communication) to be indicative of environmental degradative events.

Ordination Analysis

A reciprocal averaging ordination was performed for the benthic megafaunal data, with species occurring five times or fewer being dropped. Axis 1 of the ordination accounted for only 7% of the variation in the data. Inasmuch as the first axis, by definition, accounts for the maximum amount of variance, it is concluded that the benthic megafauna was a relative homogenous community, probably due to the dominance of Magelona through all cruises. A distribution plot of axes 1 and 2 of sample space (Figure 4.3-13) shows that the October-December samples cluster very tightly at the right end of axis 1; they are essentially indistinguishable. Samples from September, however, pulled out to the left along the length of axis 1. This is interpreted as an expression of the shift in community dominance previously noted for this community. The cluster at the right of axis 1 represents samples dominated by Magelona, while those pulled to the left are dominated by Mulinia. This is reflected by the distribution in species space (Figure 4.3-14), as Magelona is at the extreme right of axis 1, while Mulinia is at the extreme left.

4.3.4 Demersal Nekton

4.3.4.1 General Characteristics

Some 79 species were recovered from the 52 aggregate trawls taken during the the study (Table 4.3-31). The species recovered are typical of the near shore white shrimp (Penaeus setiferus) community characteristic of sandy-mud bottom in waters less than 10 fathoms of the northwestern Gulf of Mexico (cf. Gunter 1945, 1950, and Hildebrand 1954). Dominant species in the trawls are shown in Table 4.3-32. The most characteristic species recovered was the sergestid shrimp Acetes americanus louisianensis, present in over 70% of the trawls, and numbering in aggregate over 26,700 individuals. The squid, Lolliguncula brevis, was the most frequently

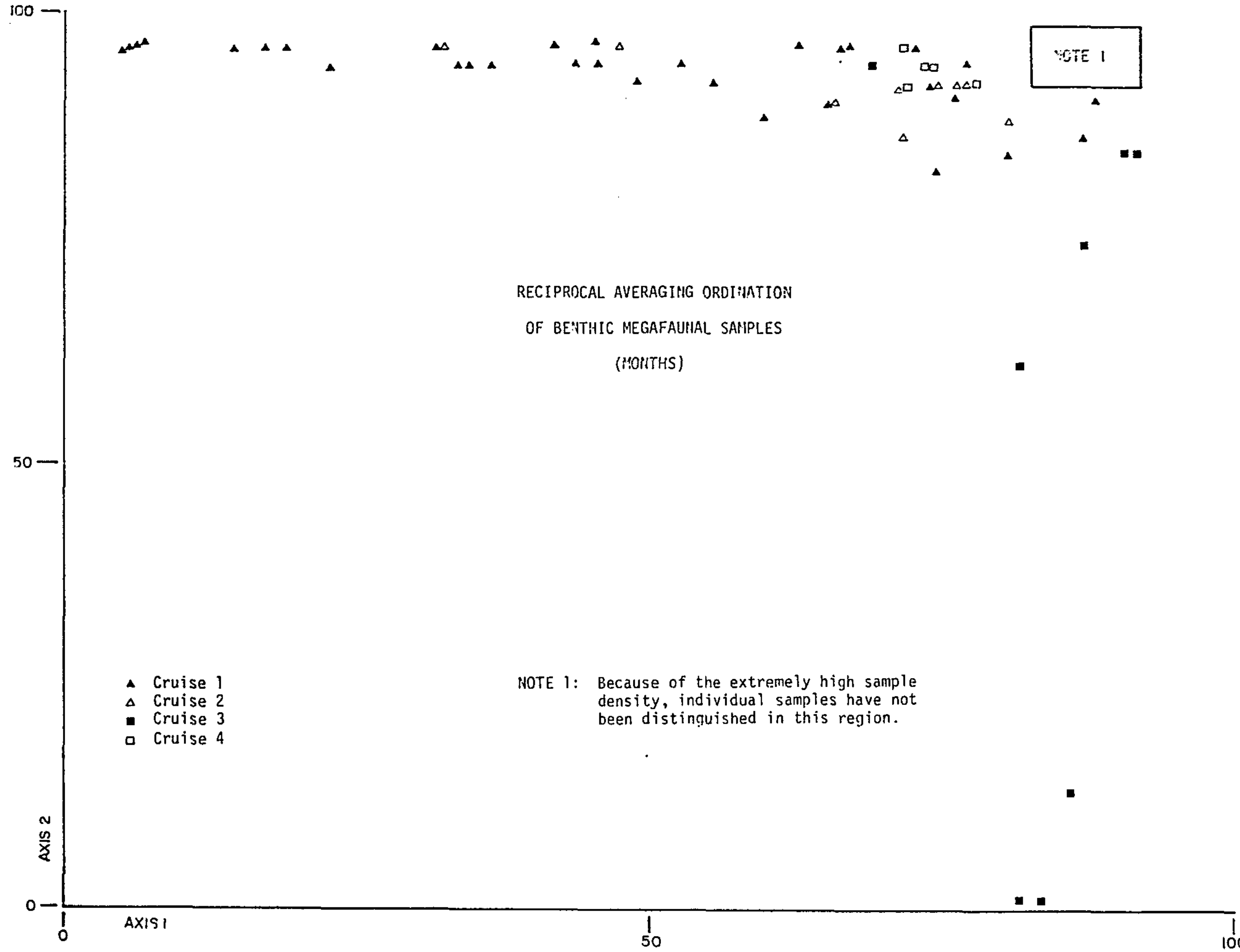


Figure 4.3-13 Reciprocal Averaging Ordination for Benthic Megafaunal, Shown in Sample Space With Dates Indicated

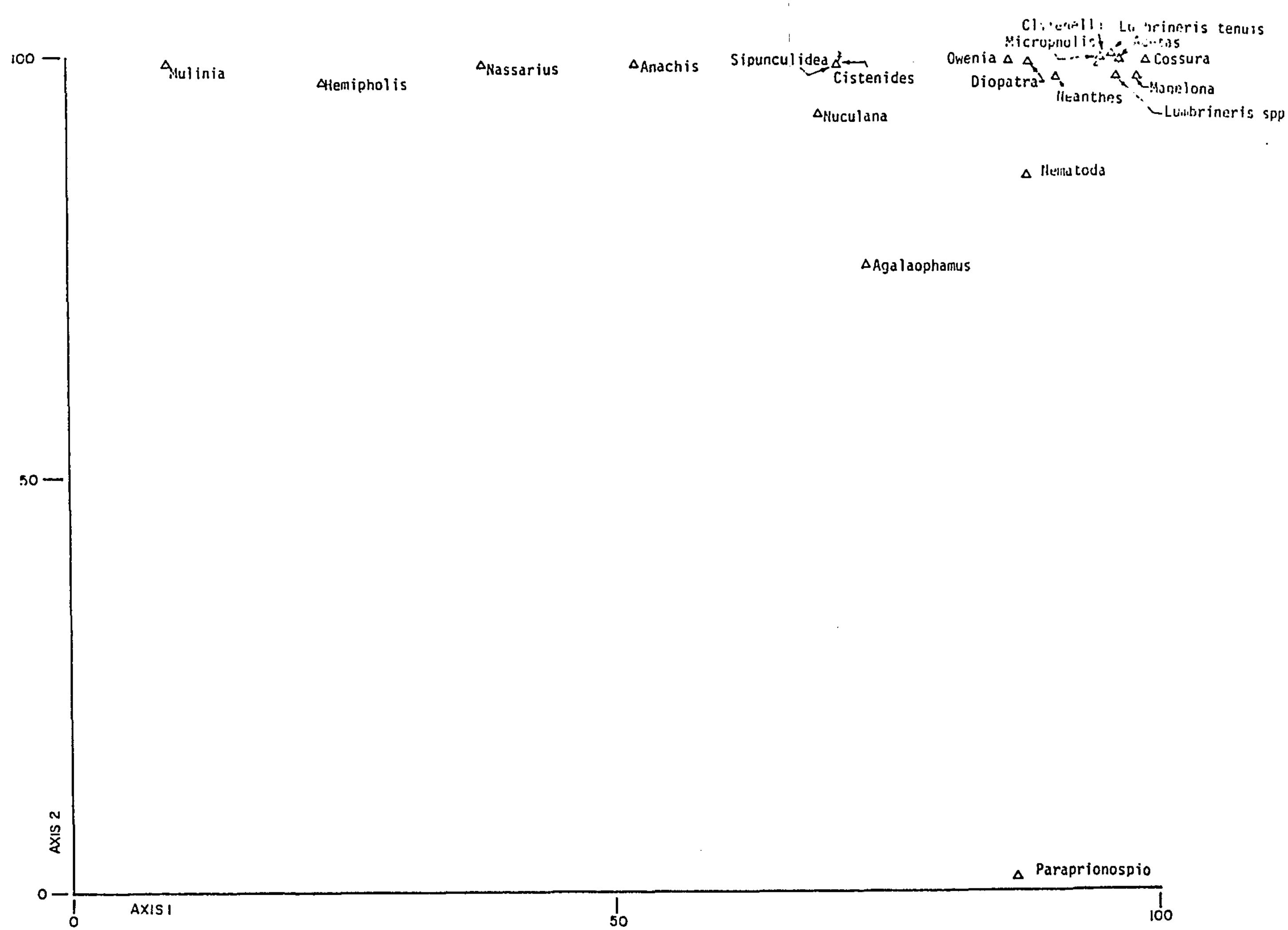


Figure 4.3-14 Reciprocal Averaging Ordination for Benthic Megafaunal, Shown in Species Space

Table 4.3-31 Relative abundances of species in trawl samples.

Taxonomic Group	Species	Common Name	CRUISE 1	CRUISE 2	CRUISE 3	CRUISE 4
COELENTERATE	Aurelia aurita	Jellyfish		X		
	Rhizostomeae	----------	X	X	X	X
	Bunodactis texaensis	Anemone		X		X
	Minyas olivacea	Anemone				
	Paranthus rapiformis	Anemone		X	X	X
	Calliactis tricolor	Anemone	X	X	X	X
	Ctenophore	Comb jellyfish				
POLYCHAETE	Chaetopterus variopedatus	----------			X	
	Diopatra cuprea	Chimney worm			X	
	Neanthes succinea	----------	X	X		
MOLLUSK	Polinices duplicatus	Shark's eye	X	X	X	
	Cantharus cancellarius	Cancellate cantharus				X
	Nassarius acutus	Sharp-knobbed nassa	X		X	
	Thais haemastoma floridana	Florida rock shell	X			
	Nuculana concentrica	Concentric nut clam			X	X
	Anadara ovalis	Blood ark	X			X
	Abra aequalis	Common Atlantic abra			X	
	Mulinia lateralis	Dwarf surf clam				X
	Lolliguncula brevis	Brief squid	X	X	X	X
CRUSTACEAN	Cirolana parva	Isopod		X	X	X
	Cirolana obtruncata	Isopod			X	
	Sphaeroma quadridentatum	Isopod		X		
	Acetes americanus louisianensis	Sergestid shrimp	X	X	X	X
	Pagurus pollicaris	Hermit crab	X	X	X	X
	Palaemonetes pugio	Prawns				X
	Penaeus aztecus	Brown shrimp	X	X	X	
	Penaeus setiferus	White shrimp	X	X	X	X
	Sicyonia brevirostris	Rock shrimp	X		X	
	Sicyonia dorsalis	Rock shrimp	X	X	X	X
	Trachypenaeus similis	Mexican shrimp		X	X	
	Xiphopeneus kroyeri	Seabob	X	X	X	X
	Callianassa minima	Mud shrimp		X	X	
	Lysiosquilla empusa	Mantis shrimp	X	X	X	X
	Callinectes danae	Swimming crab	X		X	X
	Portunus gibbesii	Swimming crab	X	X	X	X
	Portunus sayi	Swimming crab	X	X		
	Neopanope texana sayi	Mud crab				X
	Hepatus epheliticus	Calico crab			X	X
	Persephona punctata	Purse crab	X	X	X	X
	Libinia dubia	Spider crab	X	X	X	X

Table 4.3-31 (Continued)

Taxomonic Group	Species	Common Name	CRUISE 1	CRUISE 2	CRUISE 3	CRUISE 4
ECHINODERM	Luidia clathrata	Sea star	X			
FISH	cf. Anguilla rostrata	American eel				X
	Myrophis punctatus	Speckled worm eel				X
	Opisthonema oglinum	Atlantic thread herring	X		X	
	Harengula pensacolae	Scaled sardine	X			
	Brevoortia patronus	Gulf menhaden			X	
	Anchoa mitchilli	Bay anchovy	X	X	X	X
	Anchoa hepsetus	Striped anchovy	X	X		X
	Synodus foetens	Inshore lizardfish	X			
	Arius felis	Sea catfish	X	X	X	X
	Bagre marinus	Gafftopsail catfish			X	
	Porichthys porosissimus	Atlantic midshipman	X	X	X	X
	Ophidion welshi	Crested cusk-eel	X	X	X	
	Syngnathus louisianae	Chain pipefish		X	X	X
	Chloroscombrus chrysurus	Atlantic bumper	X	X	X	
	Caranx ruber	Bar jack	X	X	X	
	Caranx hippos	Crevalle or common jack	X	X		
	Umbrina coroides	Sand drum		X		
	Micropogon undulatus	Atlantic croaker	X	X	X	X
	Cynoscion spp.	Spotted seatrout	X	X	X	X
	Cynoscion arenarius	Sand seatrout	X	X	X	X
	Cynoscion nothus	Silver seatrout	X	X	X	X
	Leiostomus xanthurus	Spot		X		X
	Stellifer lanceolatus	Star drum	X	X	X	X
	Larimus fasciatus	Banded drum			X	X
	Larval sciaenids		X		X	X
	Chaetodipterus faber	Atlantic spadefish	X			X
	Sphyraena guachancho	Guaguanche	X			
	Polydactylus octonemus	Atlantic threadfin	X	X		
	Astroscopus y-graecum	Southern stargazer			X	X
	Trichiurus lepturus	Atlantic cutlassfish		X	X	X
	Scomberomorus cavalla	King mackerel	X			
	Peprilus paru	Harvestfish		X	X	
	Prionotus rubio	Blackfin searobin		X	X	X
	Etropus crossotus	Fringed flounder				X
	Citharichthys spilopterus	Bay whiff			X	
	Achirus lineatus	Lined sole		X		
	Symphurus plagiusa	Blackcheek tonguefish	X	X	X	X
	Sphoeroides parvus	Least puffer	X	X	X	X

Table 4.3-32

Dominant Demersal Nekton Species Taken From Aggregate Trawls
September-December 1977

Species	Feeding Type**	Number of Occurrences	Number of Individuals Per Occurrence	Total Number of Individuals
Acetes americanus	PP	37	722	26714
Anchoa mitchilli	PP	42	100	4200
*Xiphopeneus kroyeri	Sc	28	54	1512
Lolliguncula brevis	Pr	46	36	1656
*Penaeus setiferus	Sc	44	21	924
Anchoa hepsetus	PP	10	52	520
Cynoscion nothus	Pr	35	20	700
Stellifer lanceolatus	DPr	34	16	544
Portunus gibbesii	Sc	34	9	306
*Micropogon undulatus	DPr	36	7.5	270
Lysiosquilla empusa	Pr	36	4	144
Calliactis tricolor	ZP	31	4	124
Cynoscion arenarius	Pr	19	15	285
Sicyonia dorsalis	Sc	20	4.5	90
Sphoeroides parvus	ZP	19	4	75
Cirolana parva	Dp	17	2.5	43
Larval sciaenids	ZP	17	87	1479
Rhizostomeae	ZP	15	2.5	38
Portunus sayi	Sc	10	3	30
Persephona punctata	Sc	17	2	34
Porichthys porosissmus	Pr	17	2	34
Ophidion welshi	Pr	11	3	33

*Commercial species.

**PP = phytoplankton feeder
ZP = zooplankton feeder
Sc = scavenger
Pr = predator
DPr = demersal predator
Dp = deposit feeder

recovered species (88% of the trawls) but was taken in much fewer numbers (1,656 individuals in aggregate). The bay herring anchovy, Anchoa mitchilli, was also taken frequently in relative large numbers (81%, 4200 individuals) as was the sea bob, Xiphopenaeus kroyeri (54%, 1,512 individuals) and the white shrimp, P. setiferus (85%, 924 individuals). The majority of species (73%) were recovered only once or twice and in limited numbers (four or fewer individuals per recovery).

Table 4.3-33 shows the feeding patterns for the demersal nekton community, considering only the dominant or sub-dominant species, and total number of individuals recovered by feeding type. As would be expected, the base of the food pyramid within the demersal community is the herbivorous phytoplankton filter feeders (3 species) comprising some 76.2% of the total number of individuals recovered. The predators (8 species) make up 12.6% of the community, while the scavengers (6 species) and the zooplankton feeders (4 species) comprise only 7.0% and 4.2% of the community.

A number of commercially and recreationally important species are found in the demersal nekton community. Commercially important species recovered from trawls in the study area include the brown shrimp, white shrimp, sea bob, drum, croaker, seatrout and menhaden. Of these only the shrimp (white, brown, and seabob) were of commercial size. The important commercial species, Callinectes sapidus, or the blue crab, was notable by its complete absence from the trawls. This probably reflects its seasonal distribution pattern characterized by wintering in the coastal estuaries.

Recreationally important species recovered in the trawls include: Atlantic croaker, spot, seatrout, Atlantic spade fish and the crevalle-jack. None of the specimen recovered were of fishable size from a sport fisherman's point of view.

It is somewhat difficult to compare regional trawl data collected in different studies by different sets of investigators; trawl data is quite sensitive to variations in gear and collection methodologies. However, adjusting for these differences as far as possible, the average density of individuals found in the present study ($.31/m^2$) is similar to that found elsewhere in the region (e.g. $.18/m^2$ at Weeks Island).

4.3.4.2 Spatial and Temporal Variations

Consideration of species dominance patterns (Table 4.3-34) shows that community composition is relatively consistent over space and time with only 12 species comprising the whole list of dominants. The most important of these species include Acetes, A. mitchilli, Lolliguncula brevis, Penaeus setiferus and Xiphopenaeus. Other species achieving occasional numerical importance include Cynoscion nothus, Stellifer lanceolatus, Micropogon undulatus, and Portunus gibbesii.

Table 4.3-33

Feeding Patterns of Dominant Species of Demersal Nekton

Feeding Pattern	Number of Species	Number of Individuals	% of Composition
Phytoplankton	3	31,434	79.1
Scavenger	6	2,896	7.3
Predators	8	3,666	9.2
Zooplankton	4	1,716	4.3
Deposit Feeders	1	43	.1
		39,755	

TABLE 4.3-34. Demersal Nekton Patterns of Species Dominance.

	West Hackberry Control	West Hackberry	Black Bayou	Big Hill Control	Big Hill
SEPTEMBER	A. mitchilli Lolliguncula Acetes Penaeus	Acetes C. arenarius Penaeus A. mitchilli Xiphopenaeus Micropogon Lolliguncula	A. mitchilli Lolliguncula Acetes Micropogon	Acetes Lolliguncula Penaeus Xiphopenaeus Micropogon	Acetes Xiphopenaeus Penaeus Micropogon A. mitchilli Lolliguncula
OCTOBER	A. mitchilli Lolliguncula A. hepsetus Penaeus C. nothus	Acetes Xiphopenaeus Lolliguncula Penaeus A. mitchilli C. nothus Stellifer	A. mitchilli Acetes C. nothus Lolliguncula Stellifer	Acetes Xiphopenaeus Lolliguncula Penaeus C. nothus A. mitchilli	Acetes Xiphopenaeus Stellifer C. nothus Penaeus A. mitchilli Lolliguncula
NOVEMBER	Acetes C. nothus Lolliguncula P. gibbesii Larval sciaenids Penaeus	Penaeus Acetes A. mitchilli Stellifer P. gibbesii Micropogon C. nothus Lolliguncula	Acetes Larval sciaenids Lolliguncula C. nothus A. mitchilli Penaeus P. gibbesii	Larval sciaenids Xiphopenaeus Acetes Stellifer Penaeus	Larval sciaenids Lolliguncula Penaeus Micropogon P. gibbesii C. nothus Stellifer
DECEMBER	Acetes A. mitchilli Lolliguncula Larval sciaenids	Acetes Larval sciaenids A. mitchilli C. nothus Penaeus Lolliguncula	Acetes Larval sciaenids A. hepsetus A. mitchilli Lolliguncula	Acetes C. nothus Lolliguncula A. mitchilli Penaeus	Xiphopenaeus Acetes Larval sciaenids Lolliguncula Penaeus Stellifer

The means for each site, each cruise and each cruise-site combination (with 95% confidence limits), are presented in Table 4.3-35 for all species combined and also for all species combined with Anchoa mitchilli and Acetes americanus removed from the data set. This latter data set was constructed because of the very high numbers of Anchoa and Acetes, which would lead to a masking of group trends as expressed by the less abundant species. In the former case, Black Bayou had the highest overall mean (666/trawl) followed, in descending order, by West Hackberry (505/trawl), Big Hill control (367/trawl), Big Hill (292/trawl), and West Hackberry control (199/trawl). October had the highest mean (708/trawl), while September had the lowest (127/trawl).

For the total number with the two dominant species removed, the situation is somewhat different. November had the highest mean (237/trawl), with October next highest (171/trawl) and September again the lowest (431/trawl). Big Hill control and West Hackberry control had lowest means (64 and 73/trawl, respectively), with Big Hill having the highest mean (206/trawl) and Black Bayou (164/trawl) and West Hackberry (122/trawl) intermediate.

The change in rank order of site means indicates the minor importance of Anchoa at the Big Hill site and the highest density at the Black Bayou site. Lolliguncula and Micropogon were the only other major species with highest means at the Black Bayou site.

Analysis of Variance

The results of the two-way ANOVA's for individual (major) demersal species, total individuals and total individuals minus Anchoa mitchilli and Acetes americanus are shown in Table 4.3-36. Overall the results indicate significant temporal differences, with site differences apparent for a lesser number of taxonomic groups.

For the total data set, there were no significant site differences, but there were significant cruise differences, with the trend not being strong ($p = 0.035$). Multiple means tests (Table 4.3-) indicated that the September mean was significantly lower than those for the October through December period, with none of the latter showing significant differences.

For the total number with Anchoa and Acetes removed, the trend for significant cruise differences is much stronger ($p = 0.0009$), although site differences are still not apparent. Multiple means tests (Table 4.3-37) showed that the overall trend did not change dramatically, with the September means again being significantly lower. However, in this case, the November means (highest) were significantly higher than those for December. The October means were not significantly different from those of November.

The different pattern for total numbers with and without Anchoa and Acetes can be seen as due to the lack of significant cruise differences

TABLE 4.3-35 MEAN NUMBER OF DEMERSAL INDIVIDUALS WITH CONFIDENCE LIMITS PER TRAWL BY SITE AND MONTH (all species)

SITE		SEPT.	OCT.	NOV.	DEC.	OVERALL
BLACK BAYOU	L_1[a]	10593	4591	1529	13385	1098
	$\overline{Y}$	900(2)	494(2)	563(2)	785(2)	666(8)
	L_2	75	52	207	45	403
BIG HILL	L_1	666	472	996	760	445
	$\overline{Y}$	131(3)	360(3)	382(3)	402(3)	292(12)
	L_2	25	274	1461	212	191
BIG HILL CONTROL	L_1	$9.25X10^7$	292142	244	2974	3177
	$\overline{Y}$	30.8(2)	2054(2)	199(2)	1419(2)	367(8)
	L_2	0	13	162	676	41
WEST HACKBERRY CONTROL	L_1	3714	4367	1697	475	700
	$\overline{Y}$	23(3)	558(3)	981(3)	121(3)	199(3)
	L_2	0	71	566	30	56
WEST HACKBERRY	L_1	101416	3238	231	839	1248
	$\overline{Y}$	466(3)	1107(3)	195(3)	642(3)	505(3)
	L_2	1	378	165	490	204
OVERALL	L_1	599	1259	596	814	
	$\overline{Y}$	127(13)	708(13)	391(13)	457(13)	
	L_2	26	398	256	257	

[a] L_1 and L_2 equals the lower and upper confidence limits respectively (after Sokal and Rohlf, 1969)
$\overline{Y}$ equals the mean
[b] number of samples

TABLE 4.3-35 (Cont.)

(EXCLUDING *ANCHOA MITCHILLI* AND *ACETES AMERICANUS*)

SITE		SEPT.	OCT.	NOV.	DEC.	OVERALL
BLACK BAYOU	L_1[a]	306	165	1750	14897	296
	$\overline{Y}$	163(2)	116(2)	279(2)	136(2)	164(8)
	L_2	87	82	44	0	90
BIG HILL	L_1	321	407	687	773	315
	$\overline{Y}$	91(3)	218(3)	331(3)	272(3)	206(12)
	L_2	25	116	160	95	134
BIG HILL CONTROL	L_1	3824	1136	247	235	274
	$\overline{Y}$	6(2)	120(2)	199(2)	102(2)	64(8)
	L_2	0	12	160	44	14
WEST HACKBERRY CONTROL	L_1	1437	638	385	79	225
	$\overline{Y}$	15(3)	255(3)	292(3)	20(3)	73(12)
	L_2	0	101	222	7	23
WEST HACKBERRY	L_1	1142	273	231	219	188
	$\overline{Y}$	82(3)	147(3)	138(3)	51(3)	122(12)
	L_2	5	78	82	78	80
OVERALL	L_1	133	227	308	192	
	$\overline{Y}$	43(13)	771(13)	1237(13)	103(13)	
	L_2	14	127	181	55	

[a] L_1 and L_2 equals the lower and upper confidence limits respectively (after Sokal and Rohlf, 1969)
$\overline{Y}$ equals the mean
[b] number of samples

Table 4.3-36 Results of Two-Way Analyses of Variance for Major Taxonomic Groups of Demersal Organisms

Group	Main Effect		Interaction
	Cruise	Site	Cruise* Site
Lolliguncula brevis	.0097*	.008*	.15
Anchoa mitchilli	.073	.004*	.0178*
Micropogon undulatus	.0001*	.0001*	.02*
Stellifer lanceolatus	.0092*	.0001*	.125
Penaeus setiferus	.010*	.006*	.62
Xiphopeneus krogeri	.0485*	.0001*	.0795
Portunus gibbesii	.0001*	.8948	.2945
Cynscion nothus	.0008*	.848	.005*
Larval sciaenids	.0001*	.9754	.1262
Total	.035*	.3874	.2401
Total minus *Anchoa mitchilli* and *Acetes americanus*	.0009*	.0565	.1715
Acetes americanus	.37	.069	.0112*
Lysiosquilla empusa	.235	.184	.65

*Signified at .05 level

Table 4.3-37

Summary of Multiple Means
Tests for all Possible Pairwise Comparisons of Cruise Means

Demersal Nekton

Taxonomic Group	Dependent Variable	(Highest	Cruise Means		Lowest)
Total	log N	October	December	November	September
Lolliguncula brevis	log N	November	December	October	September
Penaeus setiferus	log N	November	October	December	September
Larval sciaenids	log N	November	December	September	October
Stellifer lanceolatus	log N	November	October	December	September
Portunus gibbesii	log N	November	October	December	September
Xiphopeneus kroyeri	log N	November	October	December	September
Total minus Anchoa and Acetes	log N	November	October	Decembe.	September

Tukey's t = 2.57

Table 4.3-38

Summary of Multiple Means
Tests for all Possible Pairwise Comparisons of Site Means

Demersal Nekton

Taxonomic Group	Variable	(Highest		Site Means		Lowest)
Loliguncula brevis	log N	BB	WH	BHC	BH	WHC
Penaeus setiferus	log N	WH	BH	BHC	BB	WHC
Stellifer lanceolatus	log N	BH	WH	BB	BHC	WHC
Xiphopeneus kroyeri	log N	BH	WH	BHC	BB	WHC

Tukey's t = 2.735

WH = West Hackberry
WHC = West Hackberry Control
BB = Black Bayou
BH = Big Hill
BHC = Big Hill Control

for both species and no significant site differences for Acetes. Only Lysiosquilla in addition to Anchoa and Acetes, showed no significant temporal differences. For Anchoa, significant site differences were apparent (p = 0.004) but the trends were not consistent through all cruises at all sites. Overall, the highest mean for Anchoa was at Black Bayou, and the lowest at Big Hill. As can be seen from Table 4.3-38, this spatial pattern for Anchoa, especially regarding the position of Big Hill in the rank of means, is quite the opposite of the other major species (except Lolliguncula) showing significant differences (with no significant interaction), where Big Hill had a significantly higher mean or had a mean not significantly lower than the highest mean.

