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WEEKS ISLAND BRINE DIFFUSER SITE STUDY:
BASELINE CONDITIONS AND ENVIRONMENTAL ASSESSMENT
TECHNICAL REPORT

Prepared for:

MASTER U.S. Department of Energy
Washington, D.C. 20545

December 12, 1980
Contract No. AC01-77US08781

Dames & Moore

7101 Wisconsin Avenue, Suite 700, Washington, D.C. 20014

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December 12, 1980

Mr. Walter H. DeLaplane, Jr.
Technical Project Officer
Strategic Petroleum Reserve Office
Department of Energy--Room 3G029
Forrestal Building
1000 Independence Avenue, S.W.
Washington, D.C.   20585

RE: Contract No. DE-AC01-77US08781
     Final Technical Reports:
     Weeks Island and Chacahoula
       Brine Diffuser Sites
     Baseline Conditions and
       Environmental Assessment

Dear Mr. DeLaplane:

    Please find enclosed fifty (50) copies each of our final technical
reports on the characterization of Baseline Conditions at a Candidate
Offshore Brine Disposal Site for both Chacahoula and Weeks Island.
These reports complete our scope of services provided to the Strategic
Petroleum Reserve Office under the above contract and subsequent modifi-
cations, Nos. 011 through 020.

    We believe that these reports present a comprehensive and thorough
assessment of the oceanographic baseline conditions existing at each
site during the period of study. The reports should not only serve
as a sound basis for the assessment of environmental effects of brine
disposal at these sites, but also as indicators of those factors which
would be important for environmental monitoring and coastal zone management
should these projects be implemented.

    We particularly want to express our appreciation to you for your
personal suggestions and review which have added greatly to the final
reports. It has been a pleasure to be of service to the Strategic

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Petroleum Reserve Office on this phase of the work. We look forward
to our continuing involvement in any subsequent phases of this important
project.

Sincerely,

DAMES & MOORE

George H. Weissberg, Ph.D.
Associate and Project Director

cc: Mr. Stephen L. Lake
     Contracting Officer
     Department of Energy
     Office of Procurement Operations

GHW:lm

WEEKS ISLAND BRINE DIFFUSER SITE STUDY:
BASELINE CONDITIONS AND ENVIRONMENTAL ASSESSMENT--
TECHNICAL REPORT

Prepared by:

George H. Weissberg
Dennis G. McGrath
William M. Levitan
and
Samuel H. Blood

of

DAMES & MOORE
7101 Wisconsin Avenue
Washington, D.C. 20014

for

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EXECUTIVE SUMMARY

The Department of Energy (DOE) has proposed that caverns in the Capline Group of salt domes, on the Gulf Coast of Louisiana, be used for crude oil storage in its Strategic Petroleum Reserve (SPR) program. Solution mining of cavern refills in the Weeks Island area would require offshore brine disposal--with the salinity of the brine discharge ranging from 230 to 264 ppt and maximum temperatures at the brine diffuser head from 115° to $120^{\circ}F$ (46° to $49^{\circ}C$).

This technical report was prepared to assist DOE in the assessment of potential environmental impacts associated with brine disposal and to support its application for a brine disposal permit at one of two potential sites for the Weeks Island salt dome. Weeks Island Site A is located about 9 nautical miles (10.4 statute miles) offshore the entrance to Atchafalaya Bay, Louisiana, in approximately 21 feet (6.4 meters) of water. Weeks Island Site B is located almost 20 nautical miles (23 statute miles) from the entrance to Atchafalaya Bay. This report is based on both historical data and site-specific investigations conducted at the proposed sites. Site A was surveyed from September to December 1977 and Site B was surveyed from February to July 1978.

The continental shelf in the vicinity of the proposed diffuser sites is covered by sediments which vary from silty sands to silts or clays with some sand. Sediments are coarse nearshore and become finer with distance from the coast. Numerous shoals are present within the vicinity of the sites, especially within the 30-foot (9-meter) isobath. The slope of the shelf out to the 60-foot (18-meter) contour, which is located 30 miles offshore, is very small (0.03 percent).

Nearshore circulation in the Gulf is primarily driven by the wind; the net drift is parallel to the isobaths and northwesterly throughout most of the year. During July 1978, a southeasterly drift was observed at a depth of 11 feet (3.4 meters), while the water at 17 feet (5.2 meters) flowed northwestward. Current speeds generally ranged from 0.7 to 1.3 ft/sec (20 to 40 cm/sec), (Section 2.2).

Predictive modeling for the proposed diffusers indicates that the discharged brine plume would remain near the bottom, thus minimizing

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its effect on mid-depth and surface waters. Plume analyses were conducted using in situ current meter data collected at the sites for a variety of ambient conditions. For the time-series of currents observed during the study period, the worst case indicates that an area of approximately 52 acres (21 hectares) would be exposed to a maximum excess salinity of 5 ppt. The average or base case condition predicted that an area of 100 to 150 acres (40 to 61 hectares) would be exposed to a maximum excess salinity between 2 to 3 ppt.

A heat flow model was evaluated and analyzed to estimate the potential for excess temperature at excess salinity profiles around the diffusers. This was accomplished by assuming $90^{\circ}F$ ($32^{\circ}C$) seawater temperatures (worst case summer maximum) and brine temperatures at the diffuser head varying from 90° to $150^{\circ}F$ (32° to $65^{\circ}C$). Considering a worst case condition (i.e., the maximum ∇t expected) of $90^{\circ}F$ Gulf waters and a brine discharge of $150^{\circ}F$, the excess temperature at the 3-ppt excess isohaline (about 40 acres (16 hectares)) would be less than $0.5^{\circ}F$ ($0.3^{\circ}C$). When the ambient temperatures in these coastal waters are less than $90^{\circ}F$, the excess temperatures at any isohaline would be greater, but the maximum temperature would be less.

The water chemistry (Section 2.3) in the vicinity of the proposed diffuser sites is seasonally dependent on the freshwater discharge of the Mississippi and Atchafalaya Rivers. Hydrocarbons and trace metals, with the exception of mercury, are normally within the ranges expected for coastal waters. Heavy metal concentrations are usually greater in the sediments and interstitial waters than in the overlying water column. Zooplankton contained significantly higher concentrations of trace metals than either the shrimp or the fish. Dissolved oxygen (DO) at the sites generally ranged from 3.8 to 11.4 mg/l; periodically the bottom waters became anoxic. Levels of inorganic nutrients, the major ions, organic carbon, and suspended matter at the sites are typical of coastal estuarine areas.

The major impact of the brine discharged into the Gulf would be the localized increased concentration of several chemical species, notably the major ions sodium and chloride, and the alteration of other ion proportions in the immediate vicinity of the discharge (Section 3.1).

Many of these constituents would be quickly diluted to near ambient levels within a small area around the diffuser. Upon discharge of the brine into the seawater, precipitation of various chemical species may occur; settling out of these particulates could impact the local benthic community. The reduction of DO levels from ambient at the 20-ppt excess isohaline, resulting primarily from mixing with nearly anoxic brine, would be approximately 0.6 mg/l. No modification in the pH is anticipated. During the operational phase, brine discharge would have an estimated hydrocarbon content of 6 ppm, an order of magnitude greater than ambient. Local mixing and dispersion mechanisms would rapidly reduce these concentrations to ambient levels.

The biological assemblages at both sites are diverse and productive (Section 2.4). The phytoplankton community, strongly influenced by the mixing of oceanic and riverine discharges, was composed of freshwater, neritic, and oceanic species. Diatoms were the predominant group in these waters. Biomass (cell density) was low in the fall and winter at both sites, but increased substantially in the spring at Site B.

Bioassay studies have indicated that plankton entrained in the brine plume at the diffuser would be subjected to severe physiological (mainly osmotic) and temperature stress and would thus undergo a temporary reduction in productivity and standing stock. Since residence time of plankton in the plume area would be in terms of only a few hours, it is expected that they would not suffer any long-term impacts. Since the plume will remain near the bottom, only those organisms associated with this lower portion of the water column would be affected.

Ninety-five taxa of benthic invertebrates were collected at Weeks Island Site A and 183 taxa were collected at Site B. The species diversity at both sites was comparable, but Site B had a greater density. The mean density values at Site A remained fairly constant from September to December, ranging from 530 to 604 organisms/m^2, while at Site B mean density values increased from 958 organisms/m^2 in February to 12,478 organisms/m^2 in April. The polychaetes generally dominated the benthos, with molluscs and crustaceans also very common.

Brine disposal into the Gulf of Mexico would have significant effects on the benthic community (Section 3.3), especially organisms

in the immediate vicinity of the diffuser within the 4-ppt isohaline. Assuming total mortality in this area, a mean density of 2.1×10^6 benthic invertebrates per acre would be killed at Site A and 27.4×10^6 per acre would be killed at Site B. Based on worst-case current conditions for plume dispersion, an estimated 52 acres (21 hectares) would be covered by the 4-ppt excess isohaline at any one time. Impacts would be maximum in the spring when benthic community densities are at their maximum. Outside of this near-field area, there would be little or no significant impact on benthic organisms. The younger developmental stages of many benthic invertebrates would be the most subject to impact.

Major fisheries in the Louisiana coastal waters include shrimp, menhaden, oysters, and blue crabs. Shrimp ranked first in value ($80 million) but second in weight (82 million pounds). Menhaden was the leading species by weight (1.1 billion pounds) and second in value ($37 million). Thirty-six species of fish were collected at Site A, with bay anchovy, sand seatrout, star drum, Atlantic croaker, and sea catfish the most abundant species. At Site B, 26 species were collected, of which the bay anchovy, sand seatrout, Gulf butterfish, blackfin sea robin, and striped anchovy were most abundant. At Sites A and B, 21 and 23 taxa of invertebrates were collected, respectively, but the number of invertebrates collected and their diversity were greater at Site A than at Site B.

Because of their mobility, the majority of the nekton would be expected to avoid areas of the brine plume where excess salinities and temperatures are anticipated. Nekton entering this region would be temporarily subjected to osmotic and temperature stress. Bioassay studies have indicated that brine concentrations of about 36.5 ppt are lethal to embryonic white shrimp, while sublethal effects may occur below this concentration. Larval fish forms may be slightly more tolerant of high salinities than embryonic white shrimp. Gulf menhaden larvae are known to metamorphose at salinities approaching 40 ppt, while the larvae of spotted seatrout are reported to have a 2-hour LC_{50} (lethal dose to 50 percent of the test organisms) of about 41 ppt. The planktonic larvae and eggs of fish and shrimp entrained in the

plume where temperature and salinity values approach or exceed their upper tolerance limits would suffer lethal and sublethal impacts.

Based on analysis of the physical oceanographic data and brine plume model, it appears that the physical characteristics of the plume at Site A would not be greatly different than those expected at Site B. Based on the biological characteristics of the two sites, brine disposal would have similar impacts on the phytoplankton and zooplankton populations at either of the sites, but the benthic community at Site B would be stressed more than that at Site A because of the higher density of benthos and the greater diversity found at Site B. On the other hand, at Site A several commercial species, especially white shrimp, are present in higher numbers and for a longer period of time than at Site B; therefore, the nekton would be affected less if brine disposal was conducted at Site B.

TECHNICAL REPORT
WEEKS ISLAND BRINE DIFFUSER SITE STUDY
BASELINE CONDITIONS AND ENVIRONMENTAL ASSESSMENT

SECTION 1

INTRODUCTION

1.1 Background

This technical report presents the results of a study conducted
at two alternative brine diffuser sites (A and B) proposed for the
Weeks Island salt dome, together with an analysis of the potential
physical, chemical, and biological effects of brine disposal for this
area of the Gulf of Mexico. Brine would result from either the leaching
of salt domes to form or enlarge oil storage caverns, or the subsequent
use of these caverns for crude oil storage in the Strategic Petroleum
Reserve (SPR) program administered by the U.S. Department of Energy.
Brine leached from the Weeks Island salt dome would be transported
through a pipeline which would extend from the salt dome either 27
nautical miles (32 statute miles) for Site A, or 41 nautical miles
(47 statute miles) for Site B, into Gulf waters (Figure 1-1). The
brine would be discharged at these sites through an offshore diffuser
at a sustained peak rate of 39 ft^3/sec.

The disposal of large quantities of brine in the Gulf could have
a significant impact on the biology and water quality of the area and,
as such, this disposal is one of the most critical issues identified
in the programmatic Environmental Impact Statement (FES 76-2) developed
for the SPR program. One of the objectives of this report, therefore,
is to complement the Capline Group Final EIS (DOE/EIS-0024) with an
assessment of the environmental effects of a brine disposal operation
specific to the Weeks Island area (Figure 1-2). This assessment is
based on the results of field studies conducted at Sites A and B between
September 1977 and July 1978. Another objective of this study is to
provide DOE with information that can be used to help select an environ-
mentally appropriate location, configuration, and size for a brine
disposal diffuser system in the Louisiana offshore region. Such a
location should be within a reasonable distance of the dome storage
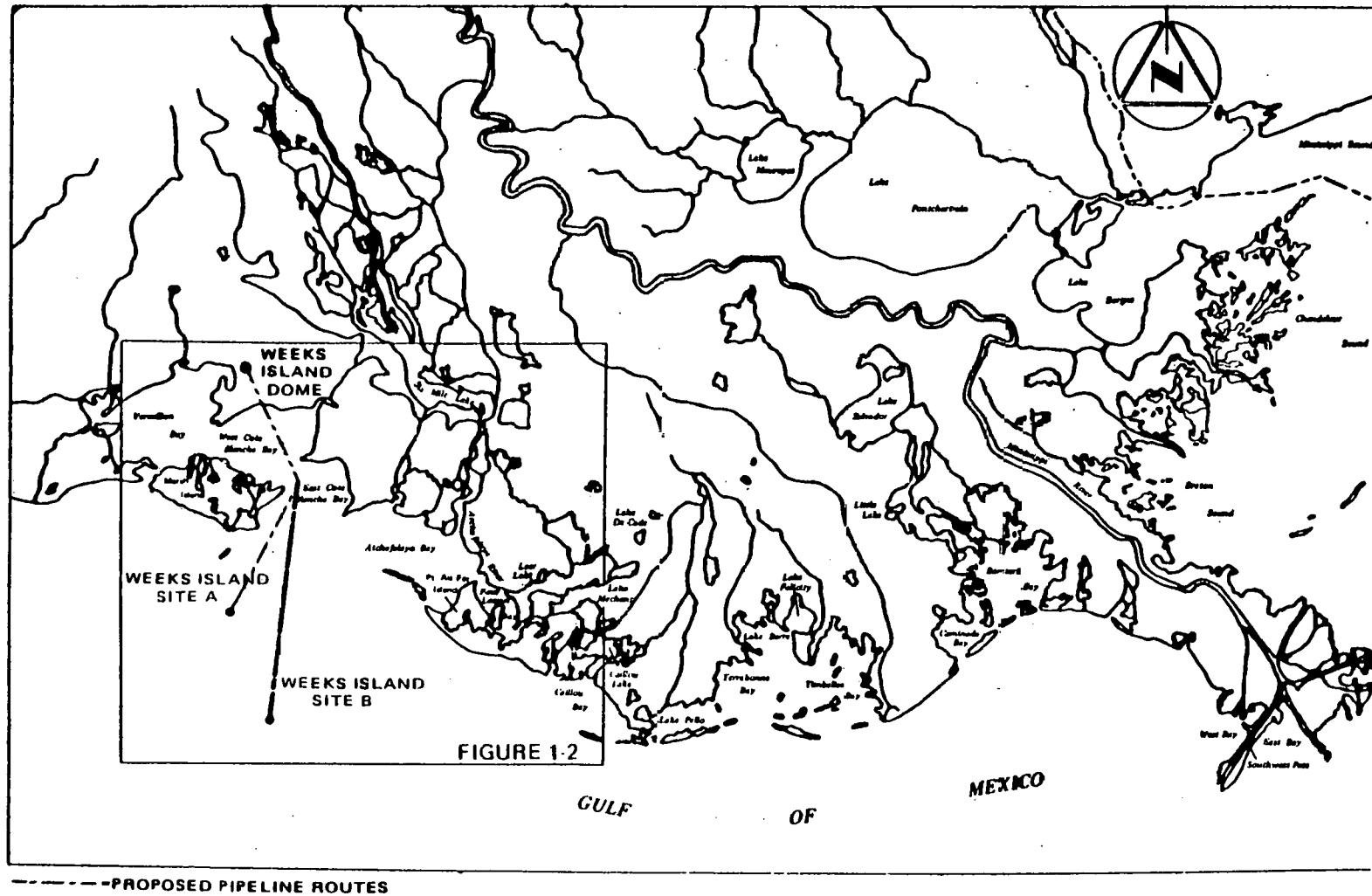
FIGURE 1-1   Coastal Louisiana showing proposed offshore brine diffuser sites.
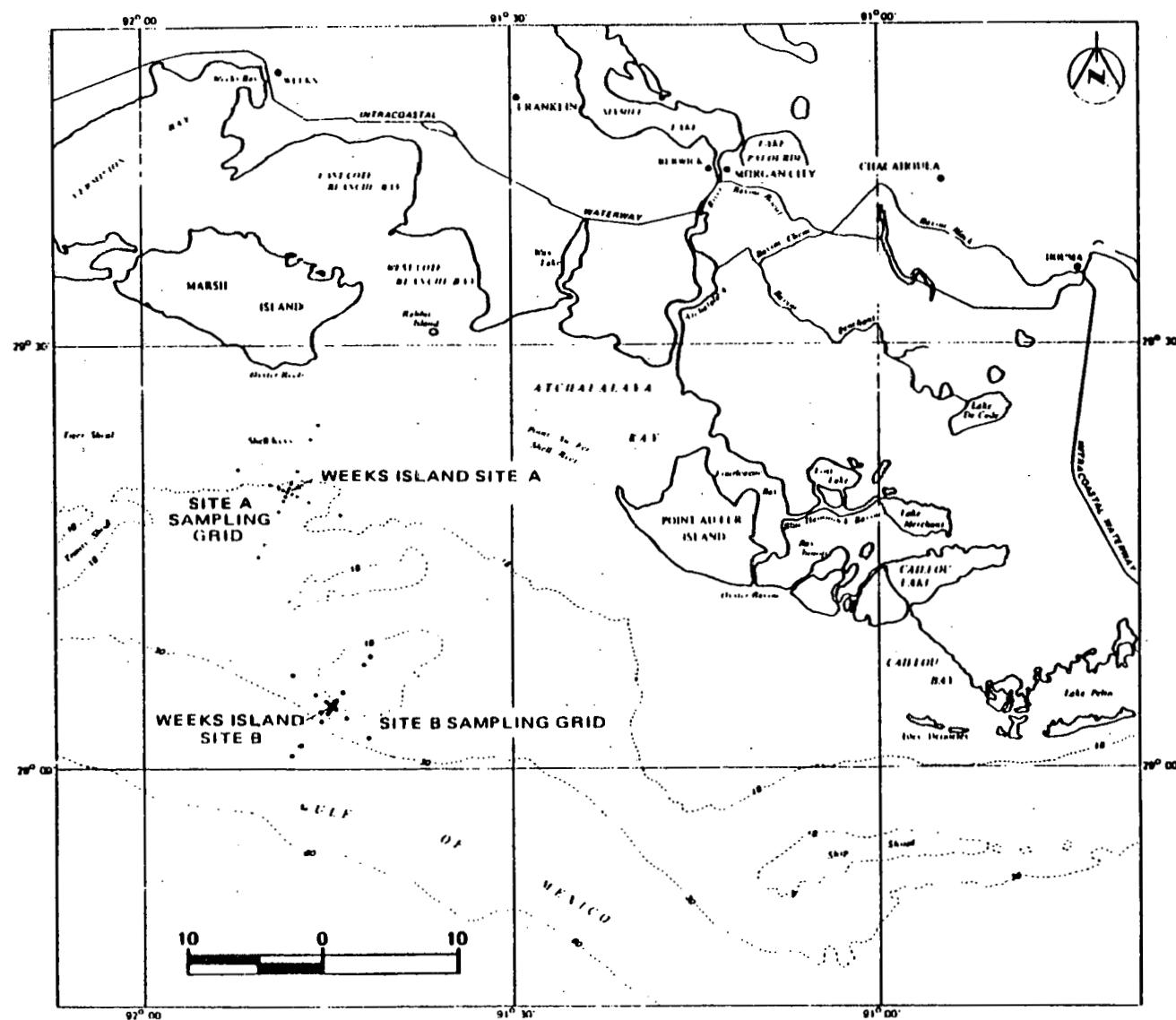
FIGURE 1-2   Region of the proposed Weeks Island brine diffuser sites, including sampling grids.

sites under consideration. In addition, this information would be used to support an application to the Environmental Protection Agency for brine disposal permits for the Weeks Island salt dome.

1.2 Operational Brine Disposal Requirements

It has been proposed that the early storage phase capacity of the Capline Group (183 million barrels (MMB)) Strategic Petroleum Reserve (SPR) program be expanded by 117 MMB to a total storage volume of 300 MMB. Expansion of the Weeks Island salt dome cavern (274 MMB total Capline Group capacity) would result in a 91 MMB increase in storage capacity. This additional capacity would be obtained by constructing new leached caverns. Each additional barrel created would require leaching by the introduction of seven barrels of water and the subsequent disposal of seven barrels of brine. It has been estimated that the new leached space and initial fill of the new capacity in the Capline Group would require the disposal of 640 to 1400 MMB of brine over a 4- to 5-year period. This disposal period includes the construction of the caverns by leaching and the initial fill when crude oil is pumped into the newly formed caverns, displacing the remaining brine to the surface for disposal.