Table 4.3-37 shows the results of the multiple means tests for the demersal groups for which significant temporal differences and no confounding interaction were found in the two-way ANOVA's. The results show the general conformity in the behavior of these major species to the temporal pattern of the total data set and total minus A. mitchilli and A. americanus. Only the larval sciaenids had a month (October) other than September with the lowest mean, but it was not significantly lower than September. Except for the total data set, November showed the largest numbers, in all cases significantly higher than September, and, in most cases, significantly higher than the December means. Rank order of cruise means were identical for P. setiferus, Stellifer, Portunus, and Xiphopenaeus and for total minus Anchoa and Acetes. Even though the larval sciaenids had the highest mean in November, the trends for the other months indicated different causal mechanisms underlying its temporal distribution. Overall, the most consistent trends were for highest population in November and lowest in September.

Overall, it appears that November was a crucial sampling period inasmuch as a number of the dominant species reach peak population sizes at that time, (Portunus gibbesii, Cynoscion nothus, Penaeus setiferus, and Micropogon). When the distributions of all species are examined (Figure 4.3-15), November also stands out in having the largest total number of species and the largest number of species achieving maximum population size. This suggests that the November sampling period coincided with the fall emigration of species out of the estuaries onto the near shelf. The drop in species in December probably coincided with the continued migration toward deeper water. This phenomenon is generally regarded as a response to decreasing temperatures. Temperature profiles for the September-December time frame show a sudden drop between October and November. The reduction in numbers of certain species (e.g. Acetes) during November, though perhaps not statistically significant, may be related to the increase in various predatory species coincident with the fall migration. The presence of larval sciaenids in large numbers in November is taken as an indication of active spawning by one or more species of drum; while this taxa numerically dominates the community in November, particularly at Big Hill and Big Hill Control, its presence must be considered of ephemeral significance.

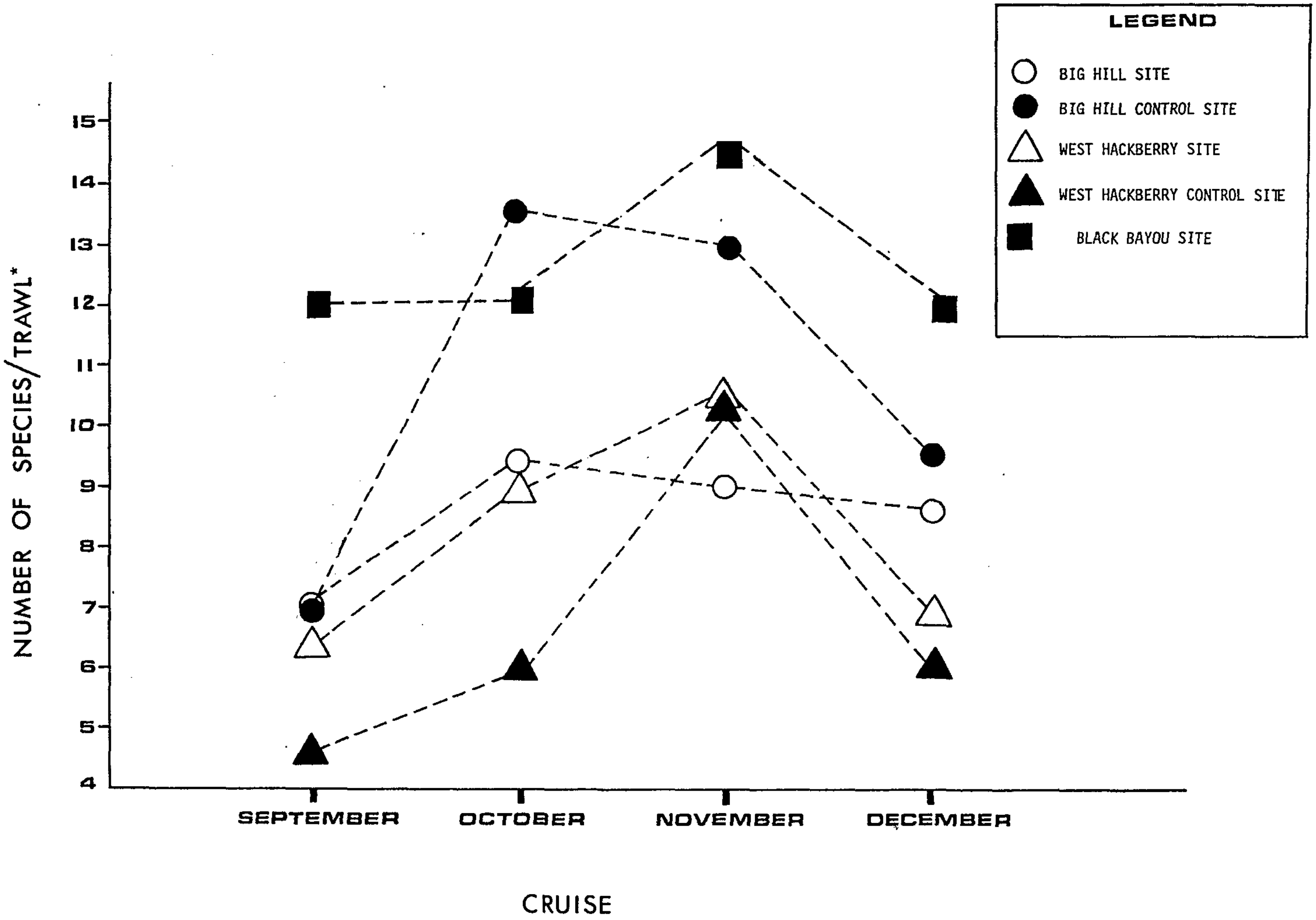


FIGURE 4.3-15. AVERAGE NUMBER OF SPECIES/TRAWL AT EACH SITE FOR EACH CRUISE.

*Site comparisons are valid only for those sites with equal numbers of replicates (i.e. West Hackberry, West Hackberry Control and Big Hill with 3 replicates each and Big Hill Control and Black Bayou with 2 replicates).

Xiphopenaeus and Stellifer were two species for which site differences were obviously of greater importance than temporal differences (Table 4.3-36), with Big Hill having significantly higher means and with West Hackberry also showing significantly higher means than either Black Bayou or West Hackberry control. West Hackberry control consistently had the lowest means for all species tested. Lack of significant site differences for the total data set was due mainly to different sites having the highest means for different species (as seen in Table 4.3-38). Anchoa had by far the highest means at Black Bayou, along with Lolliguncula. Stellifer and Xiphopenaeus dominated the Big Hill site and Penaeus was more ubiquitous, with the means at West Hackberry, Big Hill, and Big Hill Control each significantly greater than those at Black Bayou and West Hackberry Control. Overall, the most consistent trend was for significantly lowest populations at West Hackberry Control.

Correlation Analysis

Results of the correlation analyses (Table 4.3-39) show a number of significant correlations which give indications of community affinities. Of special note is the positive correlation between Anchoa mitchilli and Lolliguncula brevis ($p = 0.37$, $p = 0.0014$). Neither species is positively correlated with any other species, indicating the distinct character of their distribution, probably related to the fact that the highest populations of both species were found at Black Bayou. The distinct nature of the pattern of these two species is further substantiated by the fact that all significant negative correlations shown for the demersal species (Table 4.3-39) were associated with these two species. Anchoa was negatively correlated with Penaeus setiferus ($r = -0.28$, $p = 0.0474$), Xiphopenaeus ($r = -0.39$, $p = 0.0047$) and Stellifer ($r = 0.30$, $p = 0.0336$), while Lolliguncula was also negatively correlated with Xiphopenaeus ($r = -.29$, $p = .040$).

On the other hand, the largest positive correlation found ($r = 0.68$, $p = 0.0001$) also involved Xiphopenaeus and, in this case, Stellifer. While these two species were closely associated with each other, they were both positively associated with other species. Both were positively correlated with P. setiferus ($r = 0.39$ and 0.48 for Xiphopenaeus and Stellifer, respectively), while Lolliguncula was also correlated significantly with Acetes ($r = 0.27$ and 0.37, respectively).

Penaeus setiferus showed the greatest number of positive correlations, being also correlated with Acetes (0.37, $p = 0.0077$) and Portunus ($r = 0.39$, $p = 0.004$) as was Cynoscion nothus ($r = 0.42$, $p = 0.002$, and $r = 0.42$, $p = 0.001$ for Acetes and Portunus, respectively). Portunus also provided the only significant correlations for larval sciaenids ($r = 0.43$, $p = 0.004$). Lysiosquilla was positively correlated with Stellifer ($r = 0.34$, $p = 0.01$) as well as Portunus ($r = 0.38$, $p = 0.006$).

Ordination Analysis

A reciprocal averaging ordination was employed to examine variations in community composition from month to month and site to site. Species which occurred in five or fewer simples were excluded from the samples

Table 4.3-39 Results of Analyses of Simple Correlations For the Major Demersal Species

	Anchoa mitchilli	Acetes	Stellifer	Larval sciaenids	Cynoscion nothus	Micropogon	Portunus gibbesii	Lysiosquilla	Xiphopenaeus	Penaeus setiferus
Lolliguncula	.37	NS[a]	NS	NS	NS	NS	NS	NS	-.29[b]	NS
Penaeus setiferus	-.28	.37	.48	NS	NS	NS	.39	NS	.39	
Xiphopenaeus	-.39	.27	.68	NS	NS	NS	NS	NS		
Lysiosquilla	NS	NS	.34	NS	NS	NS	.38			
Portunus gibbesii	NS	NS	NS	.43	.42	NS				
Micropogon	NS	NS	NS	NS	NS					
Cynoscion nothus	NS	.42	NS	NS						
Larval sciaenids	NS	NS	NS							
Stellifer	-.30	NS								
Acetes	NS									

[a] NS = Not Significant.

[b] All correlation coefficients significant at $p = .05$.

in which they did occur. A total of 43% of the variation in the data set was attributable to the first or second axis of ordination. Higher order axes are considered only in passing in the present analysis.

Figures 4.3-16 and 4.3-17 show the distribution of trawl samples along the first and second axes of sample space. The date of collection is indicated in Figure 4.3-16, whereas the site of collection is indicated in Figure 4.3-17. In the first case, no pattern is seen for date, indicating that temporal variations in community composition are relatively minor. For site space, there is little segregation of sites except for the cluster of Big Hill samples along axis 2. This indicates that there are characteristics of the Big Hill assemblage which are somewhat distinct from the other sites. Also noted is a cluster of Black Bayou and West Hackberry Control samples isolated to the lower left of the site space. Comparison with Figure 4.3-16 indicates that these samples were from the September-October period for the Black Bayou site and September, October, and December at West Hackberry Control site.

Figure 4.3-18 shows the distribution of demersal species along the first two axes of species space. Relating this figure back to the site space (Figure 4.3-17), the sample distribution in site space is apparently controlled by specific important community members. The cluster in the lower left is dominated by Acetes americanus, while the cluster in the lower right is dominated by Anchoa mitchilli. The group in the upper left appears to be dominated by Xiphopenaeus and Stellifer. Two other clusters, in the mid portion of the distribution, are composite groups dominated by several members, inclduing Cynoscion nothus and larval sciaenids.

When feeding patterns for the species shown in Figure 4.3-18 are indicated (Figure 4.3-19), it becomes apparent that plankton feeders on the one hand and scavengers on the other are separated out, with predators overlapping both groups. Relating this to sample space in Figure 4.3-18, the indications are that the Big Hill samples are dominated by scavengers, while the other sites are dominated by zooplankton feeders, including Anchoa mitchilli, Acetes americanus and larval sciaenids. Whether or not this community segregation is related to the different substrate types on the low benthic megafaunal populations is not known.

Summary

The overall analytic results show good correspondence between the ANOVA, multiple means,correlation and ordination results. Several overlapping groups are apparent, with the Anchoa mitchilli/Lolliguncula group distinct in the lower right side of the ordination display (Figure 4.3-18) and the highly correlated Stellifer/Xiphopenaeus group in the left upper portion of the field. Acetes dominated the lower left corner of the display. Rank order of means showed that Stellifer and Xiphopenaeus consistently had significantly higher means at Big Hill, while Anchoa/Lolliguncula had highest numbers in the community at Black Bayou. Acetes showed no site or cruise effects. Correlation results showed that Anchoa/Lolliguncula

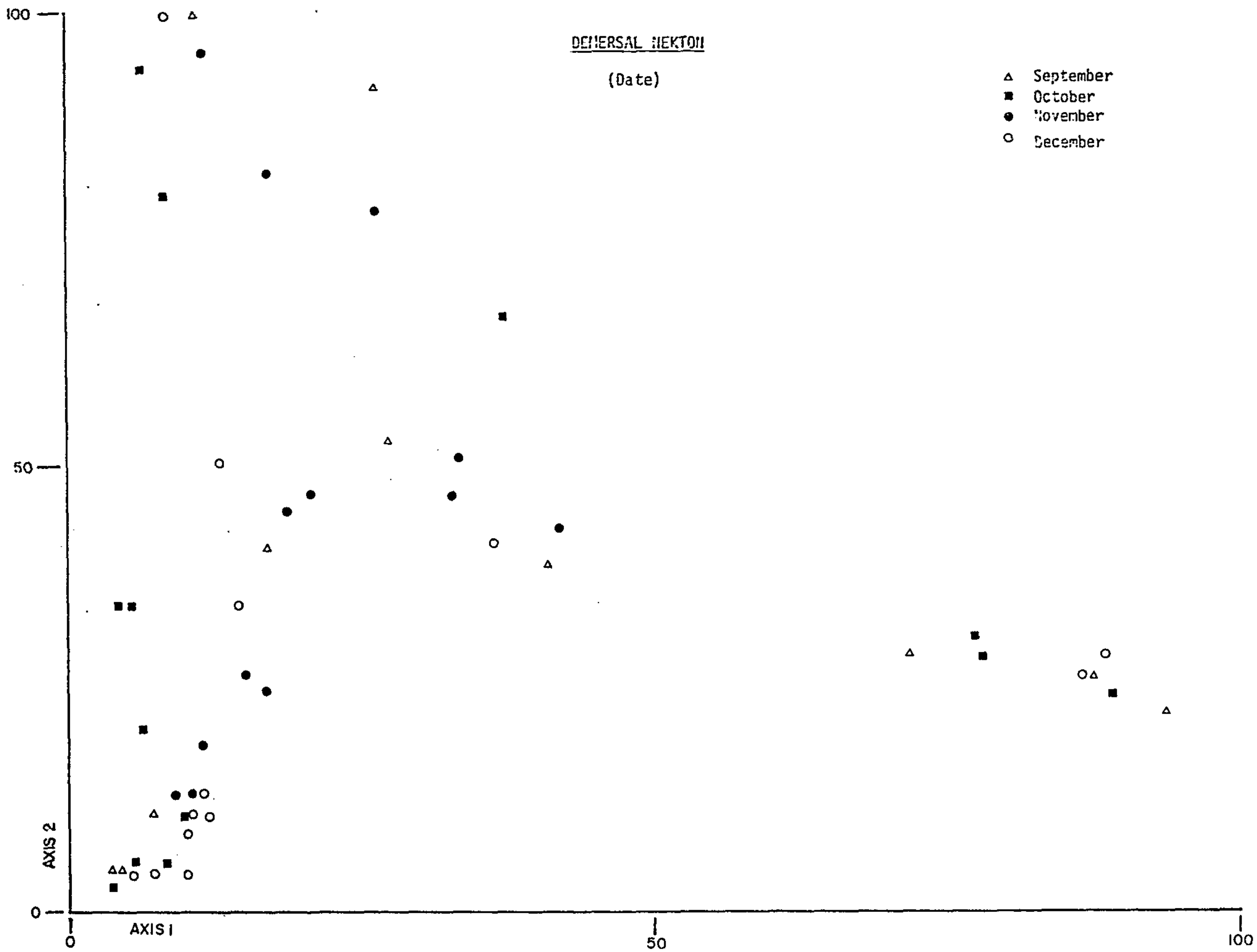


Figure 4.3-16 Reciprocal Averaging Ordination for Demersal Nekton, in Sample Space, Dates Indicated

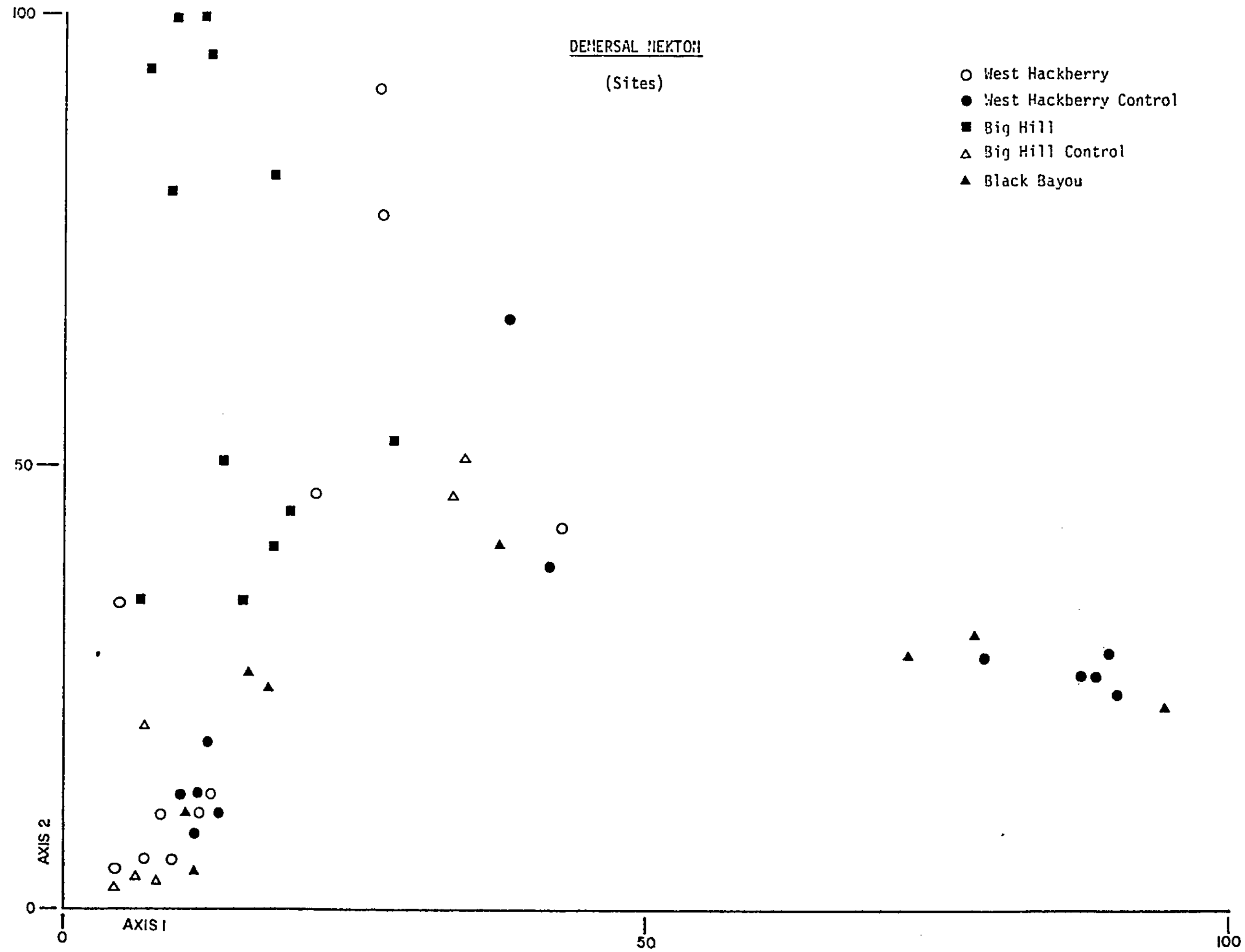


Figure 4.3-17 Reciprocal Averaging Ordination for Demersal Nekton, in Sample Space, Sites Indicated

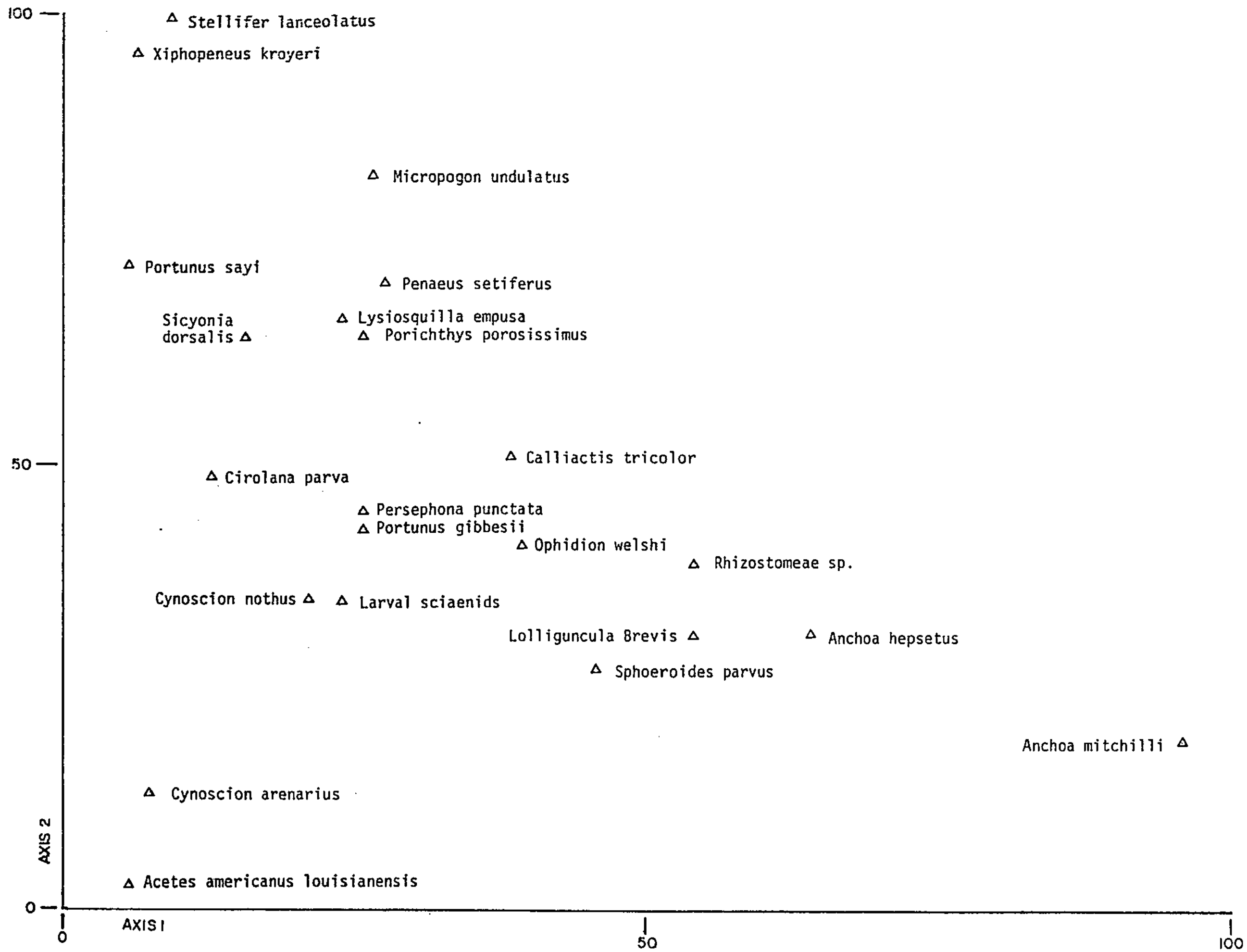


Figure 4.3-18 Reciprocal Averaging Ordination for Demersal Nekton in Species Space

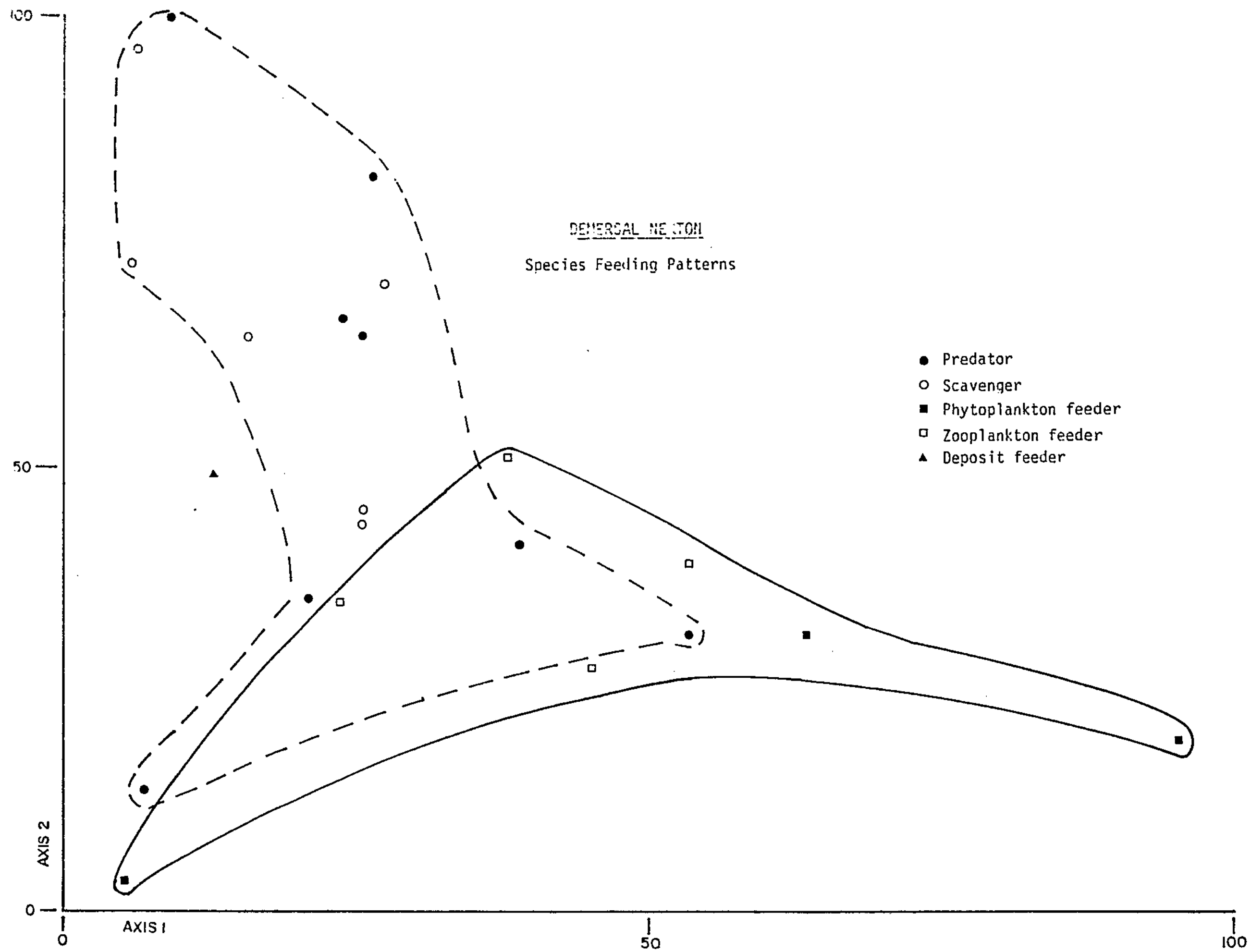


Figure 4.3-19 Reciprocal Averaging Ordination for Demersal Nekton in Species Space. Trophic Types Indicated

were positively correlated and were negatively correlated with Xiphopenaeus/Stellifer and also P. setiferus. It is concluded that site effects are the main factor responsible for the spatial arrangement of Xiphopenaeus/Stellifer and Anchoa/Lolliguncula in the ordination display. The web of positive significant correlations involving P. setiferus, Xiphopenaeus, Portunus, Cynoscion, Stellifer, and Acetes are mostly due to the temporal coincidence of the groups, along with the fact that highest populations were found at Big Hill for Stellifer, Xiphopenaeus, and Penaeus.

The cluster of all Big Hill samples in the upper right side of the sample space (Figure 4.3-17) is due to the dominance of Stellifer and Xiphopenaeus at this site. This site segregation is also responsible in large part, for the trophic display (see Figure 4.3-19), with the population at Big Hill being dominated by scavengers and the Black Bayou site, especially, dominated by a phytoplankton-feeding population. The lack of significant interaction in the ANOVA's for Stellifer and Xiphopenaeus indicates that means were consistently higher over time at Big Hill, leading to the cluster of all Big Hill samples (over four cruises) in the upper left corner of the sample space (see Figure 4.3-17).

4.3.5 Surficial Sediments

4.3.5.1 Grain Size Distribution of Surficial Sediments

Textural analyses of the surficial sediments collected during Cruises III and IV are presented in Tables 4.3-40 and 4.3-41*. The mean and median sediment size at the five sites ranges from medium silt (5ϕ to 6ϕ) to coarse clay (8ϕ to 9ϕ) (Table 4.3-42 and Figure 4.3-20). Statistical parameters are shown in Tables 4.3-43 and 4.3-44. In general, the total percentages of sand, silt and clay at the five sites shows little change from Cruise III to Cruise IV. The stations within the five sites, however, often showed a wide variation in the percentages of sand, silt and clay. The West Hackberry Control site, the easternmost of the five sites, has the highest percentage of coarse material. Considering that the currents in the region sweep the continental shelf from east to west, and that the Mississippi delta is east of the sites, the large portion of coarse sediments at the West Hackberry Control site might be expected. Furthermore, the largest portion of fine sediments occurs at the westernmost site--Big Hill (Tables 4.3-40, 4.3-41, and 4.3-42). Nevertheless, the sites between Big Hill and West Hackberry Control are not aligned in a simple "coarse-to-fine" trend (Table 4.3-42). The sediment distribution pattern is probably due in part to a number of sediment sources in addition to the Mississippi delta. These sources include the Calcasieu and Sabine Rivers, as well as an occasional influx of coarse sediments during stormy weather, derived from the near-shore, shallow water environment farther north along the coast. Irregular bottom topography can also influence sediment distribution; mainly in

*Textural analyses of samples collected during Cruises I and II in conjunction with the chemical work are not included in the discussion.

Table 4.3-40

PERCENTAGES OF SAND, SILT AND CLAY

CRUISE III

Site	Station	% Sand	% Silt	% Clay
West Hackberry Control	27	58.3	17.4	24.3
	28	57.8	15.9	26.3
	29	46.2	20.5	33.3
	30	56.3	21.2	22.5
	31	46.0	26.9	27.1
	32	48.0	24.7	27.3
West Hackberry	6	32.2	32.6	35.2
	7	30.1	32.4	37.5
	8	10.3	31.8	57.9
	10	22.8	31.1	46.1
	14	39.4	28.7	31.9
	15	9.0	33.6	57.4
	16	9.1	24.1	66.8
	17	45.1	14.9	40.0
	18	65.7	14.9	19.4
	19	25.3	39.7	35.0
	22	67.7	10.1	22.2
Black Bayou	45	55.0	18.7	26.3
	46	45.1	21.1	33.8
	47	36.2	25.4	38.5
	48	57.0	15.4	27.6
	49	41.8	23.7	34.5
Big Hill Control	50	15.1	37.0	47.9
	51	13.0	29.9	57.1
	52	17.1	28.6	54.3
	53	11.6	33.3	55.1
	54	32.0	28.9	39.1
Big Hill	37	1.0	27.6	71.4
	38	2.6	27.3	70.1
	39	3.9	28.8	67.3
	41	7.1	27.4	65.5
	42	2.6	27.2	70.2
	43	14.6	25.4	60.0
	44	14.1	29.2	56.7

Table 4.3-41

PERCENTAGES OF SAND, SILT AND CLAY

CRUISE IV

Site	Station	% Sand	% Silt	% Clay
West Hackberry Control	27	59.8	15.5	24.7
	28	59.7	19.1	21.2
	29	40.4	38.4	21.2
	30	53.0	23.1	23.9
	31	42.2	34.9	22.9
	32	35.1	31.6	33.3
West Hackberry	4	3.3	93.3	3.4
	6	26.2	38.3	35.5
	7	11.2	48.8	40.0
	8	2.0	30.5	67.5
	10	31.8	26.5	41.7
	14	32.1	30.8	37.1
	15	5.2	28.9	65.9
	16	6.8	33.1	60.1
	17	53.4	19.0	27.6
	18	46.4	51.7	1.9
	19	39.5	31.2	29.3
	22	67.7	12.7	19.6
Black Bayou	45	45.3	25.8	28.9
	46	40.4	23.2	36.4
	47	43.7	25.4	30.9
	48	63.2	13.4	23.4
	49	46.5	24.1	29.4
Big Hill Control	50	14.2	33.9	51.9
	51	13.5	28.7	57.8
	52	10.6	37.2	52.2
	53	11.0	35.8	53.2
	54	20.1	36.8	43.1
Big Hill	37	1.2	58.9	44.9
	38	2.5	34.8	62.7
	39	3.5	24.7	71.8
	41	3.8	33.9	62.3
	42	57.4	8.0	34.6
	43	5.2	34.3	60.5
	44	14.4	33.8	51.8

Table 4.3-42

Surficial Sediment Statistical Parameters

CRUISE III

	Big Hill	Big Hill Control	Black Bayou	West Hackberry	West Hackberry Control
M_d	9.07	8.05	4.57	6.02	4.10
M_ϕ	8.76	8.66	7.46	8.01	6.61
σ_I	3.09	3.83	4.53	4.26	4.01
Sk_I	-0.12	0.12	0.56	0.41	0.59
K_G	1.07	0.85	1.12	1.02	1.14

Surficial Sediment Statistical Parameters

CRUISE IV

	Big Hill	Big Hill Control	Black Bayou	West Hackberry	West Hackberry Control
M_d	7.81	7.80	4.29	6.15	4.16
M_ϕ	8.20	7.97	6.99	7.15	6.81
σ_I	3.09	3.13	4.22	3.30	3.92
Sk_I	-0.07	0.01	0.58	0.21	0.60
K_G	0.98	0.76	1.05	1.17	1.29

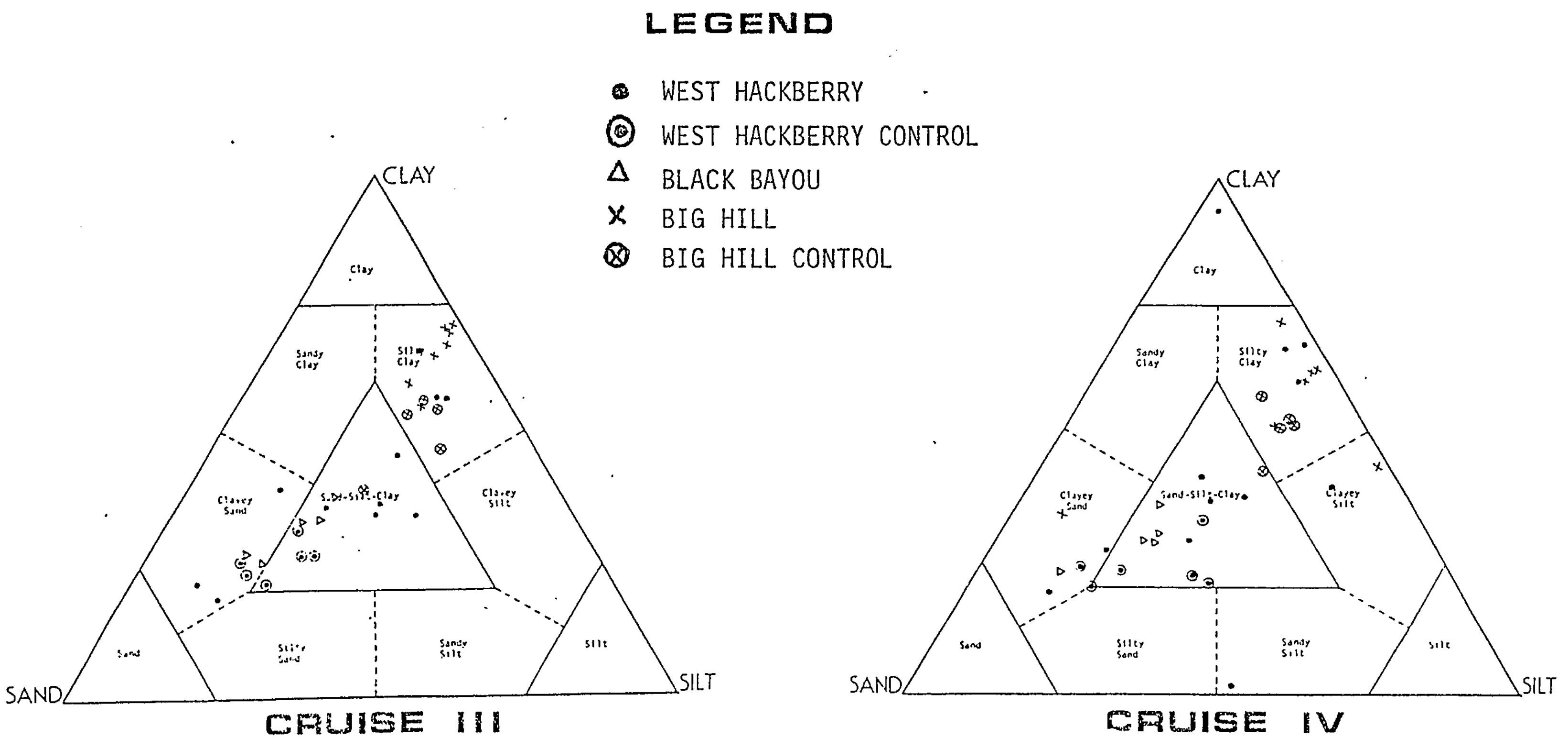


Figure 4.3-20 Triangular Facies Diagrams for Cruises III and IV.

Table 4.3-43

SURFICIAL SEDIMENT STATISTICAL PARAMETERS

CRUISE III

Site	Station	M_ϕ	M_σ	σ_I	Sk_I	K_G
West Hackberry Control	27	3.80	6.71	3.95	0.68	1.27
	28	3.70	5.58	5.00	0.40	1.30
	29	4.55	7.22	4.09	0.61	0.87
	30	3.85	7.37	4.61	0.70	1.75
	31	4.55	5.53	2.42	0.40	0.64
	32	4.15	7.25	4.02	0.72	0.99
West Hackberry	6	5.20	7.66	4.04	0.57	0.88
	7	5.70	8.66	4.92	0.56	0.94
	8	9.05	9.87	4.52	0.16	0.88
	10	7.10	8.19	4.42	0.22	0.85
	14	4.85	7.01	3.67	0.55	0.83
	15	9.20	10.62	5.16	0.25	0.94
	16	8.75	7.81	2.45	-0.34	1.41
	17	4.85	7.80	5.17	0.54	0.80
	18	3.20	6.00	3.40	0.67	1.32
	19	5.40	8.46	5.16	0.55	1.06
	22	3.00	6.12	3.96	0.73	1.32
Black Bayou	45	3.80	7.15	4.47	0.69	2.08
	46	4.50	7.06	4.08	0.59	0.81
	47	5.60	9.23	5.81	0.58	0.90
	48	3.35	7.75	5.39	0.75	1.20
	49	5.60	6.13	2.90	0.17	0.61
Big Hill Control	50	7.65	8.91	4.22	0.27	0.83
	51	8.45	8.42	3.44	-0.02	0.86
Big Hill	37	9.10	8.65	2.29	-0.17	1.14
	38	8.80	8.11	1.95	-0.32	1.16
	39	8.95	8.51	2.68	-0.16	1.11
	41	9.90	10.65	4.62	0.15	0.93
	42	9.65	9.73	3.06	0.02	0.96
	43	8.60	7.98	3.26	-0.19	0.96
	44	8.50	7.69	3.78	-0.18	1.21

Table 4.3-44

SURFICIAL SEDIMENT STATISTICAL PARAMETERS

CRUISE IV

Site	Station	M_ϕ	M_σ	σ_I	Sk_I	K_G
West Hackberry Control	27	3.65	6.30	4.03	0.61	1.05
	28	3.65	8.86	6.25	0.72	2.37
	29	4.35	6.03	3.06	0.52	1.12
	30	3.95	6.31	3.41	0.65	1.08
	31	4.35	6.73	3.37	0.65	1.29
	32	5.05	6.66	3.42	0.45	0.83
West Hackberry	4	6.80	6.18	0.95	-0.61	2.66
	6	5.55	7.13	3.17	0.47	0.77
	7	6.70	8.15	3.63	0.37	0.86
	8	9.00	8.91	2.24	-0.03	1.04
	10	7.15	6.69	4.23	-0.09	0.90
	14	5.70	8.28	4.84	0.49	0.92
	15	8.85	8.76	2.78	-0.02	1.04
	16	8.35	7.33	2.81	-0.42	1.10
	17	3.70	7.20	4.97	0.65	1.18
	18	4.40	4.47	2.14	0.04	0.61
	19	4.60	7.01	4.10	0.55	1.00
	22	3.00	5.76	4.33	0.60	2.00
Black Bayou	45	4.50	6.11	3.33	0.45	0.78
	46	4.85	8.06	5.11	0.59	0.93
	47	4.60	8.37	5.22	0.66	1.80
	48	3.00	5.88	3.65	0.74	0.92
	49	4.50	6.55	3.81	0.50	0.85
Big Hill Control	50	8.10	7.69	2.54	-0.16	0.65
	51	8.70	8.60	3.76	-0.03	0.86
	52	8.10	8.94	3.87	0.19	0.82
	53	8.15	7.40	2.40	-0.30	0.75
	54	5.95	7.26	3.12	0.39	0.75
Big Hill	37	7.75	7.03	1.69	-0.41	0.76
	38	9.05	9.24	3.13	0.04	0.92
	39	9.25	8.78	2.65	-0.16	0.95
	41	8.90	9.14	2.90	0.06	0.94
	42	3.45	9.06	6.37	0.83	1.00
	43	8.25	7.22	1.86	-0.53	1.23
	44	8.05	6.97	3.03	-0.32	1.12

two ways. First, topographic highs can contribute sediment to surrounding areas, and this sediment may not be indicative of the present current regime acting at the site. Second, the topography can alter the bottom currents with a tendency for coarser particles to settle-out into depressions or behind topographic highs. The result will be a patchy network of coarse to fine sediments. Judging from the wide variations in sand, silt and clay percentages reported for each station (Table 4.3-40 and 4.3-41), it seems likely that either (1) the area receives sediment from many sources, or (2) that the hydraulic regime is very erratic in strength and consistency, or both.

Frequency and cumulative frequency graphs were constructed for each center station of the five sites using data for Cruises III and IV (Figures 4.3-21, 4.3-22 and 4.3-23). The stations chosen are fairly representative of the total average sand, silt and clay percentages for each site (Tables 4.3-40 and 4.3-41). In general, textural differences from Cruise III to IV are very slight, the exceptions being the coarse fraction added to West Hackberry - Station 10; the coarse fraction removed from West Hackberry Control - Station 30; and the abrupt increase in fine sediment at Big Hill Control - Station 50. The significance and interpretation of these textural changes may become apparent as data from future cruises are analyzed.

According to a classification prepared by Folk (1966) based on the standard deviation of a sediment distribution (Table 4.3-42), the sediments at each of the five sites are "very poorly" to "extremely poorly sorted." Factors contributing to the poor sorting are, among others, erratic and inconsistent currents, multiple sources of sediment, and irregular or relict (Holocene) bottom topography.

Skewness (SK_I - Table 4.3-42) is a measure of the asymmetry of a distribution and can sometimes be used to identify past depositional environments. All sites except Big Hill are skewed toward the finer sediments (positive skewness - $+\phi$). Two hypothetical, though very different current regimes can account for the positive skewness. The first is a weak current regime in which the currents are unable to dislodge and remove the fine silts and clays, but are able to remove the coarser particles by traction and saltation. The second possibility is a strong current regime operating across a Holocene erosional surface. In this case, the currents are able to remove all sediments (erosional debris) equally well. The sediment distribution would therefore reflect the Holocene current regime and not the present one.

The other statistical parameters shown on Table 4.3-42 are the median diameter (Md), the mean ($M\phi$) and kurtosis (KG). No significant differences occurred in the mean and median sediment sizes from Cruise III to Cruise IV. It is interesting to note, however, that from Cruise III to IV, the mean and median sediment sizes become slightly finer at West Hackberry Control, and slightly coarser to the west at the Black Bayou, Big Hill Control and Big Hill sites (Table 4.3-42). Kurtosis is a measure of the degree of peakedness of a distribution, but has generally proven to have little geological significance.

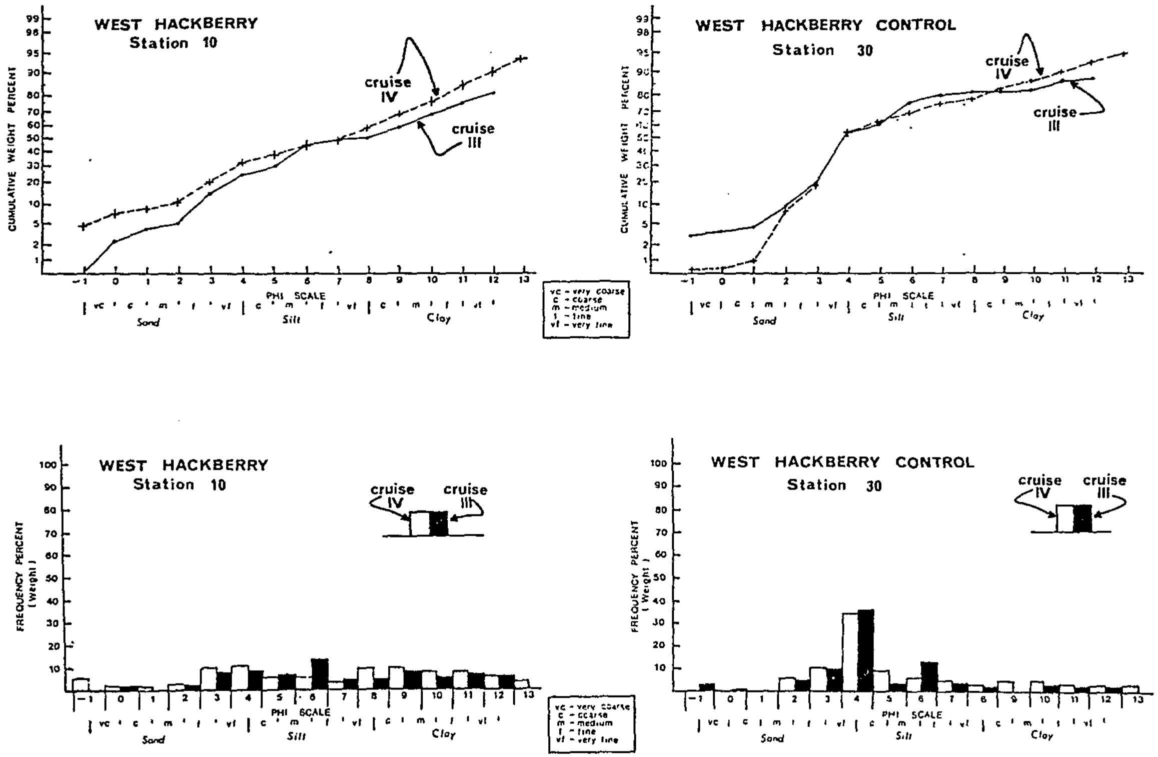
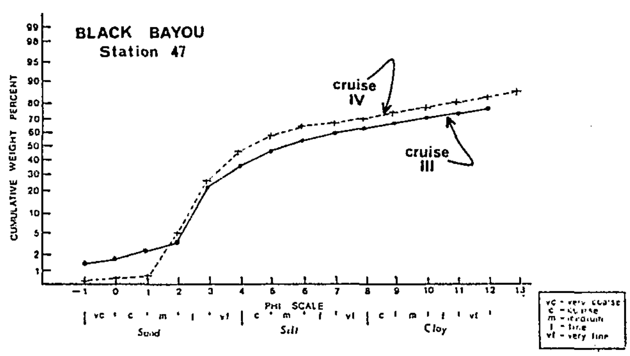


Figure 4.3-21 (Below) Histograms of sediment samples collected at West Hackberry Control (Station 30) and West Hackberry (Station 10) during Cruises III and IV.
(Above) Cumulative frequency graphs of data presented in histograms.



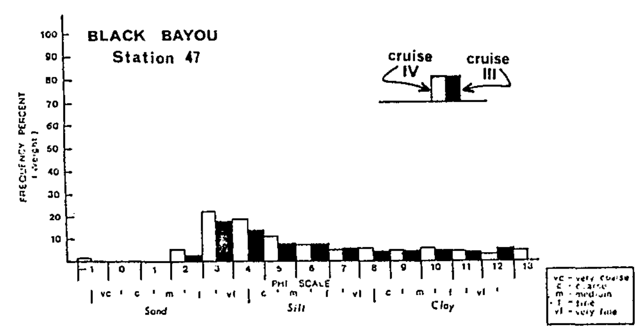


Figure 4.3-22 (Below) Histogram of sediment samples collected at Black Bayou (Station 47) during Cruises III and IV.
(Above) Cumulative frequency of data presented in histogram.

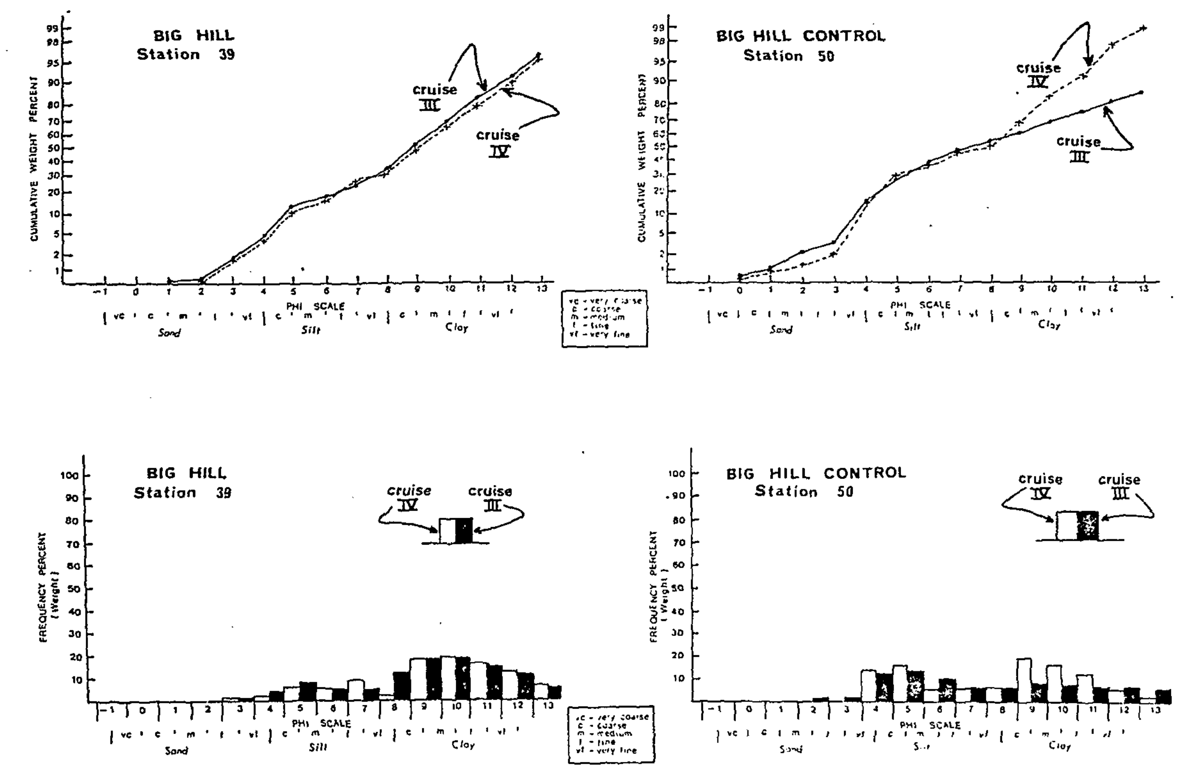


Figure 4.3-23 (Below) Histograms of sediment samples collected at Big Hill Control (Station 50) and Big Hill (Station 39) during Cruises III and IV.
(Above) Cumulative frequency graphs of data presented in histograms.

Results of the Analyses of Variance (ANOVA's) for sediment parameters are presented in Table 4.3-45. For all grain size parameters mean phi size (Mphi), median diameter (Md), percent fines (silts and clays), percent clays, and percent sands) except percent silt, results clearly show significant ($p = 0.05$) site differences with no significant cruise effects and no significant interactions, the latter indicating that over both cruises all sites were behaving similarly. Analyses for percent silt showed the opposite results, with no significant site differences but significant cruise differences, and again no significant interaction.

Because of the lack of significant interaction, multiple means tests were used in subsequent analyses. Results of these analyses of grain size parameters are shown in Table 4.3-46. Big Hill and Big Hill Control, lying west of Sabine Pass, had sediments which were signficantly finer than those of the more eastward sites. For most parameters, Big Hill and Big Hill Control did not differ significantly from each other. However, over both cruises, Big Hill had significantly higher clay content than Big Hill Control. West Hackberry, which occupies an intermediate position in sediment size distribution had, for all parameters tested, significantly coarser composition than Big Hill and Big Hill Control, and signficantly finer composition than West Hackberry Control, the latter located seven miles east of Calcasieu Pass. For percent fines and Md, West Hackberry had significantly higher means than Black Bayou, while for percent clays and Mphi, West Hackberry and Black Bayou were not significantly different. Black Bayou and West Hackberry Control, which consistently had the lowest and next lowest means, respectively, were not significantly different for any of these parameters. Poorest segragation of sites in the Analyses was found with Mphi, although the overall results are comparable with the other parameters. As expected, the results of the multiple means tests for percent sand gave results just opposite of those found for percent fines (100 percent sand), with West Hackberry Control and Black Bayou being significantly higher than the other sites and West Hackberry also significantly higher than the sites west of Sabine Pass. For percent silt, which showed significant cruise differences, no subsequent analyses were required since the means from only two cruises were used. The December means were significantly higher than those for November, but the trend was not especially strong ($p = 0.04$).

4.3.5.2 Calcium Carbonate Content in Surficial Sediments

The calcium carbonate percentages for each station, and the total average percentage for the five sites are shown in Tables 4.3-47 and 4.3-48 for Cruises I, II, III and IV. Relatively large variations in calcium carbonate percentages were measured from station to station. No significant site to site differences in the total average calcium carbonate content were measured (Table 4.3-47 and 4.3-48).

Table 4.3-45 Results of Analysis of Variance for Sediment Parameters

Parameters	Cruise	Site	Cruise* Site
<u>Cruises 3 and 4</u>			
M Phi	.10	.002*	.78
Md	.74	.0001*	.74
Fines	.56	.0001*	.83
Clays	.15	.0001*	.79
Sands	.67	.0001*	.85
Silt	.04	.12	.79
<u>Cruises 1 and 4</u>			
Organic	.83	.0001*	.08
Carbonate	.0001	.16	.04*

*Significant at .05 level.

Table 4.3-46 Results of Multiple Means Tests for Sediment Parameters By Site

Parameters	(Highest				Lowest)
Percent Organic (4 Cruises)*	BHC	BH	WH	BB	WHC
Md (2 Cruises)	BH	BHC	WH	BB	WHC
Percent Fines (2 Cruises)*	BH	BHC	WH	BB	WHC
Percent Clays (2 Cruises)*	BH	BHC	WH	BB	WHC
MphI (2 Cruises)*	BH	BHC	WH	BB	WHC
Percent Sand (2 Cruises)*	WHC	BB	WH	BHC	BH

*Analyses performed on data transformed with Arcsine (X/100)

Tukey's t = 2.73

Table 4.3-47

PERCENT CALCIUM CARBONATE
FOR CRUISES I, II, III AND IV, 1977
SURFICIAL SEDIMENT SAMPLES

SITE	STATION	CRUISE I	CRUISE II	CRUISE III	CRUISE IV
West Hackberry Control	25	0.243	0.212	-----	-----
	26	0.195	0.314	-----	-----
	27	0.561	0.225	1.228	-----
	28	0.053	0.184	0.811	0.362
	29	0.733	0.035	-----	0.259
	30	0.226	0.200	0.024	0.064
	31	0.361	0.108	0.141	0.804
	32	0.891	0.081	0.672	0.540
	33	0.307	0.326	-----	-----
	34	0.294	0.283	-----	-----
	35	0.273	0.452	-----	-----
West Hackberry	4	0.301	0.489	0.360	0.156
	5	0.675	0.194	0.612	-----
	6	0.275	0.130	0.385	0.083
	7	0.353	0.960	0.026	-----
	8	0.364	0.140	0.230	0.138
	9	0.362	0.504	-----	-----
	10	0.336	0.241	0.107	0.092
	12	0.406	0.529	-----	-----
	13	0.480	0.192	-----	-----
	14	0.354	0.422	0.231	0.031
	15	0.346	0.180	0.230	0.008
	16	0.615	0.205	0.355	0.056
	17	0.410	0.470	0.289	0.084
	18	-----	0.082	0.171	0.060
	19	0.304	0.292	0.015	0.058
	22	0.212	0.163	0.156	0.049
	24	0.101	0.313	-----	-----
Black Bayou	45	0.231	0.435	0.152	0.023
	46	0.175	0.373	0.054	0.127
	47	0.297	0.421	0.562	0.056
	48	0.109	0.168	0.110	-----
	49	1.033	0.456	0.045	0.073
Big Hill Control	50	0.601	0.220	0.278	0.153
	51	0.300	0.345	0.266	0.014
	52	0.778	0.232	0.170	0.120
	53	0.532	0.235	0.225	0.108
	54	0.634	-----	0.014	0.068
Big Hill	36	0.540	0.199	-----	-----
	37	0.037	0.090	1.758	0.044
	38	0.564	0.136	0.459	0.052
	39	0.704	0.445	0.045	0.050
	41	0.648	0.522	0.270	0.186
	42	0.487	0.075	-----	0.144
	43	0.842	0.320	0.462	0.129
	44	0.901	0.362	0.193	0.276

Table 4.3-48

SURFICIAL SEDIMENTS

PERCENTAGE OF CALCIUM CARBONATE PER SITE

	BIG HILL	BIG HILL CONTROL	BLACK BAYOU	WEST HACKBERRY	WEST HACKBERRY CONTROL
CRUISE I	0.555	0.459	0.380	0.367	0.386
CRUISE II	0.289	0.263	0.370	0.323	0.196
CRUISE III	0.529	0.190	0.184	0.243	0.575
CRUISE IV	0.125	0.093	0.085	0.074	0.405
AVERAGE	0.374	0.251	0.254	0.251	0.390

Cruise I was in September of 1977, with the next three cruises occurring in October, November and December. The general trend of the calcium carbonate content was to decrease during the four month period. Exceptions, however, were the West Hackberry Control and Big Hill sites which recorded a two-fold increase in calcium carbonate content from Cruise II to Cruise III (Table 4.3-37). The general reduction in calcium carbonate content from September to December may be related to a reduction in organic activity during this period, as well as some dissolution of calcium carbonate in colder water.