After the initial fill of new caverns, all of the storage caverns would be operated as a single system. Once the caverns are filled with oil, however, no further brine disposal or water supply will be required unless there is an interruption in foreign oil supply. Then, according to SPR program requirements, the oil will be withdrawn from the caverns within a 150-day period by displacement with raw water. Resumption of normal foreign oil supplies would then initiate a second cycle; that is, the caverns would be refilled with oil, and this oil would displace the saturated brine. The refill period and its associated brine disposal would require from 12 to 24 months. Subsequent crude oil withdrawals and refills of the Capline Group capacity could require disposal of an additional 91 to 200 MMB of brine to the Gulf (Gulf disposal would not be used for early storage capacity).

The range of projected disposal rates, durations, and total brine disposal volumes for the Weeks Island expansion of the Capline Group is presented on Figure 1-3 and summarized in Table 1-1. The maximum
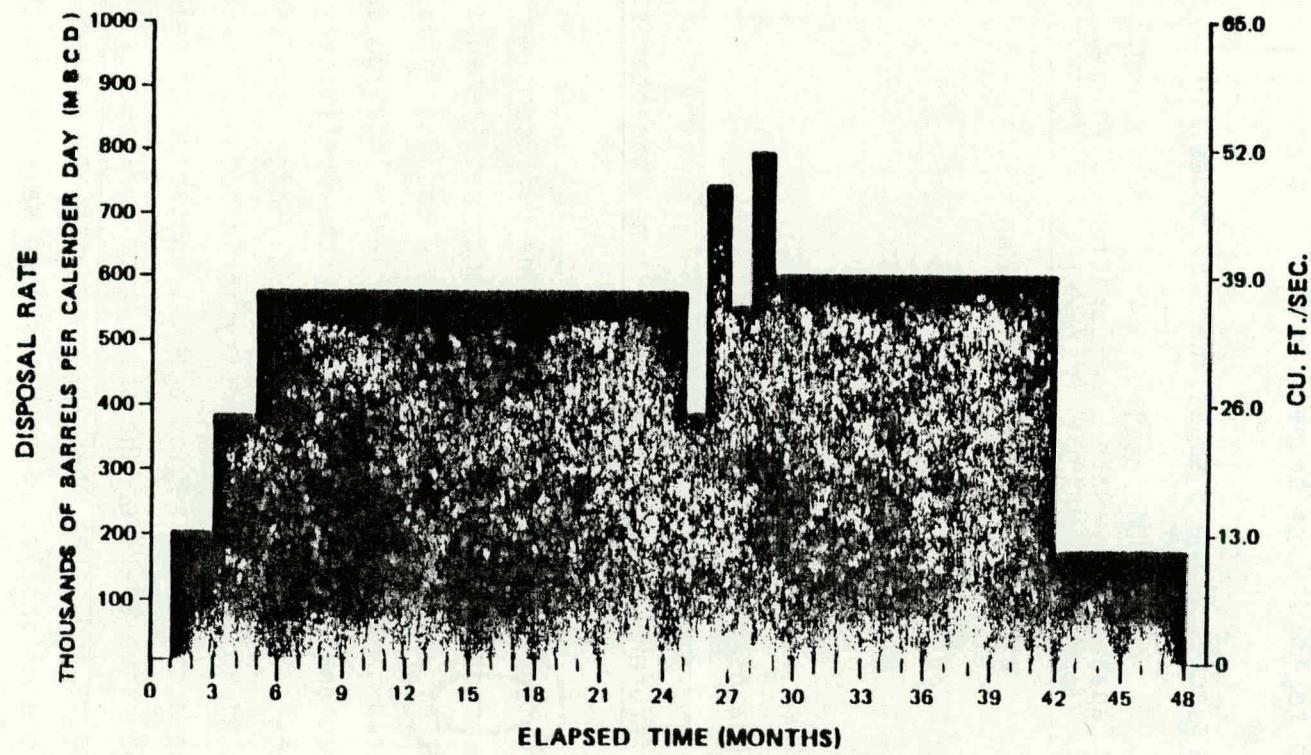
FIGURE 1-3 Projected variation in brine disposal rates.

values of discharge (570 to 600 thousand barrels per calendar day (MBCD)) in this table represent leaching of the expansion capacity for about 4 years. During oil refill periods, lesser amounts of brine would be discharged into the Gulf from the diffuser. Over the projected 22-year life of the SPR, a maximum of five fill/withdrawals is planned, displacing up to 450 MMB of brine from Weeks Island.

TABLE 1-1 Projected brine disposal data by modes.

Mode	Capacity (MMB)	Disposal Rate (MBCD)[a]	Duration (months)	Brine Volume (MMB)	Salt Mass (millions of short tons)
Leach	91	570 - 600	50 - 60	640	34.5
Initial fill	91	190	16	91	4.9
Refills	91	190	16	91	4.9

[a] MBCD = thousands of barrels per calendar day.

1.3 Brine Diffuser Design Criteria and Plume Characteristics

Design criteria for the offshore brine diffusers were based on environmental considerations and operational requirements (U.S. Dept. of Commerce, 1977a). The selection of Sites A and B as proposed diffuser sites was based on the criteria shown for each location on Figure 1-2 and on the rationale that, as a result of the preliminary biological sampling, Site A appeared to have relatively high levels of productivity. The staff at Nicholls State University in Thibodaux, Louisiana, had conducted research in the region and was contacted to help characterize the more productive areas of the shelf from a fisheries point of view. Preliminary data indicated that the most productive fishery areas are located inshore of shoals. Site B was then selected in accordance with the following criteria: (1) locate the site offshore from the nearest shoal; (2) select a location that allows for a short pipeline route; (3) select a location that minimizes interference with other pipelines and avoids existing gas or oil platforms or feeder pipelines;

and (4) select a location expected to have a sandy bottom, rather than a silt or clay bottom, since sandy sediments are usually less productive. The proposed pipeline and diffuser characteristics for Sites A and B are summarized in Table 1-2.

TABLE 1-2. Summary of pipeline and diffuser characteristics.

	Site A	Site B
Latitude	$29^{\circ}19.5'$ N	$29^{\circ}04.5'$ N
Longitude	$91^{\circ}48.2'$ W	$91^{\circ}44.6'$ W
Offshore pipeline length	27.9 nmi (32.1 mi)[a]	41.4 nmi (47.6 mi)
Distance offshore	10 nmi from entrance to Atchafalaya Bay	22 nmi from entrance to Atchafalaya Bay
Water depth	21 feet	Same as Site A
Diffuser length	2000 feet	Same as Site A
Orientation	Normal to isobaths	Same as Site A
Number of ports	34	Same as Site A
Orientation of port risers	90° to bottom	Same as Site A
Height of risers above bottom	0 - 5 feet	Same as Site A
Port exit velocity	25 ft/sec	Same as Site A

[a] nmi = nautical mile; 1 nautical mile = 1.151 statute miles.

As discussed in Section 1.2, a brine plume would occur during two separate activities. The initial discharge would result from solution mining of the salt dome to form caverns for oil storage. This discharge would occur over a period of 4 to 5 years, and the brine at the discharge ports would have a salinity of 230 to 260 ppt and a temperature near the ambient conditions found in the Gulf during the summer (86°F (30°C)). The second discharge would occur when crude oil is pumped into the completed brine-filled caverns. The oil would displace the brine and this discharge would occur over a 2-year period. The brine will have a salinity of approximately 264 ppt, and a temperature at the diffuser ports up to about 120°F (49°C).

An MIT transient plume model (U.S. Dept. of Commerce, 1977a) was used to evaluate the characteristics of the brine plume. For this evaluation, the plume was considered to result from a worst case condi-

tion which would occur during an 8-day slack period with a nontidal long-shore current component. The 8-day slack period is a conservative estimate of expected conditions since current data from the area indicate that the expected slack period would be only 2 days. To compare average and worst case conditions, Table 1-3 was derived from isopleths of bottom concentration versus bottom area covered (U.S. Dept. of Commerce, 1977a).

TABLE 1-3 Brine plume characteristics for the Weeks Island area.

Isohaline (ppt above ambient)	8-Day Slack (acres)	Average Conditions (acres)
1	2900	500
2	400	250
3	100	40
4	30	

Under average wind and current conditions, surface salinities would be essentially unaffected because the diffuser would be located on the ocean bottom and high salinities would be limited to the bottom area immediately adjacent to the diffuser. During the 8-day slack period, when currents may fall as low as 0.02 knot (1 cm/sec), a broader area near the diffusers would experience excess salinities (that is, higher than ambient conditions) and surface salinities would be increased slightly (up to 1 ppt).

1.4 Scope of Work for Baseline Characterization

Physical and chemical measurements of the marine environment at Sites A and B were taken between September 1977 and July 1978 to correlate the existing environmental conditions with the estimated physical extent of the brine discharge as predicted by the MIT model (U.S. Dept. of Commerce, 1977a). Measurements of wind, tide, waves, currents, and stratification (water column structure) were also obtained since the diffusion and dispersion of the brine plume are a function of the local circulation regime. These data were used to calculate both near- and far-field concentrations of brine, and may also be used in the design criteria for diffuser port configuration and verification of the plume model.

Biological samples were taken to characterize the sites and to predict potential areas of impact with regard to the discharge. This sampling focused on benthic organisms and demersal fish, since these organisms remain affixed to or are in close association with the ocean sediments and will be exposed to the potential effects of brine waste disposal. Also, their spatial and temporal variability is somewhat less than that of the planktonic and other neritic organisms, and thus can be more easily defined.

1.4.1 Geographical Area Covered

1.4.1.1 Cruises

Eight major cruises were made at the Weeks Island sites between September 1977 and July 1978. During September and February, biota, water, and sediment were sampled for a chemical characterization. Other cruises were conducted for the retrieval of instrumentation data tapes.