Results of the Analysis of Variance of data for percent calcium carbonate (Table 4.3-34) showed significant cruise effects. The interaction term was also significant, indicating divergence in behavior for some sites over the four months. The interaction was probably due to the behavior of calcium carbonate at West Hackberry Control and Big Hill as discussed above.

4.3.5.3 Total Organic Matter Content in Surficial Sediments

The percentage of total organic matter at each station sampled during the four cruises is shown in Table 4.3-49. The percentage of total organic matter at each site is shown in Table 4.3-50. No obvious relationship can be found between the percentage of total organic matter and the cruise that the samples were collected.

Analyses of Variance for percent organic matter (Table 4.3-45) showed that there were significant site differences with no significant interaction, indicating that trends at all sites were similar over time.

The results of the multiple means tests for percent organic matter (see Table 4.3-46) show results which are extremely similar to those for sediment type. Big Hill Control and Big Hill had percents of organic matter not significantly different from each other, but significantly higher than those at the sites east of Sabine Pass. The organic contents of the sediments at West Hackberry were significantly higher than those at West Hackberry Control, but not Black Bayou, the latter not being significantly higher than West Hackberry Control.

Clearly, in both sediment size and percent organic matter, there is an east-west gradient, with increasing percent organic matter and decreasing grain size for the more westerly sites.

Correlation analyses were run on the sediment texture parameters (percent clays, percent fines and percent sands) for Cruises 3 and 4. The results, presented in Table 4.3-51, show similar relationships for the data for the two cruises. This coincides with the lack of significant cruise differences and lack of interaction found in the ANOVA's. From the two cruises combined, percent organic matter was correlated (postively) significantly with percent fines ($r = 0.48$) and clays ($r = 0.45$), and correlated (negatively) significantly with percent sand ($r = -.43$). The percent carbonate was not significantly correlated

Table 4.3-49

PERCENT TOTAL ORGANIC
MATTER FOR CRUISES I, II, III AND IV, 1977
SURFICIAL SEDIMENT SAMPLES

SITE	STATION	CRUISE I	CRUISE II	CRUISE III	CRUISE IV
West Hackberry Control	25	0.220	0.109	-----	-----
	26	0.318	0.205	-----	-----
	27	0.095	0.167	0.175	-----
	28	0.380	0.221	0.261	0.187
	29	0.093	0.140	-----	0.188
	30	0.123	0.142	0.218	0.171
	31	0.089	0.123	0.304	0.150
	32	0.540	0.247	0.048	0.155
	33	0.217	0.105	-----	-----
	34	0.126	0.413	-----	-----
	35	0.279	0.404	-----	-----
West Hackberry	4	0.345	0.354	0.292	0.375
	5	0.220	0.486	0.412	-----
	6	0.212	0.275	0.297	0.201
	7	0.116	0.296	0.291	0.450
	8	0.295	0.397	0.524	0.320
	9	0.545	0.466	-----	-----
	10	0.224	0.334	0.363	0.290
	12	0.186	0.367	-----	-----
	13	0.122	0.338	-----	-----
	14	0.390	0.281	0.308	0.196
	15	0.383	0.435	0.394	0.179
	16	0.236	0.500	0.517	0.563
	17	0.826	0.252	0.268	0.141
	18	-----	0.308	0.263	0.179
	19	0.043	0.171	0.150	0.266
	22	0.118	0.208	0.243	0.590
	24	0.348	0.345	-----	-----
Black Bayou	45	1.294	0.260	0.340	0.195
	46	0.082	0.188	0.027	0.184
	47	0.285	0.316	0.396	0.324
	48	0.042	0.115	0.247	-----
	49	0.104	0.232	0.222	0.190
Big Hill Control	50	0.366	0.313	0.350	0.275
	51	0.502	0.425	0.600	0.479
	52	0.318	0.491	0.285	0.303
	53	1.613	0.519	0.062	0.300
	54	0.128	-----	0.251	0.334
Big Hill	36	0.036	0.630	-----	-----
	37	0.201	0.503	0.139	0.660
	38	0.230	0.505	0.420	0.360
	39	0.251	0.630	0.564	0.489
	41	0.183	0.551	0.500	0.797
	42	0.358	0.544	-----	0.515
	43	0.264	0.555	0.435	0.334
	44	0.238	0.418	0.309	0.380

Table 4.3-50

SURFICIAL SEDIMENTS

PERCENTAGE OF TOTAL ORGANIC MATTER PER SITE

	BIG HILL	BIG HILL CONTROL	BLACK BAYOU	WEST HACKBERRY	WEST HACKBERRY CONTROL
CRUISE I	0.222	0.585	0.382	0.236	0.220
CRUISE II	0.527	0.437	0.222	0.345	0.187
CRUISE III	0.394	0.309	0.246	0.332	0.201
CRUISE IV	0.503	0.339	0.281	0.312	0.170
AVERAGE	0.411	0.417	0.283	0.306	0.134

Table 4.3-51 Correlations Between Various Sediment Parameters

	r values		
	Clay	Sand	Fines
ORGANIC MATTER			
November	.53(.002)*	-.48(.006)*	.47(.006)*
December	.40(.02)*	-.39(.02)*	.47(.006)*
Total	.45(.0002)*	-.43(.0003)*	.48(.0001)*
CALCIUM CARBONATE			
November	NS	NS	NS
December	NS	NS	NS
Total	NS	NS	NS

NS = Not significant

* Significance level

with any sediment size parameters nor was it correlated with percent organic matter. This might indicate that different environmental variables govern the behavior of calcium carbonate as compared to grain size or organic matter content. This presumption is further strengthened by the fact that calcium carbonate showed (in the ANOVA's) significant cruise differences, while none of the other sediment parameters did.

When the data for Cruise 3 and 4 are analyzed by site, no significant correlation between organic matter and any textural parameters was found. This expresses the dominance of site by site differerences in texture and organic matter, as well as the within site heterogeneity found in the Texoma study area.

No signficant correlation between % organic matter and % calcium carbonate was found.

4.3.5.4 Conclusions

Tentative relationships between grain size distribution, calcium carbonate content and total organic matter content are presented in Table 4.3-52. The reader is cautioned that these conclusions are based on data collected from only four cruises, and grain size data are from only two cruises. Analysis of additional data, which will reflect seasonal variations, may significantly modify these conclusions.

Major features of the sedimentary environment in the Texoma study region include a temporal pattern in $CaCo_3$ content (decreasing with time) but no clear-cut spatial distribution. Grain size decreases to the west and organic content increases to the west. The only discernible change in grain size parameters with time occurred in the silt fraction, which showed a significant but not strong difference between the two cruises.

In conclusion, the sediment distribution patterns determined to date suggest the following:

1. Relatively gentle, though not necessarily consistent bottom currents occur from east to west. These currents can, however, become quite strong during stormy weather, at which times powerful rip currents can contribute coarse sediments to the five sampling sites.

2. Numerous sources of sediment. If this area is a modern depositional environment and not a Holocene erosional surface, then rivers from the Sabine eastward to the Mississippi have produced the silt and clay distribution pattern observed.

3. The sediments of the Big Hill site are significantly finer compared with the sites to the east. Part of this clay may have been contributed by subaqueous exposures of the Beaumont Clay.

Table 4.3-52 Summary of Sediment Relationships and Trends

	$CaCo_3$	T.O.M.	Time	Distance
GRAIN SIZE	No apparent relationship.	As average grain-size for each site decreases, T.O.M. increases. This is a very consistent relationship.	(Cruises III & IV) Silt percentages increase from Cruise III to IV. Mean grain size increased slightly at all sites except West Hackberry Control.	Except for a reversal of average sediment size at the Black Bayou and West Hackberry sites, sediments become finer to the west.
$CaCo_3$		No apparent relationship	Calcium carbonate content generally decreases from Cruise I (Nov.) to Cruise IV (Dec.)	No apparent relationship
T.O.M.			No apparent relationship	High T.O.M. content is positively correlated with decreasing sediment size, which is related to distance (see block above)

4.4 Summary and Discussion

The present report presents data on the phytoplankton, zooplankton, macrobenthos and demersal nekton, for the Texoma region collected from September and December 1977. In general the community composition of these groups of organisms is characteristic of the coastal waters and in particular of the white shrimp grounds, of the northern Gulf of Mexico. In terms of standing crop the phytoplankton, zooplankton and demersal nekton are comparable to or somewhat higher than reported elsewhere in the northern Gulf. The benthos, however, shows markedly lower standing crops than reported elsewhere. The zooplankton show little in the way of site specific trends. The benthos is also relatively constant except that the Big Hill site seems to be severely depressed. This appears to be associated with the finer sediments in this area. Phytoplankton and demersal nekton show some evidence for a westwardly increasing standing crop, No obvious explanation for this is presently apparent.

All four communities showed marked changes in standing crop from month to month. The phytoplankton standing crop generally increased from October to December. Zooplankton fell from September to November with some recovery in December. The benthos fell from September to October, and then rose from October to December. The demersal nekton increased through November and then fell off slightly. These trends seem to be related. The phytoplankton, zooplankton and benthos show a consistent pattern of minimum standing crops in October with restoration or maximum standing crops in December. This may be related to seasonal and/or climatic phenomenon marking the onset of autumnal environmental conditions. The demersal pattern is explicable in this context as an expression of the autumnal migration cycle. At any event overall changes in standing crop seem to support a general deterioration in the environment during the September-October time frame. Changes in species composition for the benthos, phytoplankton and zooplankton also support this view. Whether the source of this deterioration is climatic or anthropogenic is at this point uncertain.

The mean grain size of surficial sediments at the five sampling sites ranged from coarse clay to fine silt. With the exception of one site, mean grain size decreased westward. Variations in sediment size from Cruise III to Cruise IV were slight, but somewhat consistent, with all sites except West Hackberry Control showing an increase in mean grain size. The average percentage of calcium carbonate at each site, totaled for the four cruises, ranged from 0.25% to 0.39%. There was no apparent relationship between calcium carbonate content and grain size or total organic matter. There was, however, a general reduction in the percentage of calcium carbonate measured in the sediments from Cruise I (September) to Cruise IV (December). The average percentage of total organic matter at each site, totaled for the four cruises, ranged from 0.13% to 0.41%. No significant variations of total organic matter were measured from cruise to cruise but a very consistent relationship was determined between decreasing mean grain size and increasing total organic matter.

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Section 5.0

Synthesis and Conclusions

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5.0 SYNTHESIS AND CONCLUSIONS

5.1 INTRODUCTION

Since the initiation of SPR Program there has been concern over the environmental risks associated with offshore brine disposal. These risks, as sources of potential impact on the regional biota have been discussed or outlined in various publications (TAMU 1977, FEA 1977). The evaluation of these risks has been made difficult by the absence of detailed knowledge of the biota of the study sites, as well as a lack of thorough understanding of the hydrologic, chemical and geologic environments. Within the Texoma region, continuing studies, detailed in the foregoing sections, are rapidly improving our understanding of the regional biology and environment. While these studies, as presented here, cover only the period from September to December, they are sufficiently detailed to permit an initial evaluation of the potential impacts of offshore brine disposal.

5.2 IMPACTS ASSOCIATED WITH BRINE DISPOSAL

The potential impacts associated with offshore brine disposal have been discussed in detail in Appendix Q. It is appropriate at this point to provide a cursory outline of these impacts.

Impacts of offshore brine disposal from the Texoma storage sites would be of two types: a) physical impacts associated with the mechanical operation of the diffuser, and b) chemical impacts associated wth the nature of the effluent. Physical impacts include buffeting of biological organisms in the near field turbulent plume, the creation of a physical barrier to offshore-onshore movement of nekton, and the creation of a high density lens of brine over the bottom inhibiting vertical mixing. Chemical impacts are associated with biological responses to a) elevated salinity, b) altered ionic composition, and c) elevated trace metal and hydrocarbon concentrations. Elevations in salinity may influence the biota either through behavioral or physiological modes. Impacts through behavioral modes primarily entail interference with offshore-onshore nekton migratory patterns by distortion of the natural salinity gradient. Impacts through physiological modes include:

1. Osmotic stress influencing water balance, cellular respiration, growth and reproduction.

2. Changes in toxic responses (as to heavy metals) due to changes in pH.

3. Oxygen deficiencies due to decrease O_2 solubility.

4. Synergistic effects with regard to various tolerances (e.g., temperature).

5.3 EFFECTS OF THE BRINE PLUME ON THE ENVIRONMENT

5.3.1 Areal Extent and Orientation of the Brine Plume

In order to gain an understanding of the potential impacts of brine disposal it is necessary to have an understanding of the distribution of the effluent about the disposal point, as well as a feeling for its rate of dispersal. The initial analyses with the the MIT model (FEA 1977) describing the brine field provided a gross and (probably conservative) approximation of the behavior of the brine plume at various Texoma sites. For the West Hackberry, worst case (stagnation, see Appendix C, Figure C.3-9), this analysis indicated that the portion of the plume enclosed by the 3 ppt isohaline was typically less than 119 acres, while that enclosed by the 1 ppt isohaline was typically less than 3700 acres. These values were based on model runs assuming stochastically varying currents consonant with what was then known of the current regime. Hydrographic and meteorological records collected at the disposal sites during the September-December time frame have provided a better understanding of local current patterns. Utilizing site specific current records as model inputs, improved estimates of plume behavior have been possible. The results of these runs indicate that typically less than 207 acres will be enclosed within the 3 ppt isohaline and less than 1860 acres will be enclosed by the 1 ppt isohaline. In general the base case and the runs using measured site-specific current data were very similar. The orientation of the plume depends primarily upon current direction. It was assumed in the early work (FEA 1977) that the dominant currents were alongshore, alternating from east to west with a general westward bias. Hydrographic results for the September-December time frame generally confirm the validity of this assumption. This is clearly reflected in the plume orientation predicted by the MIT model. When the plumes generated at Black Bayou, for example, are considered, the alongshore trend is quite clear (Figures 2.3-33 to 2.3-40) as is the alternation between eastward and westward flow, with a somewhat westward bias. The model runs for October and November at West Hackberry (2.3-10 to 2.3-16) showed plumes with a north to south orientation due to the relatively high onshore-offshore component of currents during this time.

5.3.2 Brine Water Column Interaction

The water column chemistry in the near field may be affected by discharge of large volumes of brine. The presence of a dense layer of brine in the lower portion of the water column would be expected to inhibit vertical mixing and the supply of materials such as nutrients and oxygen from ocean water to animals in the mixing zone. The brine would contain precipitates which would affect light transmissivity and which could conceivably be ingested by demersal animals.

The fact that the bottom water layers do not always mix well with the rest of the water column suggests that additional large areas of the bottom may be exposed to increased salinity levels. Such a result would be most likely during summer when there is stratification of the water column.

The tendency of particles to be distributed within mixing zones and between the zones and the surrounding water is a function of the structure of the particles themselves. In the case of zooplankton, this distribution is partly due to self-propulsive behavior. The accumulation of plankton at discontinuity layers is a well-documented phenomenon. Changes in the normal dispersion of plankton may occur in the vicinity of the brine discharge areas.

The assumption of a relatively high pH (Appendix D.15) in the modeling of chemical species in the outfall mixing zone seems warranted. Heavy metal and hydrocarbon contaminants would be at relatively low levels in the source water for leaching and in the brine resulting from leaching.

These materials are also present at comparatively low levels in the seawater of the Texoma brine disposal region. Contaminant levels in the brine would be diluted along with other constituents and would not appreciably degrade water quality in the water column. One exception may be iron, which is in high concentrations in the proposed water source for the West Hackberry storage facility. This is present in particulate form in the brine, but could be released into the water column as ferrous irons under anerobic conditions. Under oxidizing conditions, the iron has a strong affinity for phosphate, with which it forms an insoluble compound, ferric phosphate.

Direct physicochemical changes in the water column resulting from brine discharge would be reversed shortly after discharge ceased. The sediments could, however, serve as a secondary source of contamination.

5.3.3 Brine-Sediment Interactions

Diffusion in interstitial water in sediments is a very slow process which is unlikely to significantly impact water column chemistry. It is simply too slow. Duursma and Eisma (1973) studied the penetration of reacting ions in pore waters of different sediments using radiotracer techniques. Starting with a 10 percent concentration in overlying water, the extrapolated time to reach constant concentration to a depth of 1 cm ranged between 20 days and 274 years, with the most typical values ranging between 200 days and 55 years. In natural situations, the thickness of the aerobic layer is a clue to whether the sediments are being actively mixed--a thin layer indicating largely diffusive change.

Sorption behavior (adsorption and desorption) of metals is sensitive to both pH and salinity fluctuations within the observed ranges at the Texoma study sites. The adsorption of various ions is also related to nedox potential. The differences between adsorption under oxygenated and anoxic conditions generally do not exceed an order of magnitude. Adsorption is higher for some dissolved materials under the oxygenated regime and higher for others under anoxic conditions. Active mixing in the water column is found to result in appreciable changes in salinity of sediments in the Pocasset River estuary in Massachusetts (Sanders, et al., 1967). The amplitude and rate of change in salinity are much smaller than those in the overlying water. Salinity levels do reflect the regime in the water column however. Diurnal salinity changes were detected in soft muds up to a depth of 4 cm, but by far the greatest amount of change occur near the surface.

It seems reasonable to project a buildup of brine components in the sediments of the disposal area. This buildup would largely be restricted to the mixed zone at the surface of the sediment. As discussed in Appendix Q, there can be a differential buildup of dominant exchange cations analagous to the situation seen in soils. However, disruption of physical structure, which occurs because of chloride leaching in soils, would not be expected since chloride would be replaced in the marine environment.

Buildup of high concentrations of brine in a thin surface layer over a relative small, restricted area should be reversed rapidly after brine release has ceased. The rate of dilution should be comparable to the rate at which the brine was concentrated. Since the storage zone is small, exchange of the concentrated dissolved materials should have considerably less impact than additional primary brine release from a diffuser.

Precipitated solids would be accumulated on surfaces in the disposal area. Impacts of these materials are not known, except for iron, which was assessed in connection with impacts on the water column. Presumably, most of these materials, which are in inactive form, would have little effect on the ecosystem. Ultimately, the precipitates would be dispersed and mixed with the sediments. Some of these compounds may dissociate under different electrochemical conditions in the sediments.

5.4 EVALUATION OF IMPACTS

Given a knowledge of the regional biota and an understanding of the likely orientation and areal extent of the plume, it is possible to say something of the magnitude of effect which various postulated impacts may be expected to exert. There are three basic assemblages of organisms which would be affected by brine discharge: the plankton, the demersal nekton and the benthos.

5.4.1 Impacts to the Plankton

The plankton can be expected to be impacted most severely in the immediate vicinity of the brine diffuser. In this area maximun turbulence as well as exposure to maximum salinity overages are to be expected. Only those organisms quite close to the diffuser (say within 400 feet) can be expected to encounter any significant problems due to turbulence per se. Even here, the diatom dominated phytoplankton community should not be significantly impacted in this fashion. The zooplankton community, particularly egg and larval forms, may be more sensitive to this type of stress, but the duration of exposure to such turbulence should be brief, and therefore inconsequential.

More critical to the plankton will be exposure to elevated salinities, or associated factors such as elevated pH, variation in ionic composition, exposure to toxic substances, etc. The extent to which these other factors represent departures from ambient conditions should be more or less proportionate to the elevation in salinity. Since these factors act in concert it is convenient to discuss their net impact on the plankton simply in terms of salinity elevation.

Consequences for the plankton of exposure to brine depend on a) the salinity excess above ambient (exposure level), and b) the length of time of the contact (exposure period or duration). Results of recent bioassay work with brine from the Bryan Mound site (USDC 1978) indicates that for Skeletonema costatum, a species characteristic of the Texoma study site excess salinities of up to at least 4 ppt have no detrimental effect on growth. The forty-eight hour median mortality of eggs of the spotted sea trout during the hatching period was 34 ppt, indicating a relatively sensitive stage in the life cycle. Larval sea trout mortality was also assayed. Exposure to brine during a full twenty-four or forty-eight hour period for this fish gave nearly the same results as exposure for one or two-hour periods. The range is 42 to 55 ppt, corresponding to the median mortality after the one-hour pulse exposure after 24 and 48 hours, respectively. Young sheephead minnows, which are salinity tolerant, had a twenty-four hour median lethal concentration of 55.5 ppt.

Blue crab larvae (zoeae) showed high average percentage mortality with a 1 ppt addition in salinity over a 30-ppt ambient level. With the twenty-four hour exposure, all treatment levels resulted in over a 50 percent mortality, while the control showed only about 20 percent. The level of 100 percent mortality was reached at about 44 ppt.

Stages of white shrimp were also studied. Egg hatching success over 24 hours was high, between the 35-45 ppt value range. Toxicity of brine to early shrimp postlarvae, observed at intervals of 24, 48, 72, and 96 hours, generally showed little relation to time although the ninety-six hour determination for one group is hard to interpret. There was however, very precipitous mortality from about 44 to 48 to 56 ppt. These concentrations were also important with respect to the metamorphosis of the shrimp from the nauplius to the protozoea stage. Most nauplii developed into protozoeae by seventy-two hours at salinity rates up to 45 ppt. Ninety-six hours after the embryo stage, development into protozoeae was inhibited by lower salinities of 32 to 36 ppt. The brine apparently is also less toxic to the nauplius stage, where mortality occurred at 56 ppt or slightly lower. It has been generally assumed that an exposure time of a few hours would not have much effect on zooplankton, however, this was not the case with larval sea trout. The time scale of effective exposure duration required for toxic effects on sensitive stages such as shrimp and sea trout eggs and crab zoeae has not been very finely resolved in most of the bioassay studies to date. Lethal effects may be expressed very rapidly. Another result which raises the same issue, but with a more tolerant stage, is the independence from time of brine-induced mortality to early shrimp postlarvae over 24-, 48-, 72-, and

96-hour exposure periods. The apparent threshold response may be a function of genetic and physiological similarity of the animals used in the toxicity tests. A wider range of response might be expected in nature, in which more susceptible individuals would be eliminated at lower toxicant levels or sooner.

Table 5.4-1 shows the period of exposure under salinities exceeding 1 ppt above ambient for a passively transported plankter under a typical (5 cm/sec) current regime. The exposure period varies from 8 to 22 hours. At higher excess salinities exposure period would be correspondingly briefer. At 4 ppt, above which reduction in growth for Skeletoma was noted, exposure period is probably less than 30 to 90 minutes. It is unlikely that such brief exposures would materially affect the diatom phytoplankton community.

With regard to the zooplankton response to the brine shows a fair degree of variability. Some of the forms tested (e.g. blue crab larvae) show significant mortality at salinities 1 ppt above ambient, under exposure periods of 24 hours. Such forms would probably experience significant mortality given the 8 to 22 hour residence time suggested by Table 5.4-1. Other forms tested were generally more tolerant of long term exposure at a few parts per thousand above ambient; mortality on this basis would probably be marginal. However, our knowledge of the effects of short term exposure at markedly elevated salinities is limited. Nonetheless, even if 50% mortality was assumed for entrained zooplankters a loss of only about .5 zooplankters per liter entrained would be realized. The total losses to the zooplankton probably represent a very small fraction of the total production of the area. On this basis the zooplankton community should be only marginally impacted.

5.4.2 Impacts to the Demersal Nekton

In general, the nekton of the Texoma study area should be less sensitive to brining operations than the plankton. For the most part they should be able to actively avoid the turbulent near field region. Their larger size should provide them with a relatively greater immunity to brief exposures to diluted brine. Further, their mobility, and probable avoidance reactions would tend to minimize their exposure to brine overages. It is likely that many forms will actively avoid the plume and so are not likely to become entrained or exposed to high salinity overages. At any rate, a swimming velocity of only 1 m/second would take a fish beyond the 1 ppt isohaline in at most between 20 and 60 minutes. Forms following the sharpest salinity gradient would be taken beyond the 1 ppt in perhaps a third of this time. Thus, direct lethal or sublethal consequences of exposure to the brine plume are likely to be minimal. It is possible that production of a brine plume lengthwise along the coast could act as a misorientatin cue for those nektonic forms utilizing salinity gradients as a guide in their offshore-onshore migrations. In the September-December time period the spatial variation in salinity at any given moment, was several parts per thousand. To act as a misorientation cue the brine plume overages would have to be as least as great as the natural variation. The extent of the plume, as indicated by the

Table 5.4-1 Periods of Exposure to Salinity Overages of 1 ppt or More for Passively Transported Plankton, Based on Various MIT Model Outputs, and an Average Current of 5 cm/sec.

Site Model Run Time (Hours)			Maximum Distance to 1 ppt Isohaline (Meters)	Time Before Organism Moves Beyond 1 ppt at 5 cm/sec Velocity
Big Hill	BH-1	0	2351	13.1
		48	2038	11.3
		78	3605	20.0
	BH-2	0	1411	7.8
		30	1881	10.5
		54	2822	15.7
Black Bayou	BB-1	0	2351	13.1
		34	2195	12.2
		70	1881	10.5
	BB-2	0	1568	8.7
		48	3762	20.9
		96	3918	21.8
	BB-3	0	2508	13.9
		24	3605	20.0
		42	3135	17.4
West Hackberry	WH-3	0	2038	11.3
		30	4232	23.5
		60	1568	8.7
	WH-4	0	3292	18.3
		24	3918	21.8
		48	3918	21.8

distance from the diffuser of the 1 ppt isohaline, is typically from 1500 to 4000 meters. It is unlikely that a plume of such an extent can seriously interfer with migration patterns, particularly at the distances which the proposed diffusers will be from the shore.

5.4.3 Impacts to the Benthos

Given the relative immobility of the benthic organisms, this assemblage is likely to be more severely impacted by brine discharge than other biotic assemblages. Exposure period, for example, will be much longer, as relief can be expected only through shifts in plume orientation. Further, removal of the plume for brief periods would not provide immediate relief for the benthos as pore water salinities would remain high and only slowly return to baseline conditions. Also, an accumulation of heavy metal contaminants, and other toxic substances would be expected in the sediments underlying the plume. Stress from this direction would not lessen if the plume were temporarily redirected. Thus, the impact of the plume on the benthos is related more to the long-term cumulative period of exposure, than to the instantaneous areal coverage. On this basis a larger area will be stressed than would be implied by instantaneous areal coverage covers.

Figure 5.4-1 shows the orientation of the Black Bayou plume at various points in time, as derived from the MIT outputs discussed in Section U.2. This suggests that the zone of highest stress will be oriented parallel to the shore line and somewhat bilobed. Given the dominance by west flowing currents, the westward lobe should be somewhat larger than that to the east.

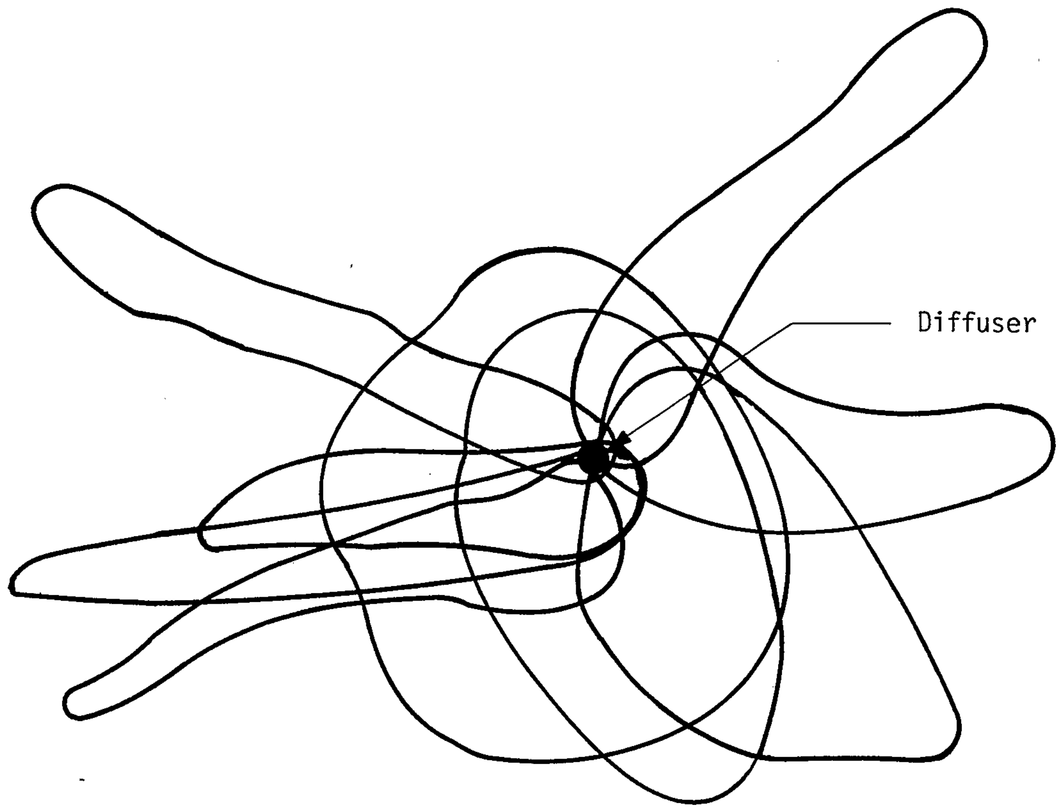
Within the stressed area a central zone of total mortality can be expected. Outward from this will be a zone in which the numbers of individuals and species will gradually return to baseline conditions. The exact areal extent of these zones cannot be accurrately predicted at this time.

This is in part because the toxic brine responses of the benthos are not well known. USDC results (1978) in brine bioassay studies, suggest that the benthic polychaete Neanthes can well tolerate slight salinity overages at least for short periods of time. In 96-hour STL_{50} bioassays 50% mortality did not occur until salinities approached 50 ppt (at 20°C). It is not clear how representative Neanthes is of the Texoma benthos, or what its tolerance is to prolonged exposure at low salinity overages. It is also uncertain what the relation is between salinity overages in the brine plume or elevated salinity and concentration of toxic substances in the sediments. Given the probable buildup of salinities, or the accumulation of heavy metals in the sediments, areas regularly exposed to a 1 ppt brine will be somewhat more stressful to the benthos than simple bioassay results for solutions with 1 ppt overages.

As a simplification, total mortality may be assumed within the region encompassed by a given isohaline. Table 5.4-2 shows the minimum and maximum areal extents for this lethal zone with 1 ppt and 3 ppt taken as

BLACK BAYOU 1 ppt.

BRINE PLUMES



Black Bayou 1 ppt. isohalines at various times under different hydrologic regimes.

FIGURE 5.4-1

Table 5.4-2 Maximum and Minimum Instantaneous Areal Extent of the Brine Plume at 1 ppt and 3 ppt,* based on Figures 2.3-25, 2.3-41, and 2.3-52.

Site	Model Run	Minimum Areal Extent 1 ppt			Maximum Areal Extent 1 ppt			Maximum Areal Extent 3 ppt		
		ft^2 $x10^7$	Acres	$Miles^2$	ft^2 $x10^7$	Acres	$Miles^2$	ft^2 $x10^7$	Acres	$Miles^2$
West Hackberry	WH-3	3.0	689	1.09	8.1	1860	3.23	.90	207	.32
	WH-4	2.0	459	.73	6.0	1377	2.18	.90	207	.32
Black Bayou	BB-1	2.5	574	.91	5.3	1217	1.92	**	**	**
	BB-2	2.2	505	.80	8.5	1960	3.60	.45	104	.16
	BB-3	1.7	390	.62	5.2	1194	1.89	.45	104	.16
Big Hill	BH-1	.7	161	.25	2.0	459	.73	.23	52	.08
	BH-2	1.0	230	.36	3.15	724	1.27	.20	46	.07

*Minimum areal extents cannot be determined at 3 ppt as this is in the near-field region where model predictions are not available.

**Model predictions for maximum areal extent at Black Bayou, Run BB-1, not available at 3 ppt.

the controlling salinity overages. For a 1 ppt contour a minimum of from about 161 to 689 acres and a maximum of from about 459 to 1960 acres would be lost, depending on site and hydrologic regime. If a 3 ppt isohaline is chosen as the controlling overage the maximum loss would be from about 46 to 207 acres. The above analysis assumes a static plume. where allowance is made for the movement in plume position larger impacted areas are to be expected.

Table 5.4-3 shows the average distance from the diffuser to the 1 ppt isohaline, for each of the proposed diffuser sites as predicted in various MIT model runs. If a radius of these magnitudes is used to define the area of impact, the standing crop in an area of from 6.7 to 12.1 square miles, depending on site, would be lost. Since the plumes do not normally extend into the north or south quadrants with respect to the diffuser, the actual area lost should be about half of the above values, or from 3 to 6 square miles.

The impacted area can be significantly reduced if a higher isohaline can be justified as encompassing the zone of mortality. For example, the distance to the outer limit of the 2 ppt isohaline in the MIT outputs (or the center of the area enclosed by the 1 ppt isohaline in cases where the 2 ppt isohaline is not present) is taken as the controlling radius, only about 0.5 square miles would typically be impacted (average of all sites).

In comparing the various sites it should be noted that the standing crop at Big Hill is significantly less than that at Black Bayou or West Hackberry. Since the impacted area is also smallest at this site the absolute loss at Big Hill will be much less than at the other sites (by a factor of five). On the other hand sediments at Big Hill are significantly finer than those at the other sites. This may enhance the accumulation of trace metals in the sediments somewhat increasing the zone of mortality.

Table 5.4-3 Impact of brine discharge on benthic communities assuming total mortality in an area swept by a radius equal to the average distance from the diffuser to the maximum extent of the 1 ppt isohaline

Site	Radius (m)	Area $m^2 \times 10^7$	Area $miles^2$	# Individuals Per $m^2 \times 10^2$	# Individuals Lost $\times 10^9$
Big Hill	2351	1.7364	6.7	1.35	2.34
Black Bayou	2769	2.4088	9.3	3.13	7.33
West Hackberry	3161	3.1391	12.1	3.80	11.93

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SECTION 6.0

PHYSICAL PARAMETERS FOR CRUISES I THROUGH IV

(September-December 1977)

CRUISE I

Site	Station	Depth Meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
West Hackberry	4	1	28.00	7.30	22.70
		2	28.00	7.40	23.40
		3	28.50	7.90	23.40
		4	28.50	7.80	23.75
		5	28.50	8.10	23.75
		6	28.50	7.60	24.46
		7	29.00	7.60	24.81
		8	29.00	7.60	24.81
		9	29.00	7.95	24.81
	5	1	28.50	8.10	26.58
		2	28.50	7.75	25.52
		3	28.50	7.70	25.52
		4	28.50	7.70	25.87
		5	28.50	7.70	25.87
		6	28.50	7.50	26.23
		7	28.50	7.10	26.23
		8	28.50	6.20	26.23
		9	28.00	4.90	26.23
		10	28.00	4.50	26.23
	6	1	28.00	7.15	26.94
		2	28.50	7.75	26.58
		3	28.50	7.80	26.58
		4	28.50	7.70	26.94
		5	28.50	7.80	26.94
		6	28.50	7.80	26.94
		7	28.50	7.80	26.94
		8	28.50	7.80	26.94
		9	28.50	7.70	26.94
		10	28.50	7.80	26.58
		11	29.00	7.80	27.30
	7	1	29.50	8.10	26.58
		2	29.25	8.10	26.58
		3	29.00	8.00	26.58
		4	28.50	8.00	26.58
		5	28.50	7.70	26.94
		6	28.25	7.50	27.66

CRUISE I

Site	Station	Depth Meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
		7	28.25	7.30	27.66
		8	28.25	7.50	27.66
		9	28.00	4.90	28.01
		10	28.00	4.40	28.37
	8	1	29.50	8.60	24.46
		2	29.25	8.80	24.81
		3	28.50	8.50	25.16
		4	28.50	5.85	25.52
		5	28.25	6.10	26.23
		6	28.00	6.10	26.94
		7	28.00	6.60	27.30
		8	28.00	4.90	27.66
		9	28.00	3.75	26.94
	9	1	28.50	7.70	25.87
		2	28.00	7.80	26.23
		3	28.00	7.80	26.58
		4	28.00	7.75	26.58
		5	28.00	7.90	26.94
		6	28.00	7.20	26.94
		7	28.00	7.10	26.94
		8	28.00	6.40	27.30
		9	28.00	4.60	28.01
		10	28.00	4.20	28.01
	10	1	28.00	8.00	25.32
		2	28.00	7.45	26.23
		3	28.00	7.45	26.58
		4	28.00	8.10	26.94
		5	28.00	7.80	26.94
		6	28.00	7.80	27.30
		7	28.00	7.80	27.66
		8	28.00	6.90	27.30
		9	28.00	6.00	27.66
		10	28.00	4.30	28.01
	12	1	28.50	7.90	26.23
		2	28.50	7.90	26.23
		3	28.50	7.80	26.58

CRUISE I

Site	Station	Depth Meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
		4	28.00	8.10	26.58
		5	28.00	8.00	26.94
		6	28.00	7.70	26.94
		7	28.00	7.40	27.30
		8	28.00	7.30	27.30
		9	28.00	5.30	27.66
		10	28.00	4.10	28.01
	13	1	29.00	7.90	26.23
		2	28.50	7.90	26.58
		3	28.25	7.80	26.58
		4	28.25	8.00	26.94
		5	28.00	7.70	27.30
		6	28.00	7.85	27.30
		7	28.00	7.30	27.30
		8	28.00	6.20	27.30
		9	28.00	4.95	27.66
		10	28.00	4.20	27.66
	14	1	28.50	8.30	26.58
		2	28.25	8.20	26.94
		3	28.00	8.30	26.94
		4	28.00	8.40	27.30
		5	28.00	8.30	27.66
		6	28.00	8.10	27.66
		7	28.00	7.50	27.66
		8	28.00	6.40	27.66
		9	28.00	5.65	28.01
		10	27.50	4.60	28.01
	15	1	29.00	8.20	26.23
		2	28.75	8.45	25.87
		3	28.50	8.30	26.23
		4	28.00	7.70	26.23
		5	28.00	7.60	26.58
		6	28.00	7.60	26.94
		7	28.00	7.40	27.30
		8	28.00	6.20	27.66
		9	28.00	5.20	27.66
		10	28.00	4.75	25.52

CRUISE I

Site	Station	Depth Meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
	16	1	28.00	7.35	24.81
		2	28.00	7.30	24.81
		3	28.50	7.20	24.81
		4	28.50	7.60	24.81
		5	28.50	7.20	25.16
		6	28.00	7.10	25.16
		7	28.75	7.15	25.16
		8	28.75	6.80	25.16
	17	1	28.50	7.35	25.87
		2	28.50	7.25	25.87
		3	28.50	7.20	24.46
		4	28.50	7.20	24.81
		5	28.50	7.20	25.16
		6	28.50	7.10	25.16
		7	28.5	7.00	25.16
		8	28.50	6.85	25.52
		9	28.50	6.60	25.52
		10	28.50	6.30	25.16
	19	1	29.50	8.10	26.58
		2	29.25	8.15	26.94
		3	29.25	8.20	26.94
		4	29.00	8.20	26.94
		5	28.50	8.20	27.30
		6	28.50	8.20	27.30
		7	28.25	7.80	27.30
		8	28.25	7.60	27.66
		9	28.00	7.00	27.66
		10	28.00	4.45	28.01
		11	28.00	3.75	28.01
	22	1	29.00	7.55	26.23
		2	28.75	7.50	26.23
		3	28.50	6.90	26.58
		4	28.50	7.70	26.58
		5	28.50	7.90	26.94
		6	28.50	8.10	26.94
		7	28.00	7.90	27.30
		8	28.00	7.90	27.30

CRUISE I

Site	Station	Depth Meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
		9	28.00	7.70	27.30
		10	28.00	7.60	27.30
	24	1	28.50	6.95	23.75
		2	28.50	7.00	23.75
		3	28.50	7.00	23.75
		4	28.50	7.00	23.75
		5	28.50	6.95	23.75
		6	28.50	7.15	23.75
		7	28.50	7.15	23.75
	25	1	30.50	7.30	27.30
		2	28.50	7.60	27.66
		3	28.50	7.80	27.66
		4	28.00	7.80	27.66
		5	28.00	7.80	27.66
		6	28.00	7.80	27.66
		7	28.00	7.75	27.66
		8	27.50	7.80	27.66
		9	27.50	7.40	27.66
		10	27.50	7.10	28.01
	26	1	28.50	8.90	24.46
		2	28.00	9.10	25.16
		3	28.00	9.10	26.23
		4	28.00	8.10	26.94
		5	28.00	7.80	27.30
		6	27.50	7.30	29.10
		7	28.00	5.65	27.66
		8	27.50	5.50	27.66
	27	1	28.00	8.50	24.81
		2	28.00	8.25	25.16
		3	28.00	7.80	26.23
		4	28.00	7.80	26.94
		5	28.00	7.80	26.94
		6	28.00	7.60	26.94
		7	28.00	7.30	27.30
		8	28.00	7.00	27.30
		9	28.00	7.05	27.30
		10	28.00	7.05	27.30

CRUISE I

Site	Station	Depth Meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
	28	1	28.00	7.20	27.30
		2	27.50	7.20	27.30
		3	27.50	7.30	27.30
		4	27.50	7.10	27.30
		5	27.50	7.20	27.30
		6	27.50	7.15	28.01
		7	27.50	7.10	27.66
		8	27.50	6.30	27.66
		9	27.50	6.05	28.01
		10	27.50	5.95	28.01
	29	1	28.00	7.95	25.16
		2	28.00	7.85	26.23
		3	28.00	7.85	26.94
		4	28.00	7.90	27.30
		5	28.00	8.00	24.94
		6	28.00	7.35	27.30
		7	27.50	7.00	27.30
		8	27.50	6.05	27.66
		9	27.50	6.05	27.66
		10	27.50	6.05	27.66
	30	1	28.00	7.50	25.16
		2	28.00	7.95	25.52
		3	28.00	7.95	26.58
		4	28.00	7.85	26.58
		5	28.00	7.80	26.94
		6	28.00	7.65	27.30
		7	27.50	7.55	26.94
		8	27.50	6.50	27.66
		9	27.50	6.35	27.66
		10	27.50	6.35	27.66
	31	1	28.00	7.85	24.46
		2	28.00	8.00	25.16
		3	28.00	8.-0	26.23
		4	28.00	8.30	26.58
		5	28.00	7.30	26.58
		6	27.50	6.70	26.58
		7	27.50	6.80	26.58

CRUISE I

Site	Station	Depth Meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
	31	8	27.50	6.80	26.94
		9	27.50	5.30	27.30
		10	27.50	5.10	26.23
	32	1	28.00	7.90	25.52
		2	28.00	7.65	26.94
		3	28.00	7.50	27.30
		4	27.50	7.50	27.30
		5	27.50	7.30	27.30
		6	27.50	6.90	27.66
		7	27.50	5.50	27.66
		8	27.50	5.30	27.66
		9	27.50	5.00	27.66
		10	27.50	4.80	26.94
	33	1	29.00	9.20	26.94
		2	28.00	9.60	26.94
		3	28.00	9.20	26.94
		4	28.00	7.25	27.30
		5	28.00	5.80	27.66
		6	28.00	6.30	27.66
		7	27.50	5.70	27.66
		8	27.50	5.50	27.66
		9	27.50	5.30	27.66
		10	27.50	5.20	28.01
	34	1	29.50	8.60	25.16
		2	28.50	8.80	25.16
		3	28.50	8.90	25.52
		4	28.50	9.00	25.52
		5	28.00	8.50	25.52
		6	28.00	6.70	26.58
		7	28.00	5.20	27.66
		8	28.00	4.80	28.01
Big Hill	35	1	27.00	8.00	26.23
		2	27.00	8.00	26.23
		3	26.50	7.95	26.58
		4	27.00	7.95	27.66
		5	27.00	7.70	27.30

CRUISE I

Site	Station	Depth Meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
		6	27.00	7.75	27.30
		7	27.00	7.75	27.66
		8	27.00	7.65	28.37
		9	27.50	7.45	29.09
		10	27.50	7.50	28.37
		11	27.50	7.20	28.37
	36	1	27.50	7.75	26.58
		2	27.50	7.70	26.58
		3	27.50	7.70	26.94
		4	27.00	7.40	26.23
		5	27.00	7.35	26.23
		6	27.50	7.00	28.37
		7	27.00	6.30	27.66
		8	27.00	6.00	27.66
		9	27.50	4.00	27.66
	37	1	27.00	7.70	22.70
		2	27.00	7.85	24.81
		3	27.00	7.75	25.16
		4	27.00	7.65	25.32
		5	27.00	7.60	25.52
		6	27.00	7.40	27.66
		7	27.50	7.50	28.37
		8	27.50	7.80	28.37
		9	27.50	6.85	28.01
		10	27.50	6.30	28.37
	38	1	27.00	8.00	25.87
		2	27.50	8.00	26.23
		3	27.00	8.00	26.23
		4	27.00	7.75	26.23
		5	27.50	7.90	27.30
		6	28.00	7.60	28.37
		7	28.00	7.20	28.37
		8	28.00	7.15	28.37
		9	28.00	7.15	28.37
		10	28.00	7.00	28.37
		11	28.00	5.60	22.70

CRUISE I

Site	Station	Depth Meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
	39	1	27.00	7.40	25.52
		2	27.00	7.40	25.52
		3	27.50	7.50	25.52
		4	27.00	7.40	25.52
		5	27.00	7.40	25.52
		6	27.00	7.40	25.52
		7	27.50	7.30	28.37
		8	27.50	7.15	28.37
		9	27.50	7.00	28.37
		10	27.50	7.20	28.37
		11	28.00	6.50	24.81
	41	1	27.50	7.60	25.16
		2	28.00	7.50	25.52
		3	28.00	7.60	25.52
		4	28.00	7.60	25.52
		5	28.00	7.60	29.10
		6	27.50	7.35	26.94
		7	27.50	6.80	26.94
		8	27.00	4.50	27.66
		9	27.00	5.10	22.00
		10	27.00	5.10	22.00
	42	1	27.50	8.10	23.75
		2	27.50	8.00	23.75
		3	28.00	7.90	25.16
		4	28.00	8.10	24.81
		5	28.00	8.00	26.23
		6	28.50	7.55	28.01
		7	28.00	7.80	28.01
		8	28.00	7.30	28.01
		9	28.00	6.90	28.37
		10	28.00	6.50	27.66
	43	1	27.00	8.10	25.52
		2	27.50	8.10	25.52
		3	27.50	8.10	25.52
		4	27.50	8.15	25.52
		5	27.50	7.90	26.58
		6	27.50	7.50	28.01

CRUISE I

Site	Station	Depth meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (PPT)
	43	7	27.00	7.35	28.37
		8	27.00	7.00	28.37
		9	27.00	6.90	29.09
		10	27.00	7.20	28.73
		11	27.00	6.75	28.73
	44	1	27.50	7.35	25.16
		2	27.50	7.35	25.16
		3	27.50	7.35	25.52
		4	27.00	7.40	25.52
		5	27.00	7.25	25.52
		6	27.00	7.10	26.58
		7	27.00	6.45	26.58
		8	27.00	4.20	22.70
Black Bayou	45	1	25.25	7.60	26.58
		2	28.75	7.75	26.58
		3	28.75	7.75	26.58
		4	28.75	7.75	26.58
		5	28.75	7.75	26.94
		6	28.75	7.85	26.23
		7	28.75	7.55	26.23
		8	28.75	7.75	25.52
		9	28.75	7.65	25.87
		10	28.50	7.55	25.87
	46	1	28.50	7.55	25.87
		2	28.50	7.70	25.52
		3	28.50	7.70	25.52
		4	28.50	7.65	25.52
		5	28.50	7.65	25.52
		6	28.50	7.70	26.23
		7	28.50	7.70	26.23
		8	28.25	7.80	26.23
		9	28.25	7.75	26.23
		10	28.25	7.75	26.23

CRUISE I

Site	Station	Depth meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
	47	1	28.75	7.90	26.94
		2	28.75	8.35	26.23
		3	28.75	8.35	26.23
		4	28.75	8.35	26.23
		5	28.75	8.35	26.23
		6	28.50	8.35	26.23
		7	28.50	8.20	26.23
		8	28.50	8.10	26.58
		9	28.50	8.00	26.58
		10	28.50	7.85	26.58
	48	1	28.50	7.85	26.58
		2	28.50	7.85	26.23
		3	28.25	8.00	26.23
		4	28.25	8.00	26.23
		5	28.25	8.00	26.23
		6	28.25	8.00	26.23
		7	28.25	8.00	26.23
		8	28.25	8.00	26.23
		9	28.25	8.00	26.23
		10	28.25	8.00	26.23
		11	28.25	8.00	26.23
	49	1	28.50	8.00	26.58
		2	28.50	8.20	26.58
		3	28.50	8.15	26.58
		4	28.50	8.15	25.87
		5	28.50	8.20	25.87
		6	28.50	8.20	25.87
		7	28.50	8.10	26.87
		8	28.50	7.85	26.87
		9	28.50	7.50	26.23
		10	28.50	7.30	26.23
	50	1	28.25	8.35	26.58
		2	29.00	8.60	26.58
		3	29.00	8.50	26.58
		4	29.00	8.55	26.58

CRUISE I

Site	Station	Depth meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
Big Hill	50	5	29.00	8.50	26.94
		6	29.00	8.25	27.66
		7	29.00	7.80	28.01
		8	29.00	7.50	28.01
		9	29.00	7.50	28.01
		10	29.00	7.30	28.01
	51	1	29.00	8.25	26.58
		2	29.00	8.20	26.58
		3	29.00	8.30	26.58
		4	29.00	8.35	26.94
		5	29.00	8.30	26.94
		6	29.00	8.40	26.94
		7	29.00	8.40	26.94
		8	29.00	8.10	27.66
		9	29.00	7.35	28.01
		10	28.75	7.05	28.01
	52	1	29.00	8.50	25.87
		2	29.00	8.40	25.87
		3	29.00	8.65	25.87
		4	29.00	8.65	25.87
		5	28.75	7.95	26.58
		6	28.75	7.60	27.30
		7	28.50	6.90	28.01
		8	28.50	6.30	28.01
	53	1	28.50	8.30	24.46
		2	28.50	8.40	24.81
		3	29.00	8.35	24.46
		4	29.00	8.55	24.46
		5	29.00	8.45	25.16
		6	29.00	8.05	25.16
		7	28.50	7.85	25.52
		8	28.50	7.80	25.52
		9	28.50	7.60	25.87
		10	28.50	7.30	25.87

CRUISE I

Site	Station	Depth meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
	54	1	29.00	8.15	26.58
		2	29.00	8.15	26.58
		3	28.75	8.10	26.94
		4	28.75	8.05	26.94
		5	28.75	8.10	26.94
		6	28.50	8.10	27.66
		7	28.50	7.90	28.01
		8	28.50	7.60	28.01
		9	28.50	7.60	28.01
		10	28.50	7.60	28.01
		11	28.50	7.40	28.37

CRUISE II

Site	Station	Depth meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
West Hackberry	4	1	23.00	7.18	23.50
		2	23.00	7.18	23.50
		3	23.00	7.18	23.50
		4	23.00	7.18	23.50
		5	23.00	7.18	23.75
		6	23.00	7.18	23.75
		7	23.00	7.18	23.75
	5	1	22.50	6.79	24.00
		2	23.00	6.70	24.00
		3	23.00	6.70	24.00
		4	22.75	6.57	24.50
		5	22.75	6.57	24.50
		6	22.75	6.57	24.50
		7	22.75	6.57	24.50
		8	22.75	6.57	24.50
		9	22.75	6.52	24.50
		10	22.75	6.52	24.50
	6	1	23.00	6.41	25.25
		2	23.00	6.41	25.25
		3	23.00	6.36	25.25
		4	23.00	6.32	25.50
		5	23.00	6.32	25.50
		6	23.00	6.32	25.50
		7	23.00	6.32	25.50
		8	23.00	6.32	25.50
		9	23.00	6.23	25.50
		10	23.00	6.10	25.50
		11	23.00	6.02	25.50
		12	23.00	5.80	25.25
	7	1	23.00	7.01	24.50
		2	23.00	7.01	24.50
		3	23.00	6.97	25.00
		4	23.00	6.88	25.00
		5	23.00	6.88	25.00
		6	23.00	6.88	25.00

CRUISE II

Site	Station	Depth meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
	7	7	23.00	6.88	25.00
		8	23.00	6.88	25.00
		9	23.00	6.88	25.00
		10	23.00	6.88	25.00
		11	23.00	6.88	24.50
	8	1	23.00	6.83	24.50
		2	23.00	6.83	24.50
		3	23.00	6.87	24.50
		4	23.00	6.92	24.50
		5	23.00	6.88	25.00
		6	23.00	6.97	25.00
		7	23.00	6.97	25.00
		8	23.00	6.97	25.00
		9	23.00	7.00	24.50
		10	23.00	6.95	23.00
	9	1	23.00	6.65	23.75
		2	23.00	6.52	24.00
		3	23.00	6.52	24.00
		4	23.00	6.52	24.50
		5	23.00	6.49	24.50
		6	23.00	6.49	24.50
		7	23.00	6.40	24.50
		8	23.00	6.40	24.50
		9	23.00	6.40	24.50
		10	23.00	6.40	24.50
		11	23.00	6.40	24.50
	10	1	23.00	6.61	24.00
		2	23.00	6.48	24.50
		3	23.00	6.57	24.50
		4	23.00	6.49	24.50
		5	23.00	6.49	24.50
		6	23.00	6.45	25.00
		7	23.00	6.45	25.00
		8	23.00	6.45	25.00
		9	23.00	6.45	25.00
		10	23.00	6.36	25.00
		11	23.00	6.24	23.00

CRUISE II

Site	Station	Depth meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
	12	1	23.00	6.56	23.75
		2	23.00	6.52	24.00
		3	23.00	6.52	24.00
		4	23.00	6.52	24.00
		5	23.00	6.52	24.00
		6	23.00	6.52	24.00
		7	23.00	6.52	24.00
		8	23.00	6.52	24.00
		9	23.00	6.52	24.00
		10	23.00	6.35	19.50
	13	1	23.00	6.57	24.50
		2	23.00	6.57	24.50
		3	23.00	6.54	25.25
		4	23.00	6.54	25.25
		5	23.00	6.54	25.50
		6	23.00	6.54	25.50
		7	23.00	6.54	25.50
		8	23.00	6.54	25.50
		9	23.00	6.54	25.50
		10	23.00	6.54	25.50
		11	23.00	6.54	25.00
	14	1	23.00	6.82	23.50
		2	23.00	6.82	23.50
		3	23.00	6.75	24.50
		4	23.00	6.75	25.00
		5	23.00	6.75	25.00
		6	23.00	6.75	25.00
		7	23.00	6.75	25.00
		8	23.00	6.75	25.00
		9	23.00	6.79	25.00
		10	23.00	6.79	25.00
		11	23.00	6.75	25.25
	15	1	23.00	6.67	25.25
		2	23.00	6.67	25.25
		3	23.00	6.67	25.25
		4	23.00	6.62	25.25

CRUISE II

Site	Station	Depth meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
	15	5	23.00	6.62	25.25
		6	23.00	6.62	25.25
		7	23.00	6.62	25.25
		8	23.00	6.62	25.25
		9	23.00	6.75	24.50
		10	23.00	6.79	24.50
	16	1	23.00	6.96	23.75
		2	23.00	7.13	24.00
		3	23.00	7.18	23.75
		4	23.00	7.13	24.00
		5	23.00	7.13	24.00
		6	23.00	7.13	23.50
		7	23.00	7.09	23.50
		8	23.00	7.09	23.50
		9	23.00	7.08	20.00
	17	1	23.00	6.74	23.50
		2	23.00	6.82	23.75
		3	23.00	6.87	23.75
		4	23.00	6.87	23.75
		5	23.00	6.82	24.00
		6	23.00	6.82	24.00
		7	23.00	6.82	24.00
		8	23.00	6.82	24.00
		9	23.00	6.79	24.00
		10	23.00	6.70	24.00
	18	1	23.00	6.96	24.00
		2	23.00	7.01	24.50
		3	23.00	7.01	24.50
		4	23.00	7.01	24.50
		5	23.00	7.01	24.50
		6	23.00	7.01	24.50
		7	23.00	7.01	24.50
		8	23.00	7.01	24.50
		9	23.00	7.01	24.50
		10	23.00	7.01	24.50