1.4.1.2 Oceanographic Station Arrays

In the experimental design for each sampling grid (Figures 1-4 and 1-5), the locations of disposal site stations and reference stations were determined by consideration of the spatial extent of the brine plume, as predicted by the MIT model, and regional data on coastal currents. Each grid was designed to extend beyond the area of predicted plume exposure for the near and far fields. Near-field stations would
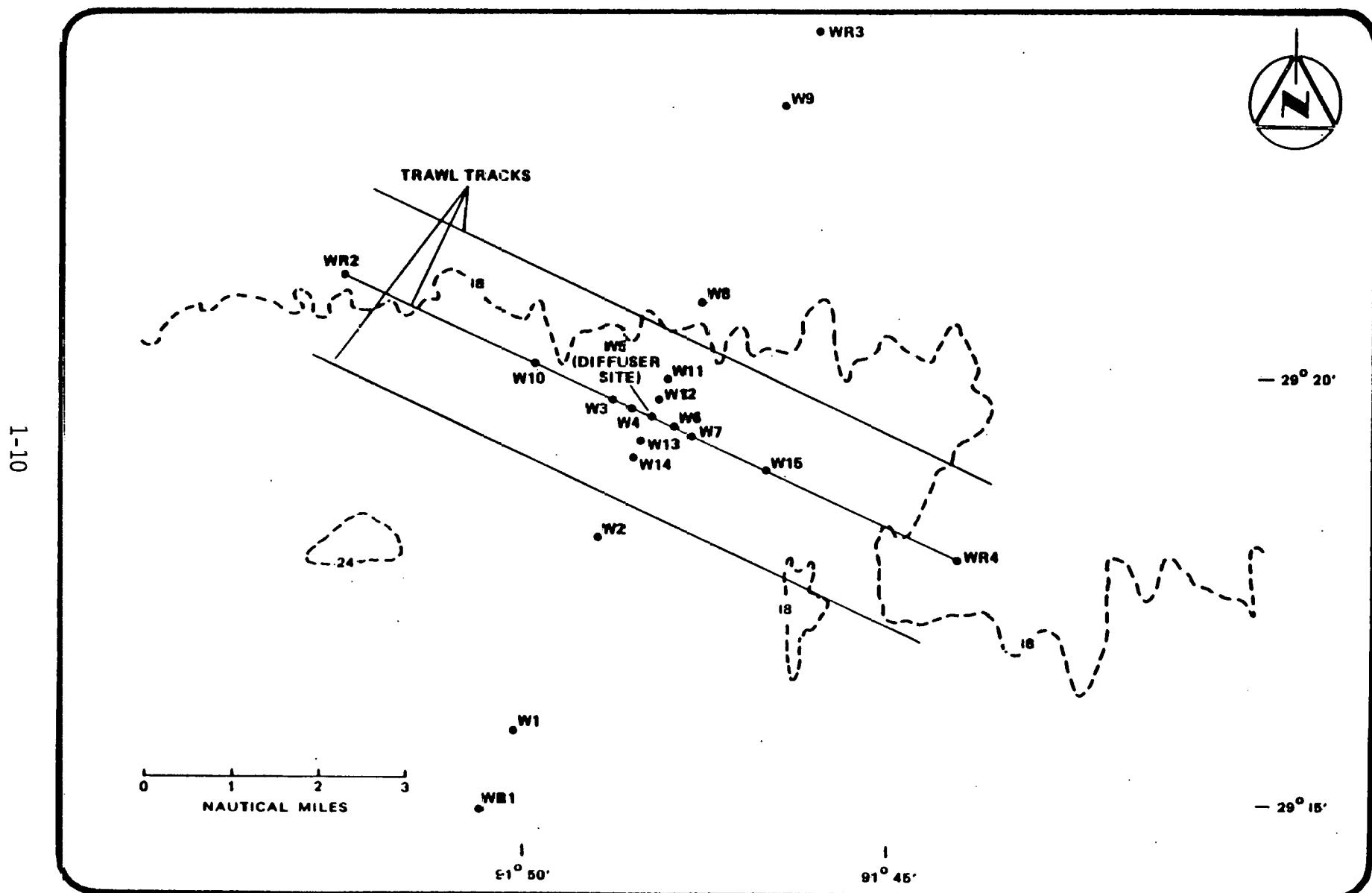
FIGURE 1-4   Weeks Island Site A sampling stations (depth contours in feet).
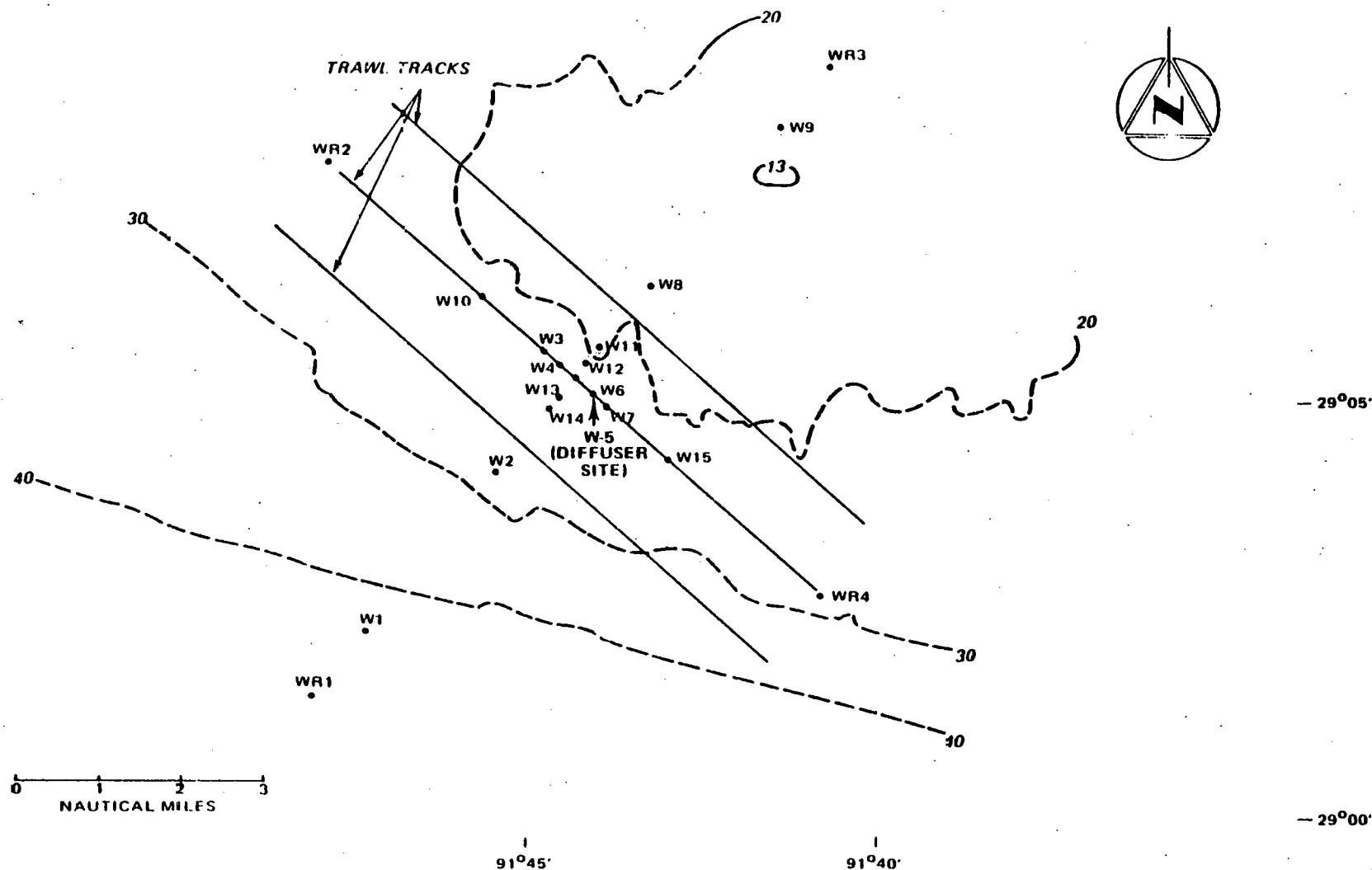
FIGURE 1-5   Weeks Island Site B sampling stations (depth contours in feet).

be in direct contact with the brine effluent during initial jet mixing near the diffuser ports. Far-field stations were located within the region that would be affected, but would lack the intense exposure to brine that may be characteristic of the near-field stations. Reference stations were established to delineate ambient conditions beyond the far field.

Initially, a small surface and subsurface buoy-pinger system was used to identify and reoccupy the wave/tide gauge and current meter stations (see Sections 1.4.2.2.1 and 1.4.2.2.2). However, because the buoy and instrument systems were either lost or damaged on several occasions, a large research buoy system was subsequently deployed offshore to ensure accurate positioning of the ship for data retrieval.

Water and sediment chemistry sampling was conducted only during the September and February cruises, and samples were taken at selected stations (W-2, W-5, W-8, W-10, W-15, and WR-3 at Site A and W-3, W-5, W-6, W-11, W-14, and WR-1 at Site B) within each of the grids. Current meters and wave and tide gauges were deployed at the proposed diffuser site, identified as Station W-5. Benthic sampling was conducted at all stations on each cruise, weather permitting. Three transects were established for each sampling region for plankton tows and for demersal fish and macroinvertebrate trawls along and adjacent to the diffuser.

1.4.2 Topical Coverage

1.4.2.1 Biological Oceanography

Major emphasis with regard to marine biology was placed on determining the species composition, abundance, and diversity of the benthic community at each diffuser site. Similar information was sought for the plankton and nekton communities, but these data were of a qualitative nature due to the communities' large temporal and spatial variability. In addition, adverse weather conditions at times necessitated a few changes in either sampling location, approach, equipment, or the number of samples recovered.

1.4.2.1.1 Benthic Sampling

The benthos were sampled at each of the 19 stations occupied (Figure 1-4), and replicate samples were collected at all stations whenever possible.

Benthic samples were taken by Peterson grab, which obtained a 0.1-m^2 sample. The organisms collected were separated from the sediment by washing with a low-pressure, high-volume flow of water through a 500-micron mesh sieve. Organisms were preserved in the field with a 5-percent buffered formalin solution and later identified in the laboratory to the lowest practical taxonomic level. These data were used to characterize species composition, abundance, and density. Underwater photography to record epifaunal distributions and visible characteristics of the sediment surface was unsuccessful because of the highly turbid waters at the sites.

To relate the benthic communities at the sites to their character-istic substrate, one sample of sediment was taken from each benthic grab and analyzed in the laboratory for particle size distribution and percent organic matter (loss on ignition).

Bathymetric data at the sites consisted of recording sample station depths with a precision depth recorder (PDR). The PDR was also operated in transit between sampling stations to determine if there were signifi-cant anomalies between observed and charted depths.

1.4.2.1.2 Demersal Fish and Macroinvertebrates

An otter trawl (0.5-inch mesh wings, 0.125-inch mesh cod end) was used to sample demersal fish populations and epibenthic and nektonic macroinvertebrates at each diffuser site. Three trawls were taken at Site A (Figure 1-4); one transect crossed the diffuser, and the other two trawls paralleled the first. Organisms taken by the otter trawl were sorted, identified, and counted, and a representative number of each species was measured.

From the September and February cruises, tissue from one shrimp species and one fish species was collected at each site and assayed for trace metals (iron (Fe), manganese (Mn), zinc (Zn), lead (Pb),

nickel (Ni), copper (Cu), cadmium (Cd), chromium (Cr), and aluminum (Al)) and high molecular weight hydrocarbons.

1.4.2.1.3 Plankton

Phytoplankton and zooplankton were sampled during each cruise. For phytoplankton, at the end of each otter trawl transect (Figures 1-4 and 1-5), 20 water samples were collected from the surface and near the bottom with an 8-liter Alpha bottle and concentrated on a 35-micron mesh screen (U.S. Screen No. 400). Samples were washed into glass containers and preserved with a 5-percent solution of buffered formalin.

Zooplankton samples were collected during each trawl and consisted of a 3-minute surface tow using a 0.5-meter conical net with a 202-micron mesh. Samples were rinsed off the net and preserved in a solution of 5-percent buffered formalin.

At the water-sediment chemistry stations, for each cruise, surface water samples were collected for chlorophyll a and phaeophytin a to be determined by fluorimetry. Planktonic organisms were identified to the lowest practical taxonomic unit, and the results were reported in terms of species composition, abundance, and distribution, and correlated with the chlorophyll and nutrient indicators of production.