CRUISE II

Site	Station	Depth meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
	19	1	23.00	6.79	25.25
		2	23.00	6.79	25.50
		3	23.00	6.88	25.50
		4	23.00	6.88	25.50
		5	23.00	6.88	25.50
		6	23.00	6.79	25.50
		7	23.00	6.79	25.50
		8	23.00	6.79	25.50
		9	23.00	6.79	24.50
		10	23.00	6.79	24.50
		11	23.00	6.79	24.50
		12	23.00	6.23	24.50
	20	1	23.00	6.87	24.00
		2	23.00	6.79	24.00
		3	23.00	6.74	24.50
		4	23.00	6.79	24.00
		5	23.00	6.79	24.00
		6	23.00	6.79	24.00
		7	23.00	6.69	24.00
		8	23.00	6.83	24.00
		9	23.00	6.53	25.00
		10	23.00	6.45	25.00
	24	1	23.00	6.77	23.50
		2	23.00	6.60	23.50
		3	23.00	6.60	23.50
		4	23.00	6.60	23.50
		5	23.00	6.52	24.00
		6	23.00	6.52	24.00
		7	23.00	6.52	24.00
		8	23.00	6.52	23.00
	25	1	23.50	7.14	25.50
		2	23.50	7.18	25.50
		3	23.50	7.27	25.50
		4	23.50	7.27	25.50
		5	23.50	7.27	25.50
		6	23.50	7.30	24.50

CRUISE II

Site	Station	Depth meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
	25	7	23.50	7.23	25.50
		8	23.50	7.23	25.00
		9	23.50	7.23	25.25
		10	23.50	7.23	25.25
		11	23.50	7.23	25.00
		12	23.50	7.23	25.25
		13	23.50	6.67	25.50
	26	1	23.50	7.22	25.25
		2	23.50	7.44	25.25
		3	23.50	7.48	25.25
		4	23.50	7.53	25.25
		5	23.50	7.57	25.25
		6	23.50	7.48	24.50
		7	23.50	7.61	23.75
		8	23.50	6.29	23.75
	27	1	23.50	7.14	25.25
		2	23.50	7.22	25.25
		3	23.50	7.22	25.25
		4	23.50	7.18	25.25
		5	23.50	7.18	25.25
		6	23.50	7.10	25.25
		7	23.50	7.01	25.25
		8	23.50	6.75	25.25
		9	23.50	5.89	25.50
		10	23.50	5.85	25.50
	28	1	23.50	7.52	26.75
		2	23.50	7.61	26.75
		3	23.50	7.61	26.75
		4	23.50	7.74	26.75
		5	23.25	7.74	26.75
		6	23.25	7.48	26.75
		7	23.25	6.88	25.75
		8	23.25	6.54	25.50
		9	23.25	6.19	25.50
		10	23.00	6.10	25.50

CRUISE II

Site	Station	Depth meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
	29	1	23.50	7.14	25.25
		2	23.50	7.18	25.50
		3	23.25	7.14	25.75
		4	23.25	7.18	25.75
		5	23.25	7.31	25.50
		6	23.25	7.39	25.50
		7	23.25	7.27	25.50
		8	23.25	6.24	26.00
		9	23.00	5.93	26.00
		10	23.00	5.63	26.00
	30	1	23.00	7.74	25.75
		2	23.00	7.83	25.75
		3	23.00	7.83	25.75
		4	23.00	7.80	25.75
		5	23.00	7.78	25.75
		6	23.00	7.65	25.75
		7	23.25	7.74	25.75
		8	23.25	7.48	25.50
		9	23.25	6.41	25.75
		10	23.25	5.89	23.00
	31	1	23.25	7.87	24.50
		2	23.25	7.83	25.25
		3	23.25	7.83	25.25
		4	23.25	7.87	25.25
		5	23.25	7.87	25.25
		6	23.25	7.87	25.25
		7	23.00	7.87	25.25
		8	23.00	6.79	25.50
		9	23.00	5.81	25.75
		10	23.00	5.79	---
	32	1	23.50	7.74	25.25
		2	23.50	7.87	25.25
		3	23.50	7.87	25.25
		4	23.50	7.91	25.25
		5	23.50	7.91	25.25
		6	23.50	7.91	25.25

CRUISE II

Site	Station	Depth meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
	32	7	23.50	7.87	25.25
		8	23.50	6.63	26.50
		9	23.50	6.01	26.50
		10	23.50	5.71	26.50
	33	1	23.50	7.57	24.00
		2	23.50	7.61	24.00
		3	23.50	7.69	24.00
		4	23.50	7.74	24.00
		5	23.50	7.53	24.50
		6	23.50	7.57	25.00
		7	23.50	7.57	25.00
		8	23.50	7.57	25.00
		9	23.50	7.48	25.25
		10	23.50	5.59	25.50
		11	23.50	5.26	25.50
	34	1	23.50	7.92	24.00
		2	23.50	7.57	24.00
		3	23.50	7.48	24.00
		4	23.25	7.48	24.00
		5	23.25	7.44	24.50
		6	23.25	7.44	24.50
		7	23.25	7.44	24.50
		8	23.05	7.27	24.50
		9	23.00	5.85	25.00
	35	1	23.25	6.79	24.50
		2	23.25	6.83	24.50
		3	23.50	6.79	24.50
		4	23.50	6.53	24.50
		5	23.50	6.66	24.50
		6	23.50	6.45	25.00
		7	23.25	6.49	25.00
		8	23.25	6.58	25.00
		9	23.25	6.58	25.00
		10	23.25	6.58	25.00
		11	23.25	6.49	25.25

CRUISE II

Site	Station	Depth meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
		12	23.25	6.49	25.25
		12 1/2	23.25	6.36	25.25
	36	1	23.25	6.56	22.50
		2	23.25	6.51	22.75
		3	23.25	6.42	23.00
		4	23.25	6.51	23.00
		5	23.25	6.51	23.00
		6	23.25	6.51	23.00
		7	23.25	6.61	23.00
		8	23.25	6.51	23.00
		9	23.25	6.52	23.75
	37	1	23.50	6.92	24.00
		2	23.50	6.88	24.50
		3	23.50	6.96	23.25
		4	23.25	6.96	23.25
		5	23.25	6.69	23.50
		6	23.25	6.69	23.50
		7	23.25	6.69	23.50
		8	23.25	6.61	23.50
		9	23.25	6.41	24.50
		10	23.25	6.41	24.50
		11	23.25	6.41	24.50
		12	23.25	6.31	24.50
	38	1	23.75	6.88	24.50
		2	23.50	6.88	24.50
		3	23.50	6.88	24.50
		4	23.50	6.70	24.50
		5	23.50	6.62	24.50
		6	23.25	6.62	24.50
		7	23.25	6.70	24.50
		8	23.25	6.53	25.00
		9	23.25	6.41	25.00
		10	23.25	6.41	25.25
		11	23.25	6.41	25.25
		12	23.25	6.30	25.25
		13	23.25	6.24	25.25

CRUISE II

Site	Station	Depth meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
	39	1	23.25	6.91	23.00
		2	23.25	6.82	23.25
		3	23.25	6.91	23.25
		4	23.25	6.91	23.75
		5	23.25	6.88	24.50
		6	23.25	6.88	24.50
		7	23.25	6.42	24.50
		8	23.25	6.92	24.50
		9	23.25	6.92	25.25
		10	23.25	6.84	25.00
	41	1	23.25	6.68	22.00
		2	23.25	6.60	22.75
		3	23.25	6.60	22.75
		4	23.25	6.56	23.00
		5	23.25	6.55	22.50
		6	23.25	6.73	23.00
		7	23.25	6.78	23.75
		8	23.25	6.69	23.75
		9	23.25	6.58	24.50
		10	23.25	6.31	24.00
	42	1	23.25	7.04	23.00
		2	23.25	7.00	23.75
		3	23.25	7.00	23.75
		4	23.25	6.82	23.75
		5	23.25	6.78	23.75
		6	23.25	6.78	23.75
		7	23.25	6.71	23.75
		8	23.25	6.65	24.00
		9	23.25	6.74	24.00
		10	23.25	6.61	24.50
		11	23.25	6.61	24.50
		12	23.25	6.44	24.50
	43	1	~~23.50~~	~~6.65~~	23.00
		2	23.50	6.78	24.00
		3	23.25	6.49	24.50

CRUISE II

Site	Station	Depth meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
	43	4	23.25	6.27	24.50
		5	23.25	6.45	25.00
		6	23.25	6.49	24.50
		7	23.25	6.53	24.50
		8	23.25	6.53	24.50
		9	23.25	6.58	24.50
		10	23.50	6.62	25.00
		11	23.50	6.62	25.00
		12	23.75	6.40	24.50
		13	23.50	6.49	25.00
	44	1	23.50	6.63	21.50
		2	23.50	6.63	22.00
		3	23.50	6.55	22.50
		4	23.50	6.59	22.50
		5	23.50	6.50	22.50
		6	23.50	6.46	22.50
		7	23.50	6.47	22.75
		8	23.50	6.38	22.75
Black Bayou	45	1	23.00	6.82	25.25
		2	23.50	6.67	25.25
		3	23.50	6.67	25.25
		4	23.50	6.58	25.25
		5	23.50	6.58	25.25
		6	23.50	6.58	25.25
		7	23.50	6.67	25.25
		8	23.50	6.67	25.50
		9	23.50	6.67	25.50
		10	23.50	6.24	25.50
	46	1	23.50	6.31	24.50
		2	23.50	6.36	24.50
		3	23.00	6.36	24.50
		4	23.00	6.37	24.50
		5	23.00	6.31	24.50
		6	23.00	6.27	24.50
		7	23.00	6.27	24.50

CRUISE II

Site	Station	Depth meters		Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
	46	8		23.00	6.27	24.50
		9		23.00	6.17	24.50
		10		23.00	6.78	24.50
	47	1		23.25	7.01	26.50
		2		23.25	6.58	26.00
		3		23.25	6.62	25.75
		4		23.25	6.60	25.75
		5		23.25	6.60	25.75
		6		23.25	6.54	25.75
		7		23.25	6.60	25.50
		8		23.25	6.60	25.25
		9		23.25	6.62	25.25
		10		23.25	6.60	25.25
		11		23.25	6.60	25.50
	47E	1		23.25	6.57	24.50
		2		23.25	6.53	25.25
		3		23.25	6.62	25.25
		4		23.25	6.62	25.25
		5		23.25	6.62	25.25
		6		23.25	6.62	25.25
		7		23.00	6.62	25.25
		8		23.00	6.58	25.25
		9		23.00	6.62	25.75
		10		23.25	6.67	25.75
		11		23.25	6.62	25.75
		12		23.25	6.58	25.50
	47W	1		23.75	6.79	24.50
		2		23.75	6.88	24.50
		3		23.50	6.88	24.50
		4		23.50	6.84	25.25
		5		23.50	6.84	25.25
		6		23.50	6.79	25.25
		7		23.50	6.75	25.25
		8		23.25	6.71	25.00
		9		23.25	6.66	25.00
		10		23.25	6.66	25.50
		11	U.6-25	23.25	6.66	25.50

CRUISE II

Site	Station	Depth meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
	48	1	23.50	6.88	25.25
		2	23.50	6.88	25.25
		3	23.50	6.88	25.50
		4	23.50	6.88	25.50
		5	23.50	6.83	25.50
		6	23.50	6.79	25.50
		7	23.50	6.75	25.50
		8	23.50	6.49	25.75
		9	23.50	6.41	25.75
		10	23.50	6.41	25.50
		11	23.50	6.41	25.50
	49	1	23.75	6.66	25.25
		2	23.75	6.66	25.25
		3	23.75	6.66	25.25
		4	23.75	6.66	25.25
		5	23.50	6.53	25.25
		6	23.50	6.45	25.25
		7	23.50	6.58	25.25
		8	23.50	6.62	25.25
		9	23.50	6.62	25.25
		10	23.50	6.62	25.25
		11	23.50	6.45	25.50
Big Hill	50	1	24.00	7.17	23.75
		2	24.00	7.17	23.75
		3	23.75	7.13	24.00
		4	23.75	6.91	24.00
		5	23.50	6.75	24.50
		6	23.50	6.88	25.00
		7	23.50	6.84	25.25
		8	23.25	6.79	25.25
		9	23.25	6.66	25.50
		10	23.25	6.58	25.50
		11	23.25	6.58	25.50

CRUISE II

Site	Station	Depth meters	Temperature ^0C	Dissolved Oxygen (ppm)	Salinity (ppt)
	50E	1	23.75	7.05	24.00
		2	23.75	6.96	24.50
		3	23.75	6.88	24.50
		4	23.50	6.75	24.50
		5	23.25	6.62	25.25
		6	23.25	6.66	25.50
		7	23.25	6.66	25.50
		8	23.25	6.28	25.50
		9	23.25	6.06	25.50
		10	23.25	5.89	25.50
	50W	1	24.25	7.22	23.75
		2	24.00	7.31	23.75
		3	23.75	7.18	24.00
		4	23.75	6.75	24.50
		5	23.50	6.58	25.25
		6	23.50	6.41	25.25
		7	23.25	6.28	25.50
		8	23.25	6.36	25.50
		9	23.25	6.23	25.50
		10	23.25	6.11	25.50
	51	1	23.50	6.64	22.00
		2	23.50	6.69	22.75
		3	23.50	6.73	23.25
		4	23.50	6.96	23.25
		5	23.50	7.05	25.25
		6	23.50	6.84	25.25
		7	23.50	6.74	25.50
		8	23.50	6.75	25.50
		9	23.50	6.71	25.50
		10	23.50	6.62	25.50
		10½	23.50	6.49	25.50
	52	1	23.75	6.78	23.75
		2	23.75	6.86	23.75
		3	23.75	6.86	23.75
		4	23.50	6.83	23.75
		5	23.50	6.74	23.75

CRUISE II

Site	Station	Depth meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
	52	6	23.75	6.57	24.50
		7	23.25	6.44	24.50
		8	23.25	6.31	24.50
	53	1	23.75	7.13	23.75
		2	23.75	7.04	23.75
		3	23.50	6.90	24.00
		4	23.50	6.70	24.50
		5	23.50	6.54	25.00
		6	23.50	6.41	25.25
		7	23.50	6.41	25.25
		8	23.50	6.36	25.25
		9	23.50	6.28	25.25
		10	23.25	6.19	25.25
	54	1	23.50	6.95	24.00
		2	23.50	6.79	25.25
		3	23.50	6.84	25.00
		4	23.50	6.22	25.25
		5	23.50	6.54	25.25
		6	23.50	6.41	25.25
		7	23.50	6.41	25.50
		8	23.50	6.41	25.75
		9	23.50	6.36	25.75
		10	22.50	6.19	25.75
		11	22.50	6.19	25.75

CRUISE III

Site	Station	Depth meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
West Hackberry	4	1	19.50	7.99	26.00
		2	19.50	7.14	26.00
		3	19.50	7.14	26.00
		4	19.50	7.05	26.00
		5	19.50	7.01	26.50
		6	19.50	7.01	26.50
		7	19.50	6.92	26.50
	6	1	19.50	7.51	27.50
		2	19.50	6.97	27.50
		3	20.00	6.97	27.75
		4	20.00	6.89	27.75
		5	20.00	6.89	27.75
		6	20.00	6.80	27.75
		7	20.00	6.80	27.75
		8	20.00	6.80	27.75
		9	20.00	6.80	27.75
		10	20.00	6.80	27.75
		11	20.00	6.80	27.75
	7	1	19.50	6.97	27.00
		2	19.50	6.89	27.00
		3	19.50	6.80	27.25
		4	20.00	6.72	27.50
		5	20.00	6.72	27.50
		6	20.00	6.72	27.50
		7	20.00	6.63	27.00
		8	19.50	6.63	27.00
		9	19.50	6.63	27.00
		10	19.50	6.63	27.25
	8	1	19.50	6.97	27.50
		2	19.50	6.97	27.50
		3	19.50	6.97	27.50
		4	19.50	6.89	27.50
		5	19.50	6.89	27.50
		6	19.25	6.89	27.00
		7	19.25	6.80	27.00

CRUISE III

Site	Station	Depth meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
	8	8	19.25	6.80	27.00
		9	19.25	6.80	27.00
	10	1	19.50	7.40	27.50
		2	19.50	7.14	27.50
		3	19.75	7.14	27.50
		4	19.75	7.14	27.50
		5	19.50	7.06	27.00
		6	19.50	7.06	27.00
		7	19.50	7.06	27.00
		8	19.50	7.06	27.00
		9	19.50	7.06	27.00
		10	19.50	7.06	27.25
		11	20.00	6.72	22.75
	14	1	19.75	7.23	27.00
		2	19.50	7.23	27.00
		3	19.50	7.14	27.00
		4	19.50	7.14	27.00
		5	20.00	7.23	27.50
		6	20.00	7.06	27.50
		7	20.00	7.06	27.50
		8	19.50	7.06	27.50
		9	19.50	7.06	27.00
		10	19.50	7.06	27.00
	15	1	19.50	7.23	27.00
		2	19.50	7.14	27.00
		3	19.50	7.06	27.00
		4	19.50	7.06	27.00
		5	19.50	7.06	27.00
		6	19.50	7.06	27.00
		7	19.50	7.06	27.00
		8	19.50	7.06	27.00
		9	19.50	6.97	27.00
	16	1	19.50	7.14	25.25
		2	19.50	7.05	25.75
		3	19.50	6.88	26.00
		4	19.50	6.88	26.00

CRUISE III

Site	Station	Depth meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
	16	5	19.50	6.88	26.00
		6	19.50	6.88	26.00
		7	19.25	6.88	25.50
		8	19.25	6.71	25.50
		9	19.50	6.62	25.50
	17	1	19.50	7.14	27.00
		2	19.50	6.97	27.00
		3	19.50	6.97	27.00
		4	19.50	6.97	27.00
		5	19.50	6.97	27.00
		6	19.50	6.97	26.00
		7	19.50	6.97	26.00
		8	19.50	6.97	27.00
		9	19.50	6.80	27.00
	18	1	19.00	7.31	27.00
		2	19.50	6.97	27.25
		3	19.50	6.80	27.25
		4	19.50	6.80	27.25
		5	19.50	6.89	27.50
		6	19.50	6.89	27.50
		7	19.50	6.72	27.50
		8	19.50	6.72	27.50
		9	19.50	6.72	27.50
		10	19.50	6.72	27.50
	19	1	19.00	7.14	27.50
		2	19.50	6.89	27.50
		3	19.50	6.80	27.50
		4	19.50	6.80	27.50
		5	19.50	6.80	27.50
		6	19.50	6.80	27.50
		7	20.00	6.89	27.00
		8	20.00	6.72	27.00
		9	20.00	6.72	27.00
		10	20.00	6.72	27.00
		11	20.00	6.46	27.00

CRUISE III

Site	Station	Depth meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
	22	1	19.50	6.89	27.00
		2	19.50	6.80	27.00
		3	19.50	6.80	27.00
		4	19.50	6.80	27.00
		5	19.50	6.80	27.00
		6	19.50	6.89	27.00
		7	19.50	6.89	27.00
		8	19.50	6.80	27.00
		9	19.50	6.97	27.50
		10	19.50	6.97	27.50
	27	1	21.25	7.86	27.25
		2	21.00	7.86	27.25
		3	20.75	7.52	27.75
		4	20.50	7.23	27.75
		5	20.25	7.06	27.25
		6	20.25	7.06	27.25
		7	20.25	6.93	27.75
		8	20.00	6.59	27.75
		9	19.95	6.21	28.00
		10	19.95	5.87	28.50
	28	1	22.00	7.31	27.75
		2	21.25	7.22	27.75
		3	20.75	7.35	27.75
		4	20.75	7.27	27.75
		5	20.50	7.14	27.75
		6	20.25	7.01	27.75
		7	20.25	6.93	27.75
		8	20.25	6.93	27.75
		9	20.25	6.88	27.75
		10	20.25	6.46	27.75
	29	1	22.25	7.44	25.50
		2	22.25	7.40	27.25
		3	20.75	7.35	27.25
		4	20.50	7.18	27.25
		5	20.25	7.06	27.50
		6	20.25	6.93	27.75

CRUISE III

Site	Station	Depth meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
	29	7	20.25	6.76	27.75
		8	20.00	6.25	27.75
		9	19.95	6.04	28.50
		10	19.95	5.87	28.50
	30	1	22.50	7.27	27.25
		2	21.25	7.57	27.25
		3	20.75	7.35	27.25
		4	20.25	7.18	27.25
		5	20.25	7.06	27.25
		6	20.25	7.01	27.50
		7	20.25	6.84	27.50
		8	20.25	6.75	27.75
		9	20.00	6.25	27.75
		10	19.95	5.95	28.50
	31	1	21.25	7.52	27.25
		2	21.25	7.52	27.25
		3	20.50	7.35	27.25
		4	20.25	7.06	27.50
		5	20.25	6.93	27.50
		6	20.25	6.76	27.50
		7	20.00	6.50	27.50
		8	19.95	6.12	27.75
		9	19.95	5.99	28.50
	32	1	22.25	7.32	27.25
		2	21.25	7.32	27.25
		3	20.75	7.27	27.50
		4	20.75	7.18	27.50
		5	20.50	7.18	27.50
		6	20.25	7.05	27.75
		7	20.25	6.97	27.75
		8	20.25	6.75	27.25
		9	20.25	6.71	27.75
		10	20.25	6.58	27.75

CRUISE III

Site	Station	Depth meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
Big Hill	37	1	20.50	6.80	27.75
		2	20.00	6.72	27.75
		3	20.00	6.72	27.75
		4	20.00	6.72	27.75
		5	19.50	6.55	27.75
		6	19.50	6.96	27.75
		7	19.50	6.55	27.75
		8	19.50	6.46	27.75
		9	19.50	6.46	27.75
		10	19.50	6.21	27.75
	38	1	21.50	5.93	28.00
		2	21.25	7.01	28.50
		3	21.50	7.01	28.50
		4	20.50	6.89	28.50
		5	20.25	6.59	28.50
		6	20.00	6.67	28.00
		7	20.00	6.59	28.00
		8	19.75	6.55	28.50
		9	19.75	6.46	28.50
		10	20.00	6.30	28.50
		11	20.00	6.13	28.50
	39	1	21.00	6.97	27.00
		2	20.50	6.97	27.00
		3	20.00	6.97	27.25
		4	20.00	6.89	27.50
		5	19.50	6.65	27.50
		6	19.50	6.55	27.75
		7	19.50	6.55	27.75
		8	19.50	6.46	27.75
		9	19.50	6.38	28.00
		10	19.50	6.21	27.50
	41	1	20.25	7.31	27.25
		2	20.25	7.36	27.50
		3	20.25	7.40	27.50
		4	20.25	7.33	27.50
		5	20.00	6.89	27.50

CRUISE III

Site	Station	Depth meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
	41	6	20.00	6.76	27.75
		7	19.75	6.55	27.75
		8	19.75	6.59	27.75
		9	19.75	6.42	27.75
		10	19.75	6.33	27.50
	42	1	21.00	7.57	27.25
		2	20.75	7.14	27.25
		3	20.25	7.14	27.25
		4	20.25	7.01	27.50
		5	20.00	6.58	27.50
		6	19.75	6.33	27.75
		7	19.75	6.25	27.75
		8	19.75	6.21	27.75
		9	19.75	6.21	27.75
		10	19.75	5.95	27.75
	43	1	21.25	6.89	27.75
		2	21.25	6.84	28.50
		3	20.75	6.84	28.50
		4	20.50	6.72	28.50
		5	20.50	6.63	28.50
		6	20.25	6.59	28.50
		7	20.00	6.55	28.50
		8	20.00	6.30	28.50
		9	20.00	6.21	28.50
		10	20.00	6.21	28.50
		11	20.00	6.17	28.50
	44	1	20.50	7.05	26.50
		2	20.25	7.18	27.00
		3	20.00	7.06	27.00
		4	20.00	7.10	27.25
		5	19.75	6.50	27.00
		6	19.50	6.38	27.25
		7	19.75	6.46	27.25
		8	19.50	6.50	27.25
		9	19.50	6.38	27.50

CRUISE III

Site	Station	Depth meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
	45	1	20.75	7.61	26.50
		2	20.25	7.65	26.50
		3	20.00	7.65	26.50
		4	20.00	7.65	26.50
		5	20.00	7.52	26.50
		6	20.00	7.23	27.00
		7	20.00	7.01	27.25
		8	20.00	6.84	27.25
		9	20.00	6.80	27.25
		10	20.00	6.76	27.25
	46	1	20.00	7.52	27.50
		2	20.00	7.48	27.50
		3	20.00	7.48	27.25
		4	19.95	7.48	27.25
		5	19.95	7.44	27.25
		6	19.95	7.31	27.25
		7	19.95	7.18	27.50
		8	19.95	7.18	27.50
		9	19.95	7.06	27.25
		10	19.95	6.97	27.25
		11	19.95	6.59	27.25
	47	1	20.00	7.52	27.25
		2	20.00	7.52	27.25
		3	20.00	7.61	27.25
		4	20.00	7.61	27.25
		5	20.00	7.44	27.25
		6	20.00	7.27	27.25
		7	20.00	7.09	27.25
		8	20.00	7.01	27.25
		9	20.00	6.84	27.25
		10	20.00	6.55	27.25
		11	20.00	5.99	27.25
	48	1	20.75	7.57	25.25
		2	20.50	7.65	26.00
		3	20.25	7.91	26.50

CRUISE III

Site	Station	Depth meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
	48	4	20.00	7.70	26.50
		5	20.00	7.57	27.00
		6	20.00	7.09	27.25
		7	20.00	6.97	27.25
		8	20.00	6.97	27.25
		9	20.00	6.93	27.25
		10	20.00	6.93	27.25
		11	20.00	6.80	27.25
	49	1	20.00	7.77	27.75
		2	20.00	7.69	27.50
		3	20.00	7.65	27.50
		4	20.00	7.69	26.50
		5	20.00	7.65	26.50
		6	20.00	7.35	27.25
		7	20.00	7.27	27.25
		8	20.00	7.18	27.25
		9	20.00	6.93	27.25
		10	20.00	6.50	27.25
Big Hill	50	1	20.00	6.46	27.50
		2	20.00	6.55	27.75
		3	20.00	6.55	28.00
		4	20.00	6.55	28.00
		5	20.00	6.55	28.00
		6	20.00	6.55	28.00
		7	19.50	6.55	28.00
		8	19.50	6.55	27.50
		9	19.50	6.46	27.50
		10	19.50	6.28	25.00
	51	1	20.00	8.25	28.00
		2	20.00	8.15	29.00
		3	20.00	8.15	29.00
		4	20.00	7.31	29.00
		5	20.00	6.55	29.00
		6	19.50	6.55	29.00
		7	19.50	6.55	29.00

CRUISE III

Site	Station	Depth meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
	51	8	19.50	6.46	27.50
		9	19.50	6.46	27.50
		10	19.50	6.28	25.00
	52	1	20.75	6.58	27.50
		2	20.50	6.58	27.75
		3	20.25	6.58	27.75
		4	20.00	6.58	27.75
		5	20.00	6.58	27.75
		6	20.00	6.58	27.75
		7	20.00	6.58	27.75
		8	20.00	6.54	27.75
	53	1	20.75	6.58	27.50
		2	20.50	8.67	27.75
		3	20.25	6.67	27.75
		4	20.00	6.67	27.75
		5	20.00	6.67	27.75
		6	20.00	6.67	27.75
		7	20.00	6.58	27.75
		8	20.00	6.58	27.75
		9	20.00	6.50	27.75
	54	1	20.00	6.69	24.00
		2	20.00	6.62	25.00
		3	20.00	6.62	25.00
		4	20.00	6.62	25.00
		5	20.00	6.70	25.25
		6	20.00	6.70	25.25
		7	20.00	6.70	25.25
		8	19.50	6.70	25.25
		9	19.50	6.62	25.25
		10	20.00	6.53	25.50
		11	20.00	6.53	25.50