Sufficient zooplankton biomass was reserved for chemical assay of trace metals as previously described for shrimp and fish; no hydrocarbon analyses were attempted.

1.4.2.2 Physical Oceanography

The physical oceanographic effort consisted primarily of monthly shipboard determinations of the salinity, temperature, and dissolved oxygen, and monthly data retrieval and instrument servicing for the wave and tide gauges and current meters.

1.4.2.2.1 Waves and Tides

Automatic-recording wave and tide gauges deployed at the disposal site required only periodic visits to retrieve data.

Commencing October 13, 1977, a wave gauge (Bass Engineering Model WG/100) and tide gauge (Bass Engineering Model STG/100) were deployed

and then attached to a platform designed to position the instruments approximately one foot above the bottom. The platform consisted of a 1/2-inch (1.3-cm) thick steel-plate shelf (3x3 feet (0.9 meters x 0.9 meters)) with a 60-pound (27-kilogram) drilling bit welded to the underside at each corner. A four-legged "A" frame of 1-1/2 inch (3.8 cm) pipe was welded to the topside of the shelf and served as a lifting point for the instrument pack. Upon deployment, a diver team unhooked the lowering cable and checked the platform for proper positioning. A Helle pinger was attached to the platform which would allow divers to relocate the instruments on subsequent trips.

On March 17, 1978, the platform concept was abandoned in favor of taut line mounted gauges that could easily be incorporated into the existing current meter array units. Endeco wave gauges (Model 817) and tide gauges (Model 820) were used. Initially these gauges were placed near the bottom of the taut line below the current meters. The wave gauge was attached to the taut line 21 feet (6.4 meters) below the surface and the tide gauge was placed at 23 feet (7.0 meters). Subsequent data analysis by Endeco revealed that wave and tide action in this area of the Gulf of Mexico was of insufficient amplitude to properly register on gauges near the bottom. On May 25, 1978, the wave gauge was repositioned to a depth of 13.5 feet (4.1 meters) below the subsurface buoy. The tide gauge was removed due to malfunctions in the instrument and the gauge was not replaced. SCUBA divers were used throughout the project to retrieve and deploy the instruments during routine servicing.

1.4.2.2.2 Currents

Continuous, direct Eulerian current measurements were obtained at both sites A and B using *in situ* current meters. Generally, two current meters were deployed at Station W5 located at each of the proposed diffuser sites (Figures 1-4 and 1-5). All meters were deployed on a taut line mooring with a subsurface flotation buoy and surface marker buoy(s). An array consisted of a stainless steel cable connecting a large bottom weight (approximately 800 lbs (363 kilograms)) and a 3-foot (0.9-meter) diameter subsurface float which was approximately 5 feet (1.5 meters) below MLW. The neutrally bouyant meter was designed

to trail horizontally on a 5-foot (1.5-meter) tether from the mooring line. The current meters were positioned approximately 4 feet (1.2 meters) apart at a mid-depth and near-bottom position in the water column.

Initially (October-November 1977) two arrays, each consisting of two current meters located at depths of 11 and 14.5 feet (3.4 meters and 4.4 meters), were deployed at Site A. Current meters were designated as I-A, I-B, II-A, II-B, and refer to the 11- and 14.5-foot meters on each array, respectively. After November 1977, only one array containing two current meters was deployed at Sites A and B. At Site B, meters were positioned at 12 and 21 feet (3.7 meters and 6.4 meters) from January 7 through March 18, 1978, and at 17 and 21.5 feet (5.2 meters and 6.6 meters) after March 18, 1978.

Servicing of the current meters to replace film cassettes and batteries was usually performed every 2-4 weeks. Scuba divers retrieved the current meters and serviced the meters on-board ship. Following a servicing interval of approximately three hours, the current meters were reinstalled. Film cassettes were sent to the manufacturer for processing, but all interpretation and computer-plotted graphical illustrations were performed by Dames & Moore. Additionally, the current data were provided to NOAA in a format directly compatible for use in computer runs of the plume model for impact analysis.

1.4.2.2.3 Salinity, Temperature and DO Fields

Local temperature, salinity, and dissolved oxygen fields were determined by _in situ_ readings from the surface to the bottom at all stations.

1.4.2.3 Chemical Oceanography

Chemical oceanographic sampling was conducted during the September and February cruises. Chemical assays of the biota for hydrocarbons and trace metals are discussed under Biological Oceanography (Section 2-4). The remaining chemical analyses were made on water and sediment samples from designated chemical stations. Chemical analyses for both shipboard and laboratory tests followed EPA-approved methods.

1.4.2.3.1 Sediments

Two sediment samples were collected for trace water and pore water analysis at each chemical station with push cores taken by divers. One sample was reserved for chemical analysis of bulk properties; the other was reserved for chemical analysis of pore water. Hydrocarbon content, sediment texture, and total organic carbon were analyzed in sediments taken with a Peterson grab sampler. No replicate measurements were made.

Each pore water sample was analyzed for micro-nutrients, phosphate, reactive silicate, and nitrate and nitrite nitrogen; the six bulk ions, calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+), sulfate (SO_4^{2-}), and chlorine (Cl^-); and the seven trace metals, Fe, Mn, Zn, Pb, Ni, Cu, and Cd. (Al, Cr, and Hg were additionally measured at Site B.)

Each bulk properties sample was homogenized and divided into four subsamples for the following tests:

- determination of particle size composition

- analysis of total inorganic carbon, total organic carbon, and adenosine triphosphate (ATP)

- analysis for biologically available, acid-leachable fraction of metals (Al, Cd, Cr, Cu, Fe, Pb, Mn, and Ni, with Hg additionally measured at Site B)

- solvent extraction-gas chromatographic determination of hydrocarbons.

1.4.2.3.2 Water

Surface and bottom samples were taken at each chemistry station. Samples were filtered through a 0.45-micron membrane filter. The suspended biologically available particulate fraction (leachable) and the suspended refractory fraction were analyzed for Fe, Mn, Zn, Pb, Ni, Cu, and Cd (and Cr at Site B), plus particulate organic carbon and total suspended matter.

Filtered water was analyzed for the six bulk ions and the trace metals Cd, Cu, Pb, Ni, Hg, Zn, Fe, and Mn (and Al and Cr at Site B), plus dissolved organic carbon, dissolved hydrocarbons, and nutrients.

1.4.2.3.3 Wind Speed and Direction

Wind speed and direction was measured near the site by a Climatronics Wind Mark III recording instrument between June 1st and November of 1978. The instrument was mounted on a Chevron Oil Company drilling platform located in Ship Shoal Block No. 108 at 28° 51' 29" N., 91° 06' 58" W.

1.4.2.3.4 Data Management

All physical, chemical, geological, and biological data collected during the Weeks Island cruises, from September 1977 to July 1978, were entered into the national archives of the National Oceanic and Atmospheric Administration's (NOAA) National Oceanographic Data Center (NODC) as part of the SPR Brine Disposal Analysis Program. This program will enable any researcher studying the region to have access to baseline data and will contribute to the growing world-wide oceanographic information contained in this centralized data bank.

After the samples had been collected and analyzed, species names were converted to the 10-digit NODC taxonomic codes and all data were entered onto the appropriate NOAA data coding forms. The cruise numbers used to identify the data were CPLN01 (September 1977), CPLN02 (October), CPLN03 (November), CPLN04 (December) for Site A; and CPLN11 (February 1978), CPLN12 (early March), CPLN13 (late March), and CPLN14 (April) for Site B. The forms were then submitted to NODC for keypunching; they included "Benthic Macrofauna (002)," "Groundfish (023)," "Zooplankton (024)," and "Phytoplankton Species (028)" for biological data; "Benthic Organisms (032)" and "Sediment Characteristics, Grain Size Analysis (073)" for sediment size and composition; and "Primary Productivity (029)," "Primary Productivity 2 (049)," and "Water Chemistry and Physics (004)" for water quality data. Current data were submitted to NODC on magnetic tape; some water chemistry data were submitted in raw form due to a lack of appropriate coding sheets.

SECTION 2

BASELINE CHARACTERISTICS

2.1 Climatology and Meteorology

2.1.1 Climate

The area around Weeks Island Sites A and B (Figure 1-1) has a
marine climate largely influenced by the characteristically warm waters
of the Gulf of Mexico. These waters temper the extremes of summer
heat, shorten winter cold spells, and provide abundant moisture and
rainfall to coastal Louisiana.

The Bermuda high, an extensive, persistent high-pressure cell
located in the southwestern part of the Atlantic Ocean, dominates the
spring and summer weather conditions at the sites. The prevailing
southeasterly winds bring moist air to the area, with the result that
humidities are high and convective shower activity occurs almost daily.
Coastal circulation is affected by sea breezes during the afternoon
and evening hours.

Although the sites are south of the mean winter continental storm
track, occasional intrusions of polar air into the area can cause sudden
drops in temperature and sometimes snowfall. The cold airmasses also
tend to lower sea-surface temperatures and are important in the formation
of advection-radiation fog which is prevalent along the coast, especially
during winter and spring.

2.1.2 Meteorological Data

2.1.2.1 Air Temperature

The average summer air temperature for the area is 85°F (29°C);
the average winter air temperature is 60°F (16°C).

Table 2-1 presents long-term monthly average and extreme air tempera-
tures based on marine observations between 1952 and 1971. The annual
mean air temperature is 74°F (23°C). July and August are the warmest
months, with a mean temperature of 84°F (29°C); January and February,
the coldest months, have a mean temperature of 63°F (17°C). The highest
and lowest recorded temperatures are 100°F (38°C) and 30°F (-1°C),
respectively.

TABLE 2-1   Average monthly air temperatures for the Weeks Island area, 1952-1971.

Month	Mean (^0F)	Minimum (^0F)	Maximum (^0F)
January	63.2	30	84
February	63.8	32	85
March	66.1	37	88
April	71.4	46	91
May	77.4	58	94
June	82	67	99
July	84.1	70	100
August	84	70	100
September	81.9	62	99
October	76.7	52	99
November	69.8	39	90
December	65.5	36	90
Annual	74.3	30	100

SOURCE: U.S. Dept. of Commerce, 1972.

2.1.2.2 Precipitation

Table 2-2 summarizes long-term, mean monthly and extreme precipitation for New Orleans, Louisiana. The highest amount of rainfall occurs during the summer months in association with either local thunderstorms or an occasional tropical storm. Winter precipitation generally results from frontal activity and falls as slow, steady rainfall; it may occur at any time of day and continue intermittently for several days.

The mean annual precipitation is 53.9 inches (137 centimeters). The maximum 24-hour precipitation was 14.01 inches (36 centimeters) in April 1927 (U.S. Dept. of Commerce, 1971).

Frozen precipitation in the area is rare; over a 25-year period from 1946 to 1971, the mean annual snowfall was 0.2 inches (0.5 centimeters). In February 1895, an unusual storm dumped 8.2 inches (21 centimeters) of snow on New Orleans (U.S. Dept. of Commerce, 1971).

TABLE 2-2   Long-term mean monthly precipitation, New Orleans, Louisiana.