CRUISE IV

Site	Station	Depth meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
West Hackberry	4	1	14.50	10.17	18.15
		2	14.25	10.79	18.15
		3	14.25	10.97	18.15
		4	14.25	10.97	18.50
		5	14.25	10.09	19.75
		6	14.50	9.80	21.25
		7	14.75	9.46	23.00
		8	15.00	9.31	24.00
		9	15.00	8.79	24.00
	6	1	14.75	10.05	17.50
		2	14.50	10.35	18.15
		3	14.25	10.61	18.15
		4	14.25	10.41	18.50
		5	14.25	10.21	19.25
		6	14.50	9.98	21.25
		7	14.75	9.72	23.00
		8	15.00	9.20	25.00
		9	15.50	8.89	25.00
		10	15.75	8.52	26.00
		11	16.00	7.77	27.50
	7	1	14.75	10.41	18.50
		2	14.50	10.77	18.50
		3	14.50	10.93	18.90
		4	14.50	10.35	19.75
		5	14.50	10.21	20.50
		6	14.50	9.79	21.65
		7	14.75	9.48	22.75
		8	15.00	9.34	23.25
		9	15.50	8.84	25.25
		10	15.25	8.41	25.25
	8	1	14.75	10.04	18.90
		2	14.50	10.58	18.90
		3	14.50	10.66	19.25
		4	14.25	10.57	19.25
		5	14.25	10.27	19.75

CRUISE IV

Site	Station	Depth meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
	8	6	14.25	9.97	20.15
		7	14.50	9.71	21.15
		8	14.50	9.59	22.00
		9	15.00	9.00	23.25
		10	15.00	8.61	24.50
	10	1	14.50	10.41	18.50
		2	14.50	10.67	18.90
		3	14.25	10.74	19.25
		4	14.25	10.53	19.75
		5	14.25	10.23	20.15
		6	14.25	10.03	20.50
		7	14.50	10.54	20.90
		8	14.50	10.38	22.00
		9	15.00	9.55	23.00
		10	15.00	8.98	25.50
	14	1	15.00	10.82	19.50
		2	14.75	11.00	19.50
		3	14.75	10.97	19.75
		4	14.50	10.56	20.50
		5	14.50	10.50	21.25
		6	15.00	10.81	22.00
		7	15.00	10.80	22.40
		8	15.00	10.42	23.00
		9	15.25	9.55	25.00
		10	15.50	8.89	25.50
	15	1	14.50	11.09	19.50
		2	14.25	10.71	19.75
		3	14.25	10.53	19.75
		4	14.25	10.44	19.75
		5	14.25	10.30	20.50
		6	14.50	10.27	20.90
		7	14.75	10.40	21.65
		8	14.75	10.12	22.00
		9	15.00	8.94	25.00
		10	15.25	8.30	23.25

CRUISE IV

Site	Station	Depth meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
	16	1	15.00	10.40	18.90
		2	14.75	11.37	19.25
		3	14.75	11.53	19.50
		4	14.50	10.97	19.75
		5	14.50	10.74	20.50
		6	14.75	10.28	22.40
		7	15.00	10.37	23.60
		8	15.25	9.57	24.00
	17	1	15.25	10.41	20.15
		2	15.00	10.74	20.50
		3	15.00	10.74	20.50
		4	14.75	10.54	20.50
		5	14.75	10.44	22.75
		6	15.00	10.38	23.25
		7	15.25	10.02	23.60
		8	15.50	10.02	23.60
		9	15.50	9.46	25.00
		10	15.50	9.24	22.00
	18	1	15.00	10.62	19.75
		2	15.00	10.85	20.15
		3	14.75	10.85	20.15
		4	14.75	10.76	21.25
		5	15.00	10.61	22.75
		6	15.00	10.42	23.00
		7	15.00	10.29	23.25
		8	15.25	10.11	23.60
		9	15.25	10.11	23.60
		10	15.25	9.61	25.25
		11	15.50	9.22	24.00
	19	1	15.00	10.53	19.75
		2	15.00	10.85	20.15
		3	15.00	10.94	20.15
		4	14.50	10.56	20.50
		5	14.50	10.46	22.00
		6	15.00	10.35	22.75

CRUISE IV

Site	Station	Depth meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
	19	7	15.00	10.27	22.75
		8	15.00	10.21	23.25
		9	15.00	10.21	23.25
		10	15.00	10.21	23.25
		11	15.50	9.16	27.00
		12	16.00	8.29	27.25
	22	1	15.50	10.89	20.90
		2	15.50	11.11	21.25
		3	15.50	10.97	22.40
		4	15.50	10.73	23.25
		5	15.75	10.54	23.60
		6	15.75	10.34	24.00
		7	15.50	10.34	24.00
		8	15.50	10.34	24.00
		9	15.50	9.80	25.00
		10	15.50	9.23	25.50
	27	1	15.00	11.26	15.40
		2	14.95	11.19	16.15
		3	14.95	10.04	18.90
		4	14.95	9.68	22.00
		5	15.00	9.42	23.60
		6	15.25	9.21	24.50
		7	15.25	9.03	25.00
		8	25.75	9.01	25.25
		9	15.75	8.80	25.75
		10	15.00	8.45	25.75
		11	16.00	8.37	25.75
	28	1	14.75	10.27	16.15
		2	14.25	10.25	16.90
		3	14.50	9.79	20.15
		4	14.75	9.18	21.65
		5	15.00	9.16	23.60
		6	15.25	9.16	23.60
		7	15.25	9.21	24.50
		8	15.75	9.01	25.25

CRUISE IV

Site	Station	Depth meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
	28	9	15.75	8.81	25.50
		10	15.75	8.55	25.50
		11	15.75	8.55	25.50
	29	1	14.75	11.21	15.75
		2	14.25	10.85	17.50
		3	14.50	10.64	19.50
		4	14.75	10.02	22.40
		5	15.00	9.68	23.60
		6	15.00	9.13	24.50
		7	15.05	9.01	25.25
		8	15.15	8.81	25.50
		9	15.15	8.62	25.75
		10	15.15	8.46	25.50
		11	15.75	8.38	25.50
	30	1	14.50	10.64	16.15
		2	14.25	10.43	16.90
		3	14.25	10.13	18.90
		4	14.25	9.61	20.15
		5	14.75	9.29	23.00
		6	15.00	9.07	24.50
		7	15.25	9.04	24.50
		8	15.25	9.01	25.25
		9	15.75	8.84	25.25
		10	15.75	8.66	25.25
	31	1	15.00	10.70	16.90
		2	14.95	10.83	17.75
		3	14.50	10.76	18.90
		4	14.50	10.49	18.90
		5	14.75	10.00	22.75
		6	15.00	9.68	23.60
		7	15.00	9.48	24.00
		8	15.25	9.30	24.50
		9	15.25	9.20	25.00
		10	15.75	8.84	25.25

CRUISE IV

Site	Station	Depth meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
	32	1	13.50	10.16	16.90
		2	14.00	10.51	17.25
		3	14.25	10.13	18.90
		4	14.25	9.57	20.90
		5	14.50	9.35	21.65
		6	14.75	9.24	23.60
		7	15.00	9.14	24.00
		8	15.05	9.13	24.50
		9	15.05	9.01	25.25
		10	15.75	8.71	25.75
Big Hill	37	1	14.50	9.40	24.00
		2	14.50	9.56	24.50
		3	14.50	9.55	25.00
		4	14.75	9.52	25.25
		5	15.25	9.29	26.00
		6	15.25	9.10	26.50
		7	15.75	8.99	27.00
		8	15.75	8.88	27.25
		9	15.75	8.88	27.25
	38	1	15.75	9.21	24.50
		2	15.75	9.56	24.50
		3	15.25	9.72	25.00
		4	15.25	9.72	25.00
		5	15.00	9.63	25.00
		6	15.25	9.39	27.25
		7	15.75	9.14	27.25
		8	16.00	9.05	27.25
		9	16.00	9.04	27.50
		10	16.00	8.87	27.50
		11	16.00	8.87	27.50
		12	16.00	9.03	25.00
	39	1	14.50	9.73	24.50
		2	14.90	9.73	24.50
		3	14.90	9.73	24.50
		4	14.95	9.63	25.00

CRUISE IV

Site	Station	Depth meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
	39	5	14.95	9.52	25.25
		6	15.50	9.24	27.00
		7	15.50	9.07	27.00
		8	15.75	9.07	27.00
		9	15.75	8.97	27.25
		10	25.75	8.80	27.25
		11	15.75	8.88	27.25
		12	15.75	8.92	26.50
	41	1	14.75	9.90	24.50
		2	14.75	9.90	24.50
		3	14.75	9.90	24.50
		4	15.25	9.41	27.00
		5	15.25	9.22	27.25
		6	15.50	9.05	27.25
		7	15.75	9.07	27.00
		8	15.75	8.90	27.00
		9	15.75	8.90	27.00
		10	15.75	8.90	27.00
	42	1	15.25	9.38	24.50
		2	15.00	9.56	24.50
		3	15.00	9.72	25.00
		4	15.00	9.52	25.25
		5	15.00	9.40	25.50
		6	15.75	9.14	27.25
		7	15.75	8.97	27.25
		8	15.75	8.96	27.50
		9	15.75	8.88	27.25
		10	15.75	8.70	27.50
	43	1	15.25	9.94	23.60
		2	15.00	9.56	24.50
		3	15.00	9.38	24.50
		4	15.00	9.37	25.00
		5	15.00	9.18	25.25
		6	15.75	8.50	27.75

CRUISE IV

Site	Station	Depth meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
	43	7	15.75	8.42	27.75
		8	15.75	8.34	27.75
		9	15.75	8.84	27.75
		10	15.75	8.38	27.25
		11	15.75	8.15	25.25
	44	1	14.75	9.52	25.25
		2	14.75	9.58	25.50
		3	14.75	9.58	25.50
		4	14.75	9.58	25.50
		5	15.00	9.33	27.00
		6	15.25	9.05	27.25
		7	15.50	8.96	27.50
		8	15.50	8.89	27.50
	45	1	14.25	9.73	20.90
		2	14.25	10.00	20.90
		3	14.25	10.08	20.90
		4	14.50	9.66	22.75
		5	14.75	9.43	23.25
		6	15.00	9.40	25.50
		7	15.25	9.26	26.50
		8	15.75	9.07	27.00
		9	15.75	8.97	27.25
		10	16.00	8.71	27.25
	46	1	13.50	10.14	20.15
		2	13.75	10.14	20.15
		3	13.75	10.14	20.15
		4	14.00	10.03	20.50
		5	14.00	9.68	22.00
		6	14.50	9.59	23.60
		7	14.75	9.40	24.00
		8	15.25	9.10	26.50
		9	15.50	8.92	26.50
		10	15.50	8.58	26.50

CRUISE IV

Site	Station	Depth meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
	47	1	13.75	10.24	21.25
		2	14.00	10.22	21.65
		3	14.25	10.21	20.90
		4	14.25	9.89	21.25
		5	14.25	9.81	23.00
		6	14.75	9.56	24.50
		7	15.25	9.35	26.50
		8	15.50	9.22	27.25
		9	15.75	9.07	27.00
		10	15.75	8.90	27.00
		11	16.00	8.56	26.50
	48	1	14.25	9.49	22.40
		2	14.25	9.67	22.40
		3	14.25	9.67	22.40
		4	14.25	9.60	23.25
		5	14.50	9.21	24.50
		6	15.25	9.10	26.50
		7	15.75	9.01	27.75
		8	16.00	8.82	28.50
		9	16.00	8.88	27.25
		10	16.00	8.63	27.25
		11	16.25	8.04	27.25
	49	1	13.75	11.41	19.75
		2	13.75	10.85	20.15
		3	14.00	10.47	20.15
		4	14.00	9.92	22.40
		5	14.50	9.60	23.25
		6	14.75	9.42	23.60
		7	15.00	9.29	26.00
		8	15.75	9.18	26.50
		9	15.75	9.10	26.50
		10	15.75	8.56	27.00
Big Hill	50	1	13.25	9.98	23.00
		2	13.25	9.77	23.25
		3	13.50	9.68	23.60

CRUISE IV

Site	Station	Depth meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
	50	1	13.25	9.98	23.00
		2	13.25	9.77	23.25
		3	13.50	9.68	23.60
		4	13.50	9.41	25.50
		5	14.75	9.32	25.50
		6	15.00	9.27	26.50
		7	15.25	9.10	26.50
		8	15.25	9.10	26.50
		9	15.50	8.82	27.00
	51	1	13.25	10.70	22.75
		2	13.25	10.02	22.40
		3	13.25	9.81	23.00
		4	13.75	9.63	23.00
		5	15.00	9.27	25.25
		6	15.00	9.01	26.50
		7	13.25	8.93	26.50
		8	15.25	8.84	26.50
		9	15.25	8.73	27.00
	52	1	14.00	9.33	23.60
		2	14.00	9.33	23.60
		3	14.25	9.42	23.60
		4	14.50	9.21	24.50
		5	15.00	9.14	25.75
		6	15.25	9.10	26.50
		7	15.25	9.01	26.50
		8	15.50	8.82	27.00
	53	1	14.25	9.52	25.25
		2	14.25	9.40	24.00
		3	14.25	9.42	23.60
		4	14.25	9.40	24.00
		5	15.00	9.27	25.25
		6	15.25	9.10	26.50
		7	15.50	9.10	26.50
		8	15.50	8.99	27.00

CRUISE IV

Site	Station	Depth meters	Temperature °C	Dissolved Oxygen (ppm)	Salinity (ppt)
	53	9	15.75	8.88	27.75
		10	15.75	8.88	27.75
	54	1	13.75	9.72	23.00
		2	13.75	9.63	23.00
		3	13.75	9.55	23.00
		4	13.75	9.55	23.00
		5	14.50	9.42	23.60
		6	15.0	9.10	26.50
		7	15.25	8.90	27.00
		8	15.50	8.88	27.25
		9	15.75	8.88	27.25
		10	15.75	8.71	27.25
		11	15.75	8.71	27.25

APPENDIX V

COMMENTS RECEIVED

FEDERAL

A. U.S. Army Corps of Engineers
B. National Oceanic and Atmospheric Administration; St. Petersburg, Florida
C. National Oceanic and Atmospheric Administration; Rockville, Maryland
D. Environmental Protection Agency

DEPARTMENT OF THE ARMY
NEW ORLEANS DISTRICT, CORPS OF ENGINEERS
P. O. BOX 60267
NEW ORLEANS, LOUISIANA 70160

IN REPLY REFER TO
LMNPD-RE

9 November 1977

Mr. Michael E. Carosella
Executive Communications
Room 3309
Federal Energy Administration
Washington, DC 20461

Dear Mr. Carosella:

Your four-volume draft environmental impact statement (EIS), with cover letter dated 12 September 1977, concerning the Texoma Group of salt dome crude oil storage sites was referred to the New Orleans and Galveston Districts from our Washington office for review comments. This is a coordinated reply.

We have reviewed these documents in accordance with our areas of responsibility and expertise as outlined in the Council on Environmental Quality guidelines, Title 40, CFR, Part 1500, published in the "Federal Register" dated 1 August 1973; and US Army Corps of Engineers administrative procedures for permit activities in navigable waters or ocean waters, Title 33, CFR, Parts 320-329, published in the "Federal Register" dated 19 July 1977.

We offer the following comments regarding the draft EIS:

a. There are numerous misspelled and/or misused genera and species in the text, and several biological references are misquoted.

b. The statements on pages 3.2-21 and B.2-57 which describe Choupique Island as being created by filling with dredged material are incorrect. The island is the result of a dredged cutoff associated with the construction of the Calcasieu Ship Channel.

c. The sections which describe the environmental setting of each proposed project site should include discussions of the vector problems and potentials that exist at each site. The impact sections also should discuss the impacts of the proposed projects on the vector problems and potentials.

d. Review of the adverse impacts which would be caused by construction of the Big Hill, Vinton, and Black Bayou facilities indicates that these environmental impacts would be severe and unnecessary since adequate capacity would be afforded by expansion of the West Hackberry site.

e. The brine disposal line diffuser for the West Hackberry site must be located at a sufficient distance offshore in the gulf and west of the Calcasieu Ship Channel so as to preclude introduction of waters of higher salinities to the Ship Channel and Calcasieu Lake. The brine disposal system, including the settling ponds, must be properly constructed and monitored to insure that only the lower salinity levels projected in the draft EIS would enter the surrounding marshlands and the gulf.

f. The entire study area is subject to hurricane tidal flooding to some extent, and the Black Bayou site and pipeline terminal site in particular appear to be subject to flooding from the 1 percent chance hurricane tidal surge.

g. The impact statement does not appear to address (except in one or two brief references) the flood potential of the sites, the susceptibility of the sites or offsite facilities to flood damage, the possible environmental impacts of such flood damage, or the flood protection measures planned if required.

h. On pages 9.2-2 and 9.2-3, references to Corps of Engineers regulations should be changed to agree with the current regulations. On 19 July 1977, Title 33, CFR, Parts 209.120 and 209.131 were rescinded and superseded by regulations contained in Title 33, CFR, Parts 320 through 329.

i. Appendix O, paragraph 5, page O-40 should specify the wave heights at the facilities.

LMNPD-RE

9 November 1977

Mr. Michael E. Carosella

Personnel of the Federal Energy Administration and the Corps of Engineers have been maintaining close liaison concerning the required Corps regulatory permits. Thank you for the opportunity to review and comment on the draft EIS.

Sincerely yours,

EARLY J. RUSH III
Colonel, CE
District Engineer

Copy furnished:

Mr. Charles Warren, Chairman
Council on Environmental Quality
Washington, DC 20506

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Duval Building
9450 Gandy Boulevard
St. Petersburg, FL 33702

October 27, 1977 FSE61/GB

TO: Director, Ofc of Ecology & Environmental Conservation, EE NOV 01 1977

THRU: Assistant Director for Scientific and Technical Services, F5

FROM: William H. Stevenson
Regional Director

SUBJECT: Comments on Draft Environmental Impact Statement - Texoma Group Salt Domes (FEA 77-8) (DEIS #7709.26)

The draft environmental impact statement for Texoma Group Salt Domes that accompanied your memorandum of September 21, 1977, has been received by the National Marine Fisheries Service for review and comment.

The statement has been reviewed and the following comments are offered for your consideration.

General Comments:

The 5 brine disposal sites in the Gulf of Mexico are located in water depths of either 30 or 44 feet. The proposed sites are located within the limits of Grid Nos. 17 and 18 identified by the NMFS for the purpose of computing Gulf of Mexico shrimp fishery statistics. During 1975, 70% of the shrimp harvested within Grid No. 17, or more than 3.7 million pounds of shrimp valued at more than $5.4 million, were caught in water depths of 60 feet or less. (Anon. 1976, Gulf coast shrimp data, annual summary 1975. Current Fishery Statistics No. 6925, U.S. Dept. of Commerce, NOAA-NMFS, 26). Also during 1975, 45% of the shrimp harvested within Grid No. 18, or about 2.8 million pounds of shrimp valued at about $5.4 million, were caught in water depths of 60 feet or less. Because of the importance of this area to marine fisheries the sections of the FEIS containing discussions concerning proposed brine disposal in the Gulf should provide the rationale for selecting the brine discharge sites and discuss alternatives including discharging in waters deeper than 60 feet. The anticipated impacts on marine life and their habitats should be compared, especially with regard to migration routes and spawning areas of major components of the fishery. The FEIS, or a supplement thereto, should include results of laboratory studies on larval stages of several species of marine fishes and crustaceans endemic to the proposed disposal sites, including white shrimp. These bioassays should, for each dome, test the tolerance of those selected species to the brine, at discharge temperatures, that have been put into solution with water from each proposed intake location. The need for such tolerance studies prior to brine disposal at a nearby site has been discussed by NMFS participants in a Strategic Petroleum Reserve workshop on environmental considerations of brine disposal near Freeport, Texas, held in Houston, Texas, on February 17 and 18, 1977. These discussions are included in the proceedings of the workshop. The FEIS should also discuss the feasibility of, as well as environmental impacts associated with, alternative methods of brine disposal for the enlargement or creation of those possible storage areas for which FEA is presently considering disposal in the Gulf.

From the DEIS review, it appears that the alternative least damaging to freshwater commercial and marine fishery resources and their habitats would be storage at the Vinton and Big Hill salt domes, especially if that enabled all the brine to be disposed by injection wells.

Specific Comments:

Volume I

3.0 Description of the Environment
3.2 Regional Environment
3.2.5 Species and Ecosystems
3.2.5.2 Ecosystems

Page 3.2-25, paragraph 2. The FEIS should note that two Louisiana Department of Wildlife and Fisheries marine biologists reported that the decline in shrimp harvests from Sabine Lake since 1968 could be directly attributed to the operational procedures of Toledo Bend Dam. (White, C.J. and W.S. Perret. 1974. Short term effects of the Toledo Bend Project on Sabine Lake, Louisiana. Proc. 27th S.E. Assoc. Game and Fish Comm. pp.710-721).

4.0 Environmental Impacts of the Proposed and Alternative Actions
4.3 Proposed Site - West Hackberry Expansion
4.3.5 Species and Ecosystems
4.3.5.2 Operations Impacts
Displacement Water Systems Impacts

Page 4.3-42, paragraph 1. The proposed water intake location in Black Lake is relatively near the mouth of Black Lake Bayou, a migration route for marine organisms to the Lake. The FEIS should discuss whether operation of the structure at the proposed location would result in minimal entrainment of organisms in Black Lake. If not, the FEIS should determine the location which would result in the least amount of entrainment. The FEIS should also include drawings showing water circulation patterns in the Lake under various wind and tidal conditions.

4.4 Alternative Site - Black Bayou
4.4.2 Water
4.4.2.1 Construction Impacts

Page 4.4-2, paragraph 3. The present salinity regime of Black Bayou and Right Prong should be discussed since those salinities would be increased by the withdrawal of leaching water.

4.4.5 Species and Ecosystems
4.4.5.1 Construction Impacts

Page 4.4-10, Impacts at the Storage Location. The FEIS should discuss measures to reduce wetland impacts resulting from construction of the 10 acre fill for the central plant. These measures include (1) using any previously altered areas for the plant site and (2) using spoil from existing and new disposal areas rather than dredging additional wetlands for fill.

4.4.5.2 Operational Impacts

Page 4.4-12, Displacement/Leaching Water System Impacts. The FEIS should discuss the impacts associated with water withdrawal from the Gulf Intracoastal Waterway (GIWW) instead of Black Bayou. The salinities in Black Bayou and Right Prong would probably not be increased as much, and there would probably be less entrainment of marine organisms since the structure would be further from Sabine Lake.

4.5 Alternative Site - Vinton
4.5.5 Species and Ecosystems
4.5.5.1 Construction Impacts

Page 4.5-7, Brine Disposal System Impacts. The FEIS should discuss the alternative of locating all ten of the proposed injection wells in areas other than tidal marshes. This should eliminate the wetland destruction resulting from the dredging of a 2.2 mile-long access canal with its associated spoil disposal (35 acres). For the presently proposed system, the FEIS should evaluate and compare the impacts of using land-based drilling rigs and constructing board roads for access with the impacts of using barge-mounted drilling rigs and draglines, the latter for excavation.

4.6 Alternative Site - Big Hill
4.6.5 Species and Ecosystems
4.6.5.1 Construction Impacts

Page 4.6-8, Displacement/Leaching Water System Impacts. The FEIS should explain why the less environmentally damaging displacement/leaching water pipeline route and brine disposal pipeline route are considered only as alternatives to the proposed routes, not the proposed routes.

4.6.5.2 Operations Impacts

Page 4.6-15, Brine Disposal System Impacts. The impacts of brine disposal from the Big Hill storage site should be discussed in at least the detail as the West Hackberry site.

5.0 Mitigation Measures and Unavoidable Adverse Impacts

Page 5.0-2, Table 5.2-1. Proposed Site-West Hackberry Expansion Site Construction and Operation

The Draft EIS, in discussing impacts resulting from water withdrawal from Black Lake, indicates that salinities in the Black Lake area should decrease slightly and that the habitats of commercially important species would not be changed irreversibly. Because of the fragile condition of the Black Lake estuarine system, the FEA should develop a contingency plan for water withdrawal that could be put into effect should the withdrawal result in increased salinity in Black Lake rather than a decrease as predicted. In such a plan, water could be withdrawn from the GIWW, west of the Alkali Ditch, which should reduce the amount of entrainment of marine organisms as well as reduce any salinity increase in Black Lake.

8.0 Summary of Proposed and Alternative Activities

The FEIS should discuss the various alternatives suggested in these comments.

Volume II

Appendix A Description of the Project
A.4 Proposed Storage Site - West Hackberry Expansion
A.4-4 Site Development
A.4.4.2 Alternative Physical Facilities
A.4.4.2.1 Raw Water Supply

Page 4-27. Another possible alternative water source that should be considered in the FEIS is the GIWW west of the Alkali Ditch. This alternative would be less damaging to marine fishery resources in that there would probably be less entrainment of marine organisms at a water intake structure in the fresher waters of the GIWW.

A.4.4.2.2 Brine Disposal

Page 4-29. The FEIS should consider, as an alternative to the proposed brine disposal pipeline which parallels the Calcasieu Ship Channel, another pipeline alignment also paralleling the Ship Channel which would maximize the use of existing spoil disposal areas and other non-wetland areas. This alignment was suggested by the Environmental Assessment Branch Area Supervisor of NMFS in Galveston, Texas, in an August 19, 1977, response to a request from the New Orleans District, Corps of Engineers' Regulatory Functions Chief, for a preliminary evaluation of the permit application by FEA prior to issuance of the public notice. This alignment would impact much less wetlands and oyster beds than the proposed alinement and would cause much less disturbance to marine life migration than the alinement in Starks Canal.

It is requested that one copy of the Final EIS be sent our Area Supervisor, Environmental Assessment Branch, 4700 Avenue U, Galveston, TX 77550.

cc:
F53 (3)
FSE612

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Rockville, Maryland 20852

To: William Aron, Director
Office of Ecology and Environmental Conservation

G. Crenmore for,
From: Gordon Lill, Deputy Director
National Ocean Survey

Subj: DEIS 7709.26 - Strategic Petroleum Reserve
Texoma Group Salt Domes

The subject statement has been reviewed within the areas of NOS responsibility and expertise, and in terms of the impact of the proposed action on NOS activities and projects.

The following comments are offered for your consideration:

Appendix D.25 - The MIT Transient Plume Analysis -
The modeling approach used to characterize the dispersion of brine into surrounding waters may suffer from assumptive mathematical simplifications. The assumptions of constant depth and vertically constant current would appear to be weaknesses in the MIT model.

Appendix G - Oil Spill Risk and Oil Pollution
The present state-of-the-art for oil spill analysis includes models which provide lines of probabilistic impact and probabilistic time to impact in this area. This information, missing in the subject DEIS, would improve the plan for containment and removal of spilled oil.

November 17. 1977

Mr. Thomas A. Noel
Acting Assistant Secretary
Resource Application
Department of Energy
1725 M Street
Washington, D.C. 20461

Dear Mr. Noel:

We have reviewed the Draft Environmental Impact Statement for the proposed Texoma Group Salt Domes of the Strategic Petroleum Reserve (SPR) Program. The Texoma group consists of four proposed candidate sites located in the Gulf Coast region of southwestern Louisiana and southeastern Texas. The primary site for (SPR) development in this group is an expansion of the West Hackberry Early Storage Reserve (ESR) facility located in Cameron Parish, Louisiana. The three other candidates are new sites. They are the Black Bayou salt dome located in Cameron Parish, Louisiana, the Vinton salt dome located in Calcasieu Parish, Louisiana, and the Big Hill salt dome in Jefferson County, Texas. One or a combination of these sites may be developed as an alternative to the expansion of the West Hackberry Early Storage Reserve (ESR) facility.

We offer the following comments for consideration in preparation of the Final EIS:

1. The draft statement indicates that for unloading purposes, displacement water for the salt domes will be withdrawn from Black Bayou, Sabine Lake, Intercoastal Waterway, or Vinton Canal. This procedure will necessitate the construction of a water intake structure in either one of these water supplies. The Final would be strengthened if it included more information addressing the intake structure and design. This information should include working drawings of proposed intake facilities and should address intake flow velocity and the screening design that will be used.

2. According to the statement, construction of numerous pipeline systems for both brine disposal or raw water supply could necessitate the utilization wetland habitat. We would like to point out that the policy of the Environmental Protection Agency, as published in the Federal Register (40 CFR 230, September 5, 1975) requires that particular cognizance and consideration be given any proposal that has potential to damage or destroy wetlands by dredging activity. The applicant should provide, where any dredging operations in wetlands are concerned, substantive evaluation of the proposed project and alternative actions. In conclusion, the selected project action should be the most practicable of all alternatives and provide possible mitigative measures to minimize harm to the wetland environment. In the selection of any right-of-ways, efforts should be made to avoid wetlands. Adequate discussion on this matter should be provided in the Final EIS.