Month	Normal Total[a] (in.)	Maximum Monthly[b] (in.)	Year[c]	Minimum Monthly[b] (in.)	Year[c]	Maximum Daily[b] (in.)	Year[c]
January	3.84	12.62	1966	0.54	1968	4.77	1955
February	3.99	10.56	1959	1.02	1962	5.6	1961
March	5.34	19.09	1948	0.24	1955	7.87	1948
April	4.55	8.78	1949	0.33	1965	4.35	1953
May	4.38	14.33	1959	0.99	1949	9.86	1959
June	4.43	8.87	1962	1.12	1952	4.19	1953
July	6.72	11.46	1954	3.45	1951	4.3	1966
August	5.34	11.77	1955	2	1952	3.06	1969
September	5.03	16.74	1974	0.24	1953	6.5	1971
October	2.84	6.45	1959	0	1952	2.58	1960
November	3.34	14.58	1947	0.21	1949	6.38	1953
December	4.1	10.77	1967	1.46	1958	3.94	1952
Annual	53.9	19.09	March 1948	0	Oct 1952	9.86	May 1959

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[a] Period of record: 1931-1960.

[b] Period of record: 1946-1971.

[c] Year of occurrence.

SOURCE: U.S. Dept. of Commerce, 1971.

2.1.2.3 Wind Speed and Direction

2.1.2.3.1 Surface Winds

The mean annual wind speed at the diffuser sites is 11.5 knots (13.2 mph), (Table 2-3). In the spring and summer, the Bermuda high usually controls surface winds. In autumn, there is a transition from a tropical wind regime to a modified continental wind regime. Accordingly, the winds shift to easterly and northerly directions, and show the highest average wind speeds and greatest frequency of occurrence for the area. Winds in the autumn can be in excess of 33 knots (38 mph). Surface wind is an important factor in the mixing and diffusion characteristics of the water column at the diffuser sites.

TABLE 2-3   Mean monthly wind speed and direction for the Weeks Island area, 1952-1971.

Month	Wind Speed (kn)	Direction
January	13.3	N
February	13.3	E
March	12.9	SE
April	12.4	SE
May	10.4	SE
June	9	SE
July	8.1	SE
August	8.5	SE
September	11.4	E
October	11.9	NE
November	13.1	N
December	13.4	E
Annual	11.5	SE

SOURCE: U.S. Dept. of Commerce, 1972.

2.1.2.3.2 Slack Wind and Persistence

Due to the coupling effects of surface winds and currents, periods of slack winds (wind speed $\leq$ 5 knots (6 mph)) are also of importance to brine disposal at the Weeks Island sites.

Figure 2-1 is a climatological record of wind persistence taken from a 15-year record (1948-1963) of hourly wind data observed at Burrwood, Louisiana, the closest primary coastal meteorological station. These data show that a period of slack wind is not likely to last longer than 12 hours. More than half of the observations have a slack wind period of less than 5 hours, indicating that these periods can occur often, but in most cases they prevail for only a short time.

A monthly percent frequency distribution of wind speed categories based on marine observations in the Bayou Lafourche area (Table 2-4)

TABLE 2-4   Monthly percent frequency of wind speeds for the Bayou Lafourche area, 1952-1971.

Month	Wind Speed (kn)					
	0-3	4-10	11-21	22-33	34-37	38+
January	5.3	36.9	46.5	10.2	1.1	0
February	4.2	38.1	46.6	10.1	1	ND[a]
March	6.6	37.3	46.3	8.8	1	0.1
April	5.9	39.7	47.3	6.5	0.6	ND
May	10.3	48.1	38.3	3.1	0.1	0
June	14.4	55.3	28.3	1.8	0.2	0
July	17	59.8	22.2	0.9	0.1	0
August	15.6	58.3	24.8	1.2	0.1	0.1
September	9	45	39	6.1	0.8	0.1
October	6.4	42.8	44	6.3	0.5	ND
November	5.5	37.6	46.3	9.8	0.9	0
December	4.4	37.5	46.8	10.4	0.9	0

[a]ND = no data.
SOURCE: U.S. Dept. of Commerce, 1972.
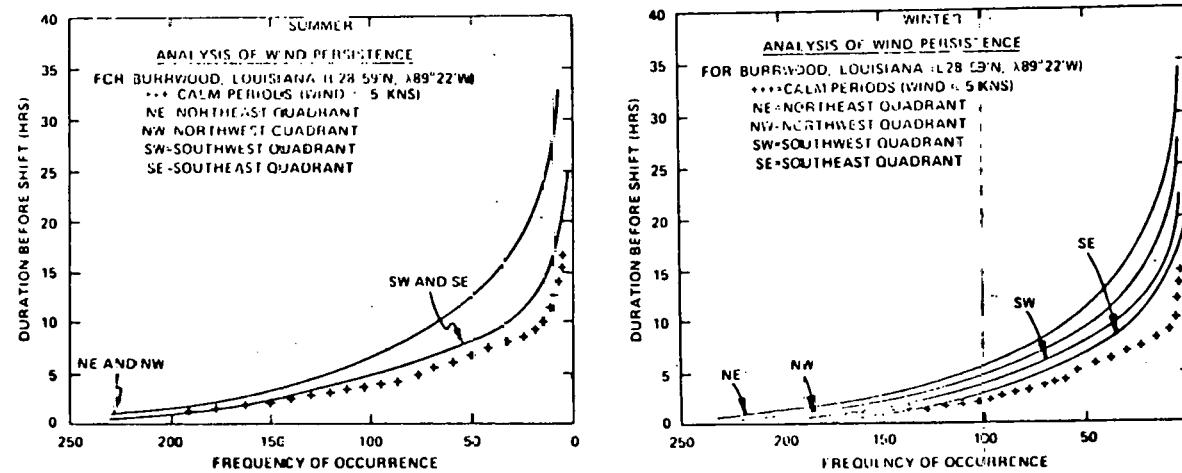
SOURCE: U.S. Dept. of Commerce, 1977a

FIGURE 2-1   Climatology of wind persistence for Burrwood, Louisiana.

shows that winds with speeds of 3 knots (4 mph) or less occur most frequently between May and September. Only 25 percent of the total observations in the area had wind speeds of 6 knots (7 mph) or less (Table 2-5). These periods of slack wind occurred most often between May and September.

Joint wind frequency distribution data obtained every 3 hours by the U.S. Coast Guard Marine Station at Grand Isle, from January to June 1978, reveal that the majority of wind speeds are within the 4- to 10-knot (4.5- to 11.5-mph) range (Tables 2-6 and 2-7), and the prevailing direction is from the north (Figure 2-2); this was partic- ularly evident during January and February. Wind speeds in the 11- to 21-knot (12.5- to 24-mph) range also occurred more frequently during these months. During the late spring, the direction was distributed from the northeast to the south, and wind speeds were most often less than 3 knots (3.5 mph).

Data were obtained from an onsite meteorological station from June 1 to August 14, 1978. A wind rose for this period shows that the most prevalent wind directions are from the northwest, west, and northeast (Figure 2-3). In June, July, and August, the prevailing wind directions were from the west, northeast, and south, respectively. The majority of wind speeds at this onsite station were also within the 4- to 10-knot (4.5- to 11.5-mph) range (Table 2-7). The average wind speed for this period was 7.9 knots (9 mph)--with averages of 8.9, 7, and 7.7 knots (10, 8, and 9 mph) for June, July, and August, respectively.

2.1.2.3.3 Extreme Winds

Table 2-8 summarizes the "fastest mile" (sustained) wind speeds in New Orleans for a 12-year period (1960-1971). Offshore, winds in excess of 175 knots (201 mph) are estimated to have occurred during hurricanes (U.S. Dept. of Commerce, 1972). Estimated extreme winds for return periods from 5 to 50 years are listed below:

Mean recurrence interval (years) -- 5, 10, 25, 50
Maximum sustained wind (knots) -- 85, 95, 110, 120.

TABLE 2-5 Monthly cumulative frequency and wind speeds for the Bayou Lafourche area.

Frequency of Occurrence	Wind Speed (kn)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1% ≤	0	0	0	0	0	0	0	0	0	0	0	0	0
5% ≤	3	4	2	2	1	1	1	1	1	1	1	4	1
25% ≤	7	6	6	6	5	4	4	4	5	6	7	6	6
50% ≤	12	12	11	11	9	8	7	7	9	11	12	12	9
75% ≤	18	18	17	17	15	12	10	11	16	16	18	18	16
95% ≤	28	28	27	25	21	20	19	19	25	24	28	28	25
99% ≤	35	35	35	30	25	25	22	24	33	30	33	33	30

TABLE 2-6   Joint wind speed frequency distribution measured at the
U.S. Coast Guard Grand Isle Marine Station from January to
June 1978.

Wind Sector	Wind Speed Categories (kn)					
	0 - 3	4 - 10	11 - 21	22 - 33	Over 33	Total
N	3[a]	81	96	4	0	184
	0.3[b]	6.8	8.1	0.3	0	15.5
NNE	1	18	15	2	0	36
	0.1	1.5	1.3	0.2	0	3.1
NE	3	21	10	6	0	40
	0.3	1.8	0.8	0.5	0	3.4
ENE	3	17	13	1	0	34
	0.3	1.4	1.1	0.1	0	2.9
E	5	68	45	1	0	119
	0.4	5.8	3.8	0.1	0	10.1
ESE	1	64	49	7	0	121
	0.1	5.4	4.1	0.6	0	10.2
SE	2	103	24	1	0	130
	0.2	8.7	2	0.1	0	11
SSE	2	49	18	0	0	69
	0.2	4.1	1.5	0	0	5.8
S	9	53	35	0	0	97
	0.8	4.5	2.9	0	0	8.2
SSW	5	31	8	0	0	44
	0.4	2.6	0.7	0	0	3.7
SW	6	32	10	0	1	49
	0.5	2.7	0.8	0	0.1	4.1
WSW	2	29	13	1	0	45
	0.2	2.4	1.1	0.1	0	3.8
W	1	13	14	6	0	34
	0.1	1.1	1.2	0.5	0	2.9
WNW	1	25	27	3	0	56
	0.1	2.1	2.3	0.3	0	4.8

[a]First line shows number of occurrences.
[b]Second line shows percent of total.

TABLE 2-6   (cont'd).

Wind Sector	0 - 3	4 - 10	11 - 21	22 - 33	Over 33	Total
NW	0	31	14	1	0	46
	0	2.6	1.2	0.1	0	3.9
NNW	1	21	43	2	0	67
	0.1	1.8	3.6	0.2	0	5.7
Calm	11					
	0.9					
Total	56	656	434 ·	35	1	1182
	5	55.3	36.5	3.1	0.1	100
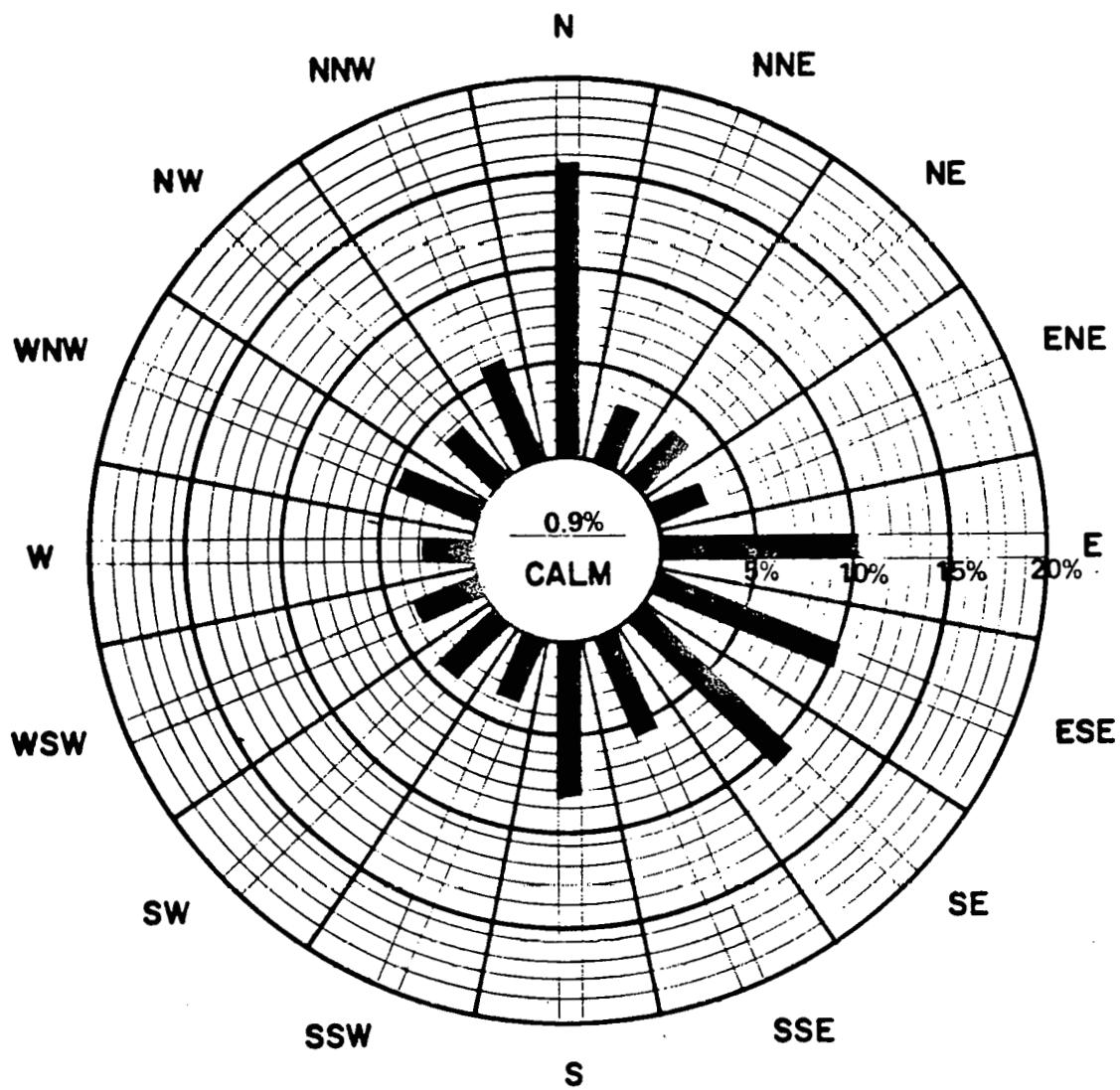
FIGURE 2-2 Wind frequency distribution at U.S. Coast Guard Grand Isle Marine Station (lat. 29°15' N., long. 89°57' W.), January to June 1978.
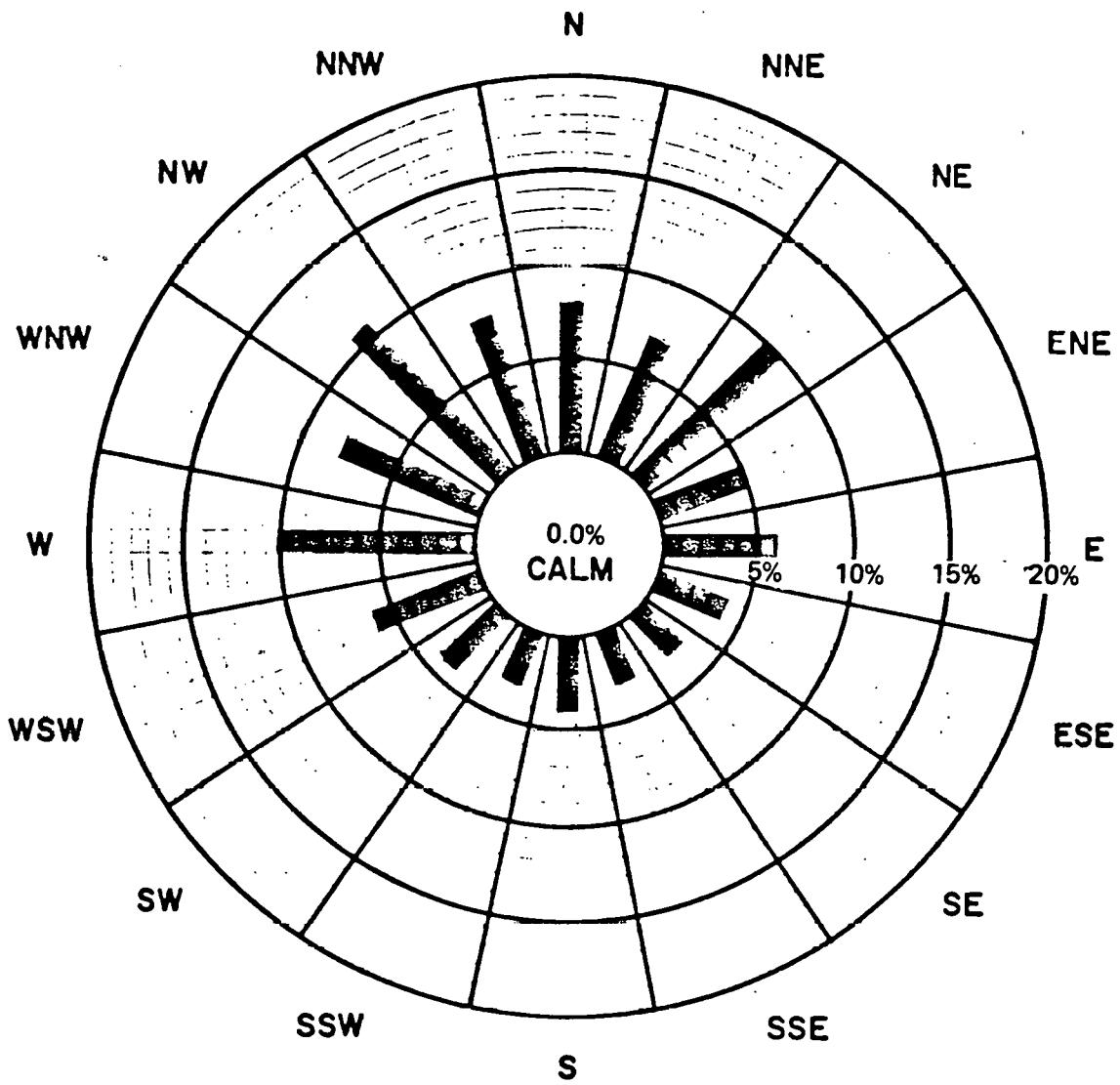
FIGURE 2-3 Wind frequency at Chevron platform, $28^{\circ}51'29"$N, $91^{\circ}06'58"$W,
June 1 to August 14, 1978.

TABLE 2-7 Wind speed frequency distribution measured in the Weeks
Island area from January to August 14, 1978.

Location/Period	Speed Category (kn)	% Frequency
January - June 1978[a]	0 - 3	5
	4 - 10	55.3
	11 - 21	36.5
	22 - 33	3.1
	Over 33	0.1
June 1 - August 14, 1978[b]	0 - 3	15.9
	4 - 10	63.5
	11 - 21	20.5
	22 - 33	0.1
	Over 33	0

[a]U.S. Coast Gaurd Grand Isle Marine Station.

[b]Onsite station (Chevron Platform (28° 51' 29" N, 91° 06' 58" W.).

2.1.2.4 Hurricanes

In the Gulf, the season for tropical cyclones is from June to
October. Between the years of 1899 and 1971, 45 tropical storms have
penetrated the Weeks Island area, with an average northward movement
of about 10 knots (12 mph); 18 of these storms were of hurricane inten-
sity--that is with winds greater than 64 knots (74 mph), (U.S. Dept.
of Commerce, 1972).

The numbers of tropical cyclones and hurricanes recorded in the
area between 1899 and 1971, and the average number of years between
occurrences, are listed below:

45 tropical cyclones (winds > 34 knots (39 mph)), with 1.6 years
between occurrences

18 hurricanes (winds > 64 knots (74 mph)), with 4.1 years between
occurrences.

In recent Gulf history, Hurricane Camille (August 1969), with estimated winds of 175 knots (201 mph), was the most severe storm to impact the area.

TABLE 2-8 Monthly variation of "fastest mile" winds for New Orleans, Louisiana, 1960-1971.

Date	Speed (mph)	Direction[a]
January 1966	33	28
February 1970	43	26
March 1969	37	18
April 1960	35	07
May 1962	31	23
June 1971	48	05
July 1969	32	07
August 1969	42	33
September 1965	69	09
October 1964	40	17
November 1969	30	31
December 1969	32	17
Annual (1965)	69	09

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[a]Direction in terms of degrees from true north; i.e., east-09; south-18; west-27; north-36.

SOURCE: U.S. Dept. of Commerce, 1971.

2.2 Physical Oceanography

2.2.1 Nearshore Features

2.2.1.1 Regional Description

The coastal area of Louisiana in which the Weeks Island brine diffuser would be located is characterized by numerous coastal bays, estuaries, lakes, marshlands, barrier islands, and cheniers (stranded beaches), (Figure 1-2). Within this area, O'Neill (1949) and Morgan and Larimore (1957) have defined two distinct morphological provinces-- an eastern portion extending from Vermilion Bay to Mississippi Sound which consists of a delta plain characterized by a highly irregular shoreline, and a western portion which possesses a more regular shoreline and represents an area of marginal deltaic sedimentation. Along this latter section, mud flats which have been developed by the westward longshore drift of previously deposited deltaic sediments alternate with sand beaches. These areas and their periods of alternation correspond to changes brought about by the flow of the Mississippi River and its distributaries.

Since the early 1950's, the Atchafalaya River, with its shorter path and steeper gradient, has been slowly capturing a significant portion of the Mississippi River discharge during high water stages. This represents a continuation of the normal shifting patterns of the lower river channel and alternation in the growth and erosion of various subdelta complexes. Since 1953, flow into the Atchafalaya River has been artificially regulated by the U.S. Army Corps of Engineers to receive approximately 30 percent of the total Mississippi discharge, together with the total flow volume of the Red River. Consequently, the Atchafalaya River is actively building a new delta complex in the Gulf of Mexico west of the Mississippi River Delta area (Figure 2-4).