3. The proposed Texoma Group Strategic Petroleum Reserve projects involve hydrocarbon storage by emplacement of crude oil into salt domes, solution mining of the salt to create or enlarge existing storage capacity, and, in some cases, disposal of the produced or displaced brines by deep well injection. All these types of operations will be regulated under the Underground Injection Control (UIC) program of the Safe Drinking Water Act (Public Law 93-523), as per Draft regulations, August 31, 1976. Therefore, the data presented in the Draft EIS needs to be strengthened to support an effective evaluation of the environmental impacts of these operations. The applicant should provide sufficient data to EPA from the testing and analysis program, before initiating any of the emplacement, mining, or disposal operations. When the State of Louisiana assumes primary enforcement authority of the Underground Injection Control Program, the data and analyses provided should be consistent both with those requirements proposed in EPA Administrator's Decision Statement #5 (39 CFR:69), or those required under the superceding UIC regulations, when they become applicable, and those required for permit application under Statewide Order 29-B of the Louisiana Department of Conservation, Oil and Gas Division. In addition, close coordination should be afforded EPA and Louisiana Department of Conservation in all phases of data requirements, collection and presentation. Also, selected technical data should be provided to the public in the form of a "by request" appendix to the Final EIS. We are requesting that the intentions of the applicant to comply with the above recommendations be adequately addressed in the Final EIS.

4. In addressing the ambient air quality standards, Table C. 3-8 on page C. 3-56 of the draft statement discusses standards for the Prevention of Significant Deterioration (PSD) in a Class II area for only Sulfur Dioxide (SO_2) and Total Suspended Particulate (TSP) criteria pollutants. The statement needs to recognize that the Clean Air Act amendment, signed August 7, 1977, has changed past PSD standards by requiring new PSD standards to include all criteria pollutants (i.e., SO_2, TSP, non-methane hydrocarbons (NMHC), nitrious oxides (NO_x), carbon monoxide (CO), and photochemical oxidants (O_3). These standards should be addressed in the Final EIS.

5. The draft EIS failed to adequately address the "emission offset" policy. Increased hydrocarbon emissions from fill and withdrawal operations may cause non-methane hydrocarbons and photochemical oxidants to be exceeded for temporary periods within the immediate storage facility areas. Although no long-term adverse impacts on air quality are expected, the "emission offset" policy should be addressed in the final statement.

6. The levels of environmental noise tabulated on page F-15, Volume IV, of the Draft EIS have been labelled as "established guidelines" from EPA. This phrase "established guidelines" is incorrect. Rather, this table reflects "identified levels" which are requisites to protect public health and welfare with an adequate margin of safety for both activity interference and hearing loss. Furthermore, the noise levels cited in this table do not constitute a regulation, specification, or standard. This discrepancy should be corrected in the Final EIS.

7. No sewage discharges are discussed for any of the Texoma Group sites. If such discharges exist, discharge points, treatment, and possible impacts to receiving streams should be discussed. In addition, National Pollutant Discharge Elimination System (NPDES) permit application for such discharges should be addressed. This subject should be addressed in the Final EIS.

8. The draft statement did not adequately address the Spill Prevention Control and Countermeasure (SPCC) Plan. The Final EIS should contain a statement that a SPCC Plan will be prepared within six months after the facilities begin operation and shall be fully implemented no later than one year after operations begin, and will meet the requirements of Code of Federal Regulations 40 CFR 112.

9. The displacement water intake located in Black Lake for the West Hackberry site could have a major impact on the extensive crab and shrimp fishery in the Black Lake area. With the projected oil withdrawal rate of 1.47 million barrels per day, the entire volume of Black Lake (8,768 acre-feet) will be pumped into the domes in 46 days, or three entire lake volumes during the five months required to empty the domes. This magnitude of withdrawal could adversely impact the crab and shrimp fishery by destroying the postlarval population in the lake. EPA recommends that the alternate intake location on the Intercoastal Waterway be strongly considered. The applicant's intention on this matter should be included in the Final EIS.

These comments classify your Draft Environmental Impact Statement as ER-2. Specifically, based on the information contained in the draft statement, we have environmental reservations concerning the loss of valuable wetland habitat, the possible long-term cumulative impacts to groundwater aquifers, and the possible adverse impacts to the crab and shrimp fishery in the Black Lake area. We are requesting additional information regarding air, noise, waste water treatment, and other areas as addressed in the above comments. The classification and the date of our comments will be published in the Federal Register in accordance with our responsibility to inform the public of our views on proposed Federal actions, under Section 309 of the Clean Air Act.

Definitions of the categories are provided on the attachment. Our procedure is to categorize our comments on both the environmental consequences of the proposed action and on the adequacy of the impact statement at the draft stage, whenever possible.

We appreciate the opportunity to review the Draft Environmental Impact Statement, and we would be happy to discuss our comments with you. Please send us two copies of the Final Environmental Impact Statement at the same time it is sent to the Council on Environmental Quality.

Sincerely,

Adlene Harrison
Regional Administrator

Enclosure

GLOSSARY OF TERMS

GLOSSARY OF TERMS

The following glossary of terms is provided for the reviewer when reading this report.

acre-foot	a measure of water drainage or runoff volume equal to the quantity of water that would cover one acre of land to a depth of one foot (43,560 cubic feet).
adsorption	an adhesion of an extremely thin layer of molecules to the surfaces of solid bodies or liquids with which it is in contact.
aldehydes	various highly reactive compounds typified by acetaldehyde and characterized by the group CHO.
alluvium deposits	rock fragments that are transported by modern rivers and deposited in river beds, flood plains, lakes and estuaries and natural levees.
amphipod	small, free-swimming crustaceans (includes beach fleas).
anaerobic	refers to life or processes occurring in the absense of free oxygen; refers to conditions characterized by the absence of free oxygen.
anhydrite	an evaporite mineral, $CaSO_4$, associated with gypsum and found in sedimentary rocks.
aquiclude	a geologic formation so impervious that for all practical purposes it completely obstructs the flow of ground water (although it may be saturated itself), and completely confines other strata with which it alternates in deposition.
aquifer	a water bearing strata.

aquitard	a geologic formation of a rather impervious and semi-confining nature which transmits water at a very slow rate compared to an aquifer.
arcuate fault	a fault that has a curved trace on any given transecting surface.
arenaceous	derived from sand or containing sand.
artesian water	ground water that is under sufficient pressure to rise above the level at which it is encountered by a well, but which does not necessarily rise to or above the surface of the ground.
artesian well	a well which reaches artesian water.
bayou	a stream or small river that is a tributary to another river - term local to southern states.
bbl	barrel or barrels - one barrel of petroleum equals 42 U.S. gallons.
benthos	organisms fixed to or growing on the bottom of water bodies.
biocide	substance destructive to many different organisms.
biotypes	organisms sharing a specified genotype.
blanket oil	used during formation of solution cavity to prevent undesired leaching of cavity ceiling.
bleb	a small, usually rounded fragment of one material enclosed in another.
bottom scour	bottom scour is the erosion of sediment by moving water from the bottom of the stream channel.
BPD	barrels per day - an oil production of distribution rate.
MB/D	thousand barrels per day.
MMB/D	million barrels per day.

brackish	slightly saline water between fresh water (<0.3 ppt) and sea water concentrations (~35 ppt).
breccia	a rock consisting of sharp cornered bits cemented together by sand clay or lime. Collapse breccias are derived from material broken up during the collapse of a solution cavity roof, while fissure breccias are accumulations of fragments in a solution fissure.
brecciated	converted into, characterized by, or resembling a breccia; esp. said of a rock structure marked by an accumulation of angular fragments.
brine	concentrated or nearly concentrated salt water achieved by dissolving water with the salt inside a salt dome, thus creating a cavity. Brine produced in this way is commonly used as feedstock (raw material) by chemical industries or for refining into common salt.
brine safety layer	the brine safety layer is that amount of brine which should be at the bottom of the cavity when it is "full" of crude to assure that crude does not get pushed out of the brine string into the brine surge pits.
^{o}C	degrees Celsius (formerly called Centigrade) - conversion of Celsius to Fahrenheit is $9/5^{o}C + 32^{o} = {}^{o}F$.
calcareous	composed of or characteristic of calcium or limestone, having a chalky nature.
calcite	calcium carbonate, $CaCO_3$, a mineral found in the form of limestone, chalk and marble.

caprock — a mantle of associated minerals across the top of most shallow, piercement salt domes. No well defined layers are evident due to complexity and irregularity; however, three fairly well-defined zones are distinguishable in developed caprock:

(1) anhydrite zone
(2) transition zone - contains sulfur, gypsum, and less important minerals
(3) calcite zone - top zone in developed caprock.

cast and stack dredging — type of dredging that deposits dredge spoil on the bank of the canal/river by means of pipeline or conveyor belt.

cavernous porosity — containing cavities or caverns, sometimes quite large. Most frequently found in limestones and dolomites. In the case of caprock "large" means tens of feet.

Centipose — unit for measuring viscosity, which is the tendency of a fluid to resist change of form.

cfs — cubic feet per second - a rate of water volume flow.

cheniers — long sinuous ridges of sand deposited on top of the swamp deposits of a delta. They represent stationary phases of a regressing shoreline. The type area for their development is the Mississippi Delta.

chlordane — a chorinated, highly poisonous, volatile oil $C_{10}H_6Cl_8$, used as an insecticide.

cladocera — small, aquatic crustaceans (includes water fleas).

CO — carbon monoxide - a colorless, odorless, highly poisonous gas, produced by the incomplete combustion of any carbonaceous material, i.e., gasoline.

COD	chemical oxygen demand.
colloid	a substance that, when apparently dissolved in water, diffuses not at all or very slowly through a membrane, and usually has little effect on freezing point, boiling point, or osmotic pressure of the solution.
concretion	a nodular or irregular concentration or aggregate of mineral matter generally formed by orderly and localized precipitation from aqueous solution in the pores of sedimentary rock and usually of a composition widely different from that of the rock in which it is found, it generally forms about a central nucleus and is harder than the enclosing rock.
cone of influence	actually a truncated cone (Frustrum), apex down, projected from the caprock to the ground surface. The angle of the frustrum is dependent on the shear angle of the overburden. It is the largest volume of material above a cavern that would be influenced, during a collapse.
consolidated rock	coherent and relatively hard, naturally formed mass of mineral matter.
Cretaceous	a period of time from 136 million years to 65 million yeaars ago.
crude oil	unrefined oil as it comes from the ground.
darcy	a measure of the permeability of rock. One darcy (D) equals a permeability such that one millilitre (ml) of fluid, having a viscosity of one centipose, flows in one second under a pressure differential of one atmosphere through a porous material having a cross-sectional area of one square centimeter (cm^2), and a length of one centimeter. The working unit is the millidarcy (mD), one thousandth of a darcy. Darcy's Law relates to the flow of fluids, especially gas oil, and water in the underground rocks.

DDT — dichloro-diphenyl-trichlorethane - powerful insecticide effective on contact.

decibels: dB — logarithmic unit method of expressing the relative intensity of sound pressure. The human ear is sensitive to changes in atmospheric pressure (sound vibrations) ranging from just barely audible at 0.0002 μbar to the threshold of pain at 2000 μbars. This range in sensitivity is so tremendous that a more workable expression of these ranges is to compress them on a logarithmic scale. In order to do this, the reference sound pressure is usually taken as the sound pressure detectable, that of 0.00002 μbars. The intensity of sound is then measured in decibels by the following function:

$$\text{Intensity (in dB)} = 20 \log_{10} \frac{(\text{Pressure})}{(0.0002\ \mu\text{bar})}$$

Using this method, the range of human sensitivity is from 0 dB (pressure at 0.00002 μbar) to approximately 140 dB (pressure at 2000 μbar).

Psychacoustic studies indicate that a 10 dB increase in sound intensity is perceived as a doubling of loudness.

dBA — A-weighted level - a unit is similar to dB Sound Pressure Level (SPL) in that it represents sound intensity level. However, the A-weighted level includes attenuation at each frequency which is similar to the ear's attenuation of frequencies. Since the human ear is much less sensitive to low frequency, it implies that a sound at 250 Hz of 65 dB (SPL) is perceived relative to a sound at 1000 Hz of 65 dB (SPL) as much less intense. The A-weighted scale has been developed to adjust by frequency the overall sound pressure level of noise to an approximation of how the ear would hear the noise.

deltaic	pertaining to or characterized by a delta; e.g., "deltaic sedimentation".
depositional basin	a segment of the earth's crust which has been downwarped, forming a basin, with intermittent risings and sinkings. The sediments in such basins increases in thickness toward the center of the basin.
detritus	material produced by the disintegration and weathering of rock that has been moved from its site of origin. Also, fragments of detached or broken down material such as leaves and other plant parts.
diapir	an intrusion of salt from the salt bed into overlying sediments, often in the form of a ridge or stalk-like piercement structure.
diazonium	the grouping (organic chemistry), $= N \equiv N$, (triple bond of nitrogen).
dieldrin	chlorinated organic chemical, $C_{12}H_8Cl_6O$, a white crystalline contact insecticide, obtained by oxidation of aldrin; used in moth-proofing.
disseminated anhydrite	particles of anhydrite ($CaSO_4$) dispersed through enclosing rock.
distributary (stream)	An irregular, divergent stream flowing away from the main stream and not returning to it, as in a delta or on an alluvial plain. It may be produced by stream deposition choking the original channel. Ant: tributary.
diurnal	recurring on a daily cycle or in the daytime as opposed to nocturnal.
DO	dissolved oxygen.
dolomite	a common rock forming mineral $CaMg(CO_3)_2$

dolomitic	containing dolomite; being composed of dolomite.
downthrown	the wall of a fault that has moved down in relation to the other wall.
dwt or DWT	deadweight capacity - naval architecture term for total carrying capacity of a ship expressed in long tons (2,240 pounds); displacement of a fully loaded vessel less the weight of the ship itself.
electric logs	the log of a well or borehole obtained by lowering electrodes in the hole and measuring various electrical properties of the geologic formations traversed.
emulsification	the process of dispersing one liquid in a second immiscible liquid (liquids that will not mix with one another).
endrin	a poisonous white crystal, $C_{12}H_8Cl_6O$, insoluble in water used as a pesticide. A stereo-isomer of dieldrin.
entrainment	capture of an object or organism by a flowing liquid or gas.
euryhaline	organisms that can tolerate a wide range of salinities.
eurythermal	organisms that can tolerate a wide range of temperature.
eutrophic	rich in nutrients and organic materials, therefore, highly productive.
evaporite	a sediment resulting from the evaporation of saline water. Most evaporites are derived from bodies of sea water. Evaporite minerals are formed in the reverse order of their solubilities, i.e., the least soluble form first.

fault	a fracture in rock along which there has been an observed amount of displacement. Faults are rarely singular planar units; normally occurring as parallel sets of planes along which movement has taken place to greater or lesser extent. Such sets are called fault or fracture zones.
flexure	bending of sedimentary layers.
floating roof tank	a vertical cylindrical tank with a roof designed to float on top of the stored liquid product (commonly oil) as the level in the tank rises and falls.
fluvial	formed or produced by the action of flowing water.
Frasch mining	much mined sulfur (elemental sulfur) is produced from caprock or salt domes by the Frasch process utilizing superheated steam to melt the sulfur in caprock. Drilling well design consists of a concentric arrangement of pipes of various diameters. Steam is injected into the sulfur bearing zone through one of the inner tubing strings. Compressed air is injected through the innermost tubing string which forces water and molten sulfur to rise in the large outer diameter pipes. The molten sulfur then flows through heated pipes to settling tanks. Frasch process sulfur is very pure, as much as 99.5 percent sulfur.
g dry wt/m^2/yr	grams dry weight per square meter per year - a measure of the rate or organic production per area of yield.

geomorphology	the science that treats the general configuration of the Earth's surface; specifically, the study of the classification, description, nature, origin, and development of present landforms and their relationships to underlying structures, and of the history of geologic changes as recorded by these surface features.
geosyncline	a large, generally linear, geologic trough which subsided deeply throughout a long period of time, in which a thick succession of stratified sediments accumulated (for example, the Gulf of Mexico depression).
geosynclinal axis	a line which is parallel to the longest horizontal dimension of, and roughly bisects, a geosyncline.
GPD	gallons per day - flow rate for liquids.
GPM	gallons per minute - flow rate for liquids.
graben	a block of the earth's surface that has a long horizontal dimension and is formed when tension faulting results in that block dropping in relationship to the surface on either side.
gypsum	an evaporite mineral, $CaSO_4 \cdot 2H_2O$ found in clays and limestones, sometimes associated with sulfur.
H_2S	hydrogen sulfide; an inflammable, poisonous gas with the characteristic smell of rotten eggs.
halite	an evaporite mineral, NaCl, common salt.

herpetofaunal	reptiles and amphibians regarded collectively as a faunistic grouping.
Holocene	the period of time from one million years ago to present.
horizons	1. the various layers of soil, each of which is a few inches to a foot or more thick; 2. a plain of stratification assumed to have been once horizontal and continuous; a particular strata-graphic level in the geologic column or in the systematic position of a stratum in the geologic time scale.
HP or hp	horsepower; equal to a rate of 33,000 foot-pounds per minute, the power required to raise 33,000 pounds a distance of one foot in a time of one minute.
humic acid	a gelatinuous material formed as a precipitate when organic matter is treated with a strong base, and the resulting solution is acidified.
hydraulic dredging	this method includes a suction pipeline with either plain suction or cutting heads for digging hard material. The sediments dredged are conveyed by pipeline either to a barge or to a deposition area on shore.
impingement	entrapping of object or organism against a screen or filter by the force of a liquid or gas moving through or against the screen.
inceptisol	an order of soil classification - an inceptisol is a very young soil, the horizons are not distinct. There is no alluvial clay in the subsoil.
injection well	a well that brine will be forced into as part of the brine disposal process.

inversion	a reversal in the normal atmospheric temperature gradient such that temperature increases with altitude (within 300 to 600 feet) and results in an atmospheric inversion. The warmer air on top acts as a ceiling to any material normally diffusing vertically.
isohaline	a line drawn on a map or chart connecting places of equal salinity.
isopach	a line on a map joining points of equal thickness of a rock or sediment type.
isopleth	(1) a graph plotting the occurrence or frequency of a phenomenon in meteorology, etc, as a function of two variables, time and space. (2) the line connecting points on a graph that have equal or corresponding values with regard to certain variables - synonym - isoline.
isostatic	subject to equal pressure from every side.
Kcal	kilocalorie.
Kcal/m^2/yr	kilocalorie per square meter per year - a measure of the rate of organic energy production per area of yield.
kg	kilogram.
leach	to remove soluble constituents from a substance by the action of a percolating liquid, in this case, water taking salt from a salt dome into solution.

littoral	a shallow zone that extends from shore to the lakeward limit or rooted aquatic plants; the shoreward region of a water body; in marine environments, the tidal zone.
log normal distribution	a distribution in which the logarithm of a parameter is normally distributed.
long ton	2,240 pounds, as opposed to 2,000 pounds in a short ton.
lotic	pertaining to flowing waters such as streams and rivers.
LPG products	liquid petroleum gas, commercial petroleum derivatives such as propane, ethane, ethylene, etc.
macrophyte	any plant that can be seen with the naked, unaided eye; e.g., aquatic mosses, ferns, liverworts, rooted plants.
Mercalli scale	a 12-point scale for classifying the magnitude of an earthquake.
meteoric water	water which occurs in or is derived from the atmosphere.
mg	milligrams - 1/1000 of a gram.
mg/l	milligrams per liter.
Miocene	the time span from 12 to 26 million years ago characterized by the development of large mountain ranges (the fourth epoch of the Tertiary Period).

Moh scale	an empirical hardness scale related to standard minerals:

Mineral		Common equivalents
10.	Diamond	
9.	Corundum	
8.	Topaz	Hard file
7.	Quartz	Penknife
6.	Orthoclase	Window glass
5.	Apatite	Teeth
4.	Fluorite	
3.	Calcite	
2.	Gypsum	Fingernail
1.	Talc	

The steps between various minerals are by no means equal, e.g., diamond is about ten times as hard as corundum, whereas corundum is only about 10% harder than topaz.

monocline	strata that dip for an indefinite or unknown length in one direction and which do not aparently form sides of hills or valleys.
	a step-like bend in otherwise horizontal or gently dipping beds.
MSL	Mean Sea Level.
N/A	not available or unknown.
NaCL	sodium chloride (salt).
nekton	macroscopic swimming organisms able to navigate at will (fish, amphibians, large aquatic insects, etc.).
NO_x	nitrogen oxides = NO, NO_2, etc.
normal fault	a fault in which the overlying wall appears to have been moved downward relative to the underlying wall. The angle of the fault is usually 45^o to 90^o.

occluded	prevents the passage of.
OCS	Outer Continental Shelf.
OD	outer diameter - in reference to pipe or tubing size.
Org/m^3	organisms per cubic meter.
overburden	material of any nature consolidated or unconsolidated that overlies a deposit of useful materials, minerals, coal, or salt.
pathogenic	disease causing.
pelagic sediments	sediments derived from open ocean settling from the shells of unicellular organisms known as foraminifera. The shells are composed of either calcium of silicon. In addition, red clays of land mass origin are also deposited.
permeability	a rock is said to be permeable if water or other liquids in contact with its upper surface tend to pass through the rock more or less freely to the lower surface. Permeability may be achieved by the rock being either porous or pervious. The essential feature of a bed of permeable rock is that the liquid it contains may be extracted by pumping. Permeability is measured in darcies.
permeability of an aquifer	the capacity of an aquifer to transmit water under pressure.
pervious	a rock is said to be pervious if it is permeable by virtue of mechanical discontinuities such as joints, bedding planes, fissures, etc. (e.g., some limestones and some igneous rocks).

pH — a measure of acidity of a liquid determined by the concentration of hydronium (H_3O^+) ions per mole of liquid. The pH value equals the negative logarithm of the hydronium concentration. A hydrogen ion concentration of 10^{-7} equals a pH of 7. The scale has a range from 1 to 14 with values below 7 indicating increasing acidity, and values above 7 indicating increasing alkalinity.

photosynthesis — the metabolic process by which simple sugars are manufactured from carbon dioxide and water by plant cells using light as an energy source.

phytoplankton — minute, passively floating plant life of a body of water.

piercement dome — a salt dome in which the salt core has broken through the overlying strata until it reaches or approaches the surface.

piezometric surface — an imaginary surface that everywhere coincides with the static level of the water in the aquifer.

pimple-mounds — small rounded circular elevations 15 to 30 feet in diameter and 2 to 6 feet in height.

pinch-out — the termination or end of a stratum or other rock body that narrows or thins progressively in a given horizontal direction until it disappears, and the rocks that it once separated are in contact; esp. a stratigraphic trap formed by the thinning out of the porous and permeable rock between two layers of impermeable rock.

Pleistocene — a time span from 1 to 2 million years ago characterized by 4 ice ages in North America (the earlier of the 2 epochs comprised in the Quaternary Period).

Pliocene — latest epoch of the Tertiary or the corresponding system of rocks.

Plowpan — A compacted layer formed in soil just below the plower layer.

porosity — a rock is said to be porous if it possesses cavities between the mineral grains making up the rock which can contain liquid. The term porosity ratio or simply porosity is given to the percentage of void space that a rock contains. Porosities of sedimentary rocks range from less than 1% to 15%; loose sand and gravel may reach 45%; while clays, which are exceedingly porous rocks, sometimes reach 50% porosity. (Porous rock is not necessarily permeable).

ppm — parts per million.

ppt — parts per thousand.

product — refined petroleum products.

progradation — the building forward or outward toward the sea of a shoreline or coastline (as of a beach, delta, or fan) by nearshore deposition of river borne sediments or by continuous accumulation of beach material thrown up by waves or moved by long-shore drift.

psi — pounds per square inch - pressure measurement.

psig — guage pressure in pounds per square inch and including pressure of atmosphere, as opposed to absolute pressure (psia), pressure measure with respect to zero pressure.

raw water	as used in this report - raw water is that water used for cavity leaching or oil displacement.
reentrant	rentering or directed inward as a rentrant angle in a coastline or any indentation in a land form, usually more or less angular in character.
revetment	a facing made on a soil or rock embankment to prevent scour by weather or water.
rose (wind rose)	a graphic illustration of wind speed and direction related to percent frequency of occurrence.
rotifer	a phylum of minute, multicellular aquatic organisms which possess a wheel-like bank of cilia at the anterior (oral) end.
saline	water containing a significant quantity (<.3 ppt) of dissolved natural salts of sodium, magnesium, etc.
salinity	the number of grams of salt(s) dissolved in one kilogram of salt solution (seawater). Usually expressed in units of parts per thousand.
salt rock	a general term for a diapiric salt body of whatever shape, cf. salt core.
sedimentary	rocks formed from material derived from pre-existing rocks by processes of denudation (deposition of eroded material) together with material of organic origin.
sedimentary differentiation	the progressive separation by erosion and transportation of a well defined rock mass into physically and chemically unlike products that are resorted and deposited as sediments over more or less separate areas, e.g., the segregation and dispersal of the components of an igneous rock into sandstone, shales, and limestones.
seismic	pertaining to an earthquake or earth vibration, including those that are artificially induced.
senescence	biological changes related to aging (often seasonal).

sessile	pertaining to those organisms that are attached to substrate and not free to move about.
shale	a fissile rock composed of laminated layers of claylike, fine grained sediments.
slip dip fault	movement along a fault plane in the direction of the dip of the fault.
SMSA	Standard Metropolitan Statistical Area.
SO_x	Sulpher Oxides - SO_2, etc.
soil catena	a soil series, a horizontal gradation of soils of a similar origin.
soil series	a specific classification of soil types for a limited geographic area.
solution cavity	cavity formed in soluble rocks (or salt) primarily by solution action (natural or man-made).
sonar	a system that uses underwater sound, at sonic or ultrasonic frequencies, to detect and locate objects in water.
sonar caliper survey	a technique for measuring internal configurations of a cavity.
sour crude	crude oil with a high sulfur content.
standard elutriate	the supernatant resulting from the vigorous 30 minute shaking of one part of bottom sediment with 4 parts water (on a volumetric basis) collected from the same sample site, followed by a 1-hour settling time and appropriate 0.45 microns (μ) filtration.
stomata (plural of stoma)	a small opening or pore in a surface.

strike	the course or bearing of the outcrop of an inclined bed or structure on a level surface; the direction or bearing of a horizontal line in the plane of an inclined stratum, joint, fault cleavage plane or other structural plane. It is perpendicular to the direction of the dip.
subangular	a grade of roundness of rock in which the fragments retain their original angular form, but the edges and corners are rounded off.
substrata	a layer of stratum of earth or rock lying immediately under another.
surge tank	a storage tank which serves to keep the pumping rate/pressure through a pipeline constant by storing excess or providing a surplus when the rate of pumping "surges" up or down, respectively.
suspended solids, suspended particulate matter (particulates)	a direct measurement quantifying any finely divided solid and/or liquid matter which does not settle from the ambient air.
sweet crude	crude oil with a low sulfur content.
taxon	the name applied to a group of plants or animals in a formal system of nomenclature.
tectonic	of, pertaining to, or designating the rock structure and external forms resulting from the deformation of the earth's crust. As applied to earthquakes, it is used to describe shocks due to volcanic action or to collapse of caverns or land slide.
Tertiary	the period of time extending from 65 million to 2 to 3 million years ago.
thalweg	a line joining the deepest points in a channel.

throw — the amount of vertical displacement as a result of faulting.

TKN — total Kjeldahl nitrogen (sum of free ammonia and organic nitrogen compounds).

toxaphene — organic compound, $C_{10}H_{10}Cl_8$, a toxic waxy, amber solid, with mild chlorine-camphor smell, soluble in organic solvents, melts at 65-90^{o}C. Used as insecticide (also known as technical chlorinated camphene).

transmissibility, coefficient of — the rate of flow of water in gallons per day through a vertical strip of the aquifer one foot wide extending through the vertical thickness of the aquifer at a hydraulic gradient of one foot per foot and at the prevailing temperature of the water. The transmissibility from a pumping test is reported for the part of the aquifer tapped by the well.

trend — (1) the direction or bearing of the outcrop of a bed, dike, silt.

(2) the intersection of the plane of a bed, dike, joint, fault, or other structural feature with the surface of the earth.

turbidity — a measure of the amount of light that will pass through a liquid. It describes the degree of opaqueness produced by suspended particulate material.

turbidity plume — a localized area of suspended sediments often associated with dredging operations that reduces the amount of light penetration through the water in that localized area.

unconformity	the structural relationship between rock strata in contact, characterized by a lack of continuity in deposition and corresponding to a period of non-deposition, weathering, or especially erosion (either subareal or subaqueous) prior to the deposition of the younger beds, and often, but not always marked by absence of parallelism between the strata.
unconsolidated (sediment)	1. a sediment that is loosely arranged or unstratified whose particles are not cemented together, occurring either at the surface, or at depth. 2. soil material that is in a loosely aggregated form.
undifferentiated	(see sedimentary differentiation)
vol.	volume.
vuggy porosity	porosity due to vugs in calcareous rock.
vugs	cavities often with mineral linings different in composition from the surrounding rock.
wind rose	a diagram showing, for a given place, the relative frequency or frequency and strength of winds from different directions.

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