An extensive study of the shelf waters immediately west of the Mississippi River Delta was conducted in conjunction with the Louisiana Offshore Oil Port (LOOP) study program (LSU, 1975). A hydrographic study of the waters immediately to the west of the LOOP study area and south of Timbalier Bay has been sponsored by the Gulf Universities Research Consortium (GURC) and is described by Oetking (1974a).

Map showing the Atchafalaya Delta with labels: LAKE Outlet, ATCHAFALAYA RIVER, ATCHAFALAYA, LOWER ATCHAFALAYA RIVER, BAY, POINT AU FER SHELL. Contour lines labeled with years 1970, 1972, 1975, 1980, 1990, 2020.
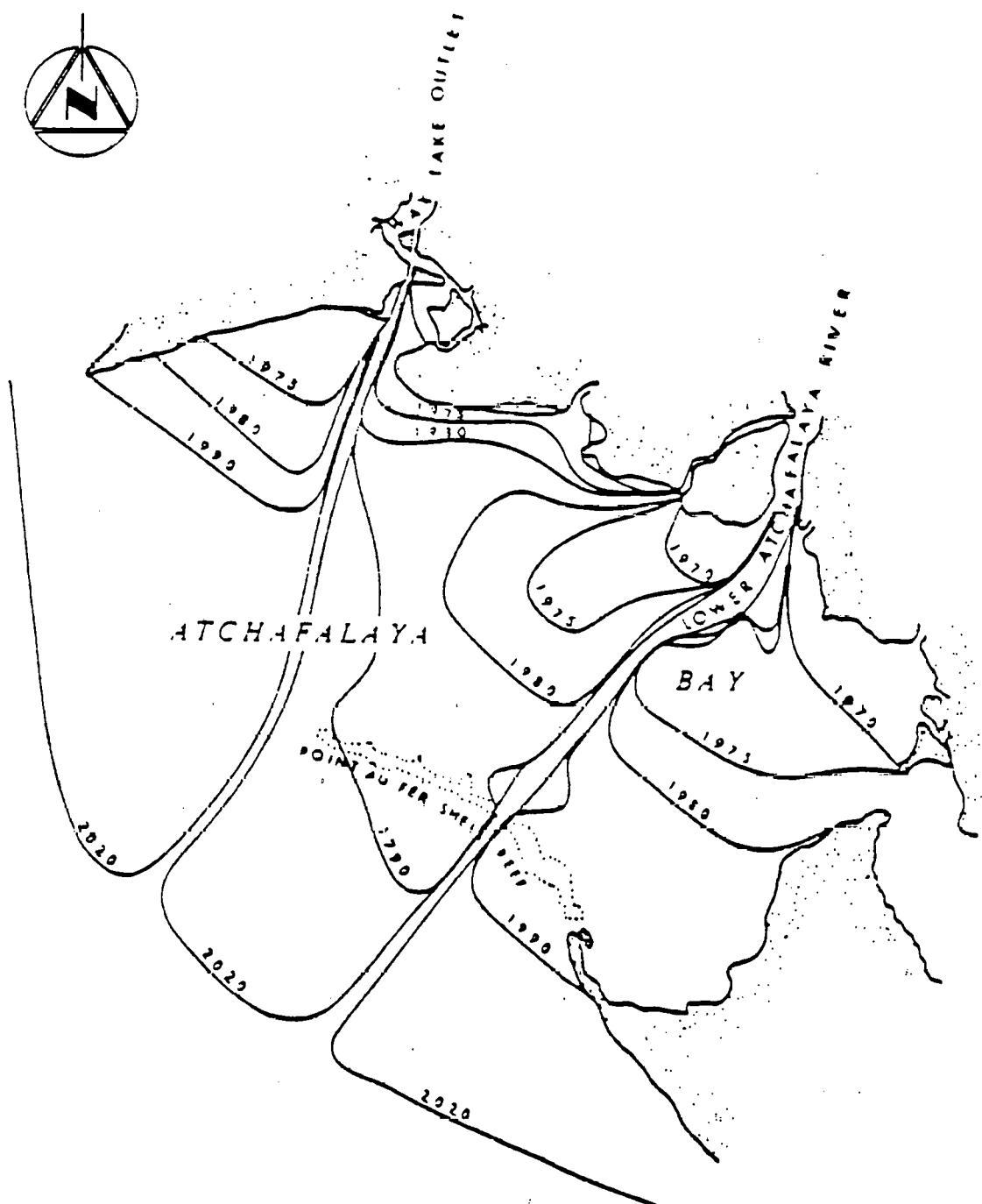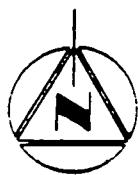
FIGURE 2-4   Anticipated configuration of the Atchafalaya Delta shoreline by
              the year 2020.

The dominant offshore bathymetric feature in the region is the Gulf Coast geosyncline. Its axis generally corresponds with the trend of the present shoreline of the Gulf Coast states. The stratigraphic record indicates that this geosyncline has been gradually subsiding since the Cretaceous period because of the voluminous deltaic sedimentation and deposition. Continued subsidence of this area is indicated by the slope of the natural levees in the region which tilt toward the Gulf of Mexico.

The continental shelf adjacent to the Mississippi Delta is very narrow and, at the delta, is almost nonexistent where the river has prograded across it. To the east or west of the delta, the continental shelf off Louisiana widens markedly to more than 124 miles (200 kilometers) off the coasts of Florida and Texas. The continental shelf west of the delta is noncarbonate in origin and has many isolated seaknolls and seamounts which are thought by some investigators to be surface expressions of salt domes (Shepard, 1937; Carsey, 1950; Moore and Curray, 1963; Ewing and Antoine, 1966).

2.2.1.2 Diffuser Site

Atchafalaya Bay and Marsh and Point Au Fer Islands are the dominant nearshore features at Weeks Island Sites A and B (Figure 1-2). The bay is approximately 20 miles (32 kilometers) long in an east-west direction, averages 7 miles (11 kilometers) in width, and is generally less than 7 feet (2.1 meters) deep. Its outer boundary is formed by Point Au Fer Shell Reef, once an oyster-producing area. Oyster productivity on the reef has been destroyed by increasing amounts of freshwater and sediment from the Atchafalaya River basin. A submarine extension of additional reefs trends northwestward for 14 miles (22 kilometers) to Rabbit Island. Beyond these reefs, water depths increase very gradually such that the 3- and 100-fathom contour lines lie 10 and 115 miles (16 and 185 kilometers), respectively, offshore.

Three large shoals lie offshore of Atchafalaya Bay in the vicinity of the proposed Weeks Island diffuser sites. Ship Shoal lies offshore to the east of the study area. This shoal is about 7 miles (11 kilometers) long, trends in an east-west direction, and has a water depth of 9 to 12 feet (2.7 to 3.6 meters). Numerous oil rigs are positioned along

the shoal. Strong tidal rips have been reported 15 miles (24 kilometers) southwest of Ship Shoal (U.S. Dept. of Commerce, 1977a).

Trinity Shoal is in the western section of the diffuser area, about 20 miles (32 kilometers) south of the west end of Marsh Island (Figure 1-2). Its major axis is about 20 miles long and trends in a west-southwest and east-northeast direction; water depth ranges from 11 to 18 feet (3.3 to 5.5 meters). The shoal is fairly steep on its south side where the 5- and 10-fathom curves are only about 5 miles (8 kilometers) apart. In calm weather, Trinity Shoal is discernible by high turbidity in the area; in stormy weather, the shoal is discernible by breaking seas, but because of its greater depth, the storm waves do not break as heavily here as they do on Ship Shoal (U.S. Dept. of Commerce, 1977a).

Tiger Shoal is located just south of Marsh Island but inshore of Trinity Shoal and is bisected by the ship safety fairway of Southwest Pass. Water depths on Tiger Shoal are generally less than 12 feet (3.6 meters).

2.2.2 Sediments

2.2.2.1 Regional Stratigraphy

Recent nearshore sediments of central coastal Louisiana and adjacent to the diffuser sites consist of a thick blanket of terrigenous silt and clay (Uchupi and Emery, 1968). The continental shelf west of the Mississippi Delta grades from sand inshore to silt and clay offshore. These sediments were derived from either a deltaic environment deposited by former Mississippi distributaries or offshore sediments transported westward by littoral currents which formed cheniers (stranded beach ridges) behind a zone of newly developed mudflat marsh.

The Mississippi deltaic plain is a composite of various active and inactive deltaic complexes which stretch 180 miles (290 kilometers) across southeastern Louisiana, resulting from the migration of the main Mississippi River channel and its distributaries. Several cycles of sedimentation, marsh development, and beach ridge formation can be traced in the shallow subsurface of central and western Louisiana (Coleman and Smith, 1964).

The Quaternary stratigraphy of Atchafalaya Bay generally consists of three distinct deltaic complexes. About 40 feet (12.2 meters) of Maringouin-age prodeltaic clays form the base of the deltaic sequence. These sediments are overlain by about 20 feet (6.1 meters) of the Bayou Sale lobe of the Teche deltaic complex. Near the top of this sequence is an ancient shell reef which is almost 5 miles (8 kilometers) wide (Frazier, 1967). Capping the Teche sediments are Lafourche-age deltaic deposits which increase in thickness from a few feet near the present shoreline to about 10 feet (3 meters) under Shell Reef off Point Au Fer. Two thin but extensive shell-mud layers have been found within this unit.

Comparison of aerial photographs of the Atchafalaya Bay area taken in 1952, 1968, and 1978 shows a general shoreline retreat; however, accretion related to the growing delta has been noticed 60 miles (97 kilometers) to the west. Accretion is occuring because colloidal clays from the Atchafalaya River are carried into the Gulf, flocculate out of suspension upon contact with saline waters, and settle to the botttom as a gelatinous mass (Thompson, 1951). During storms the clays are resuspended and transported further westward by the longshore drift and are subsequently redeposited. As more coarse-grained sediments are deposited in the lower Atchafalaya Delta, the shoreline retreat should terminate, resulting in significant accretion (Shlemon, 1972).

In September 1977, bottom sediments at Weeks Island Site A (Table 2-9, Figure 2-5) consisted mainly of silty clay with a trace of sand. Sediments at the two Site A stations located farthest from shore (W-1, WR-1) and in the deepest water (23 feet (7 meters)) were predominantly sand with some clay and little silt. Sediments collected from Site A during October consisted of mostly silt with some clay and sand; offshore sediment composition was similar to that collected in September.

Bottom sediments from Site B (Table 2-10, Figure 2-5) during February and late March were dominated by sand with little silt and clay. The average water depth at Site B was 23 feet (7 meters), with the exception of stations W-10, WR-1, and WR-2, which were deeper. At stations W-10 and WR-2, sediments had a high proportion of silt and clay.

TABLE 2-9   Particle size characteristics for Weeks Island Site A.

Station	Water Depth (ft)	Percent Sand (>0.06 mm)	Percent Silt (<0.06 mm, >0.002 mm)	Percent Clay (<0.002 mm)
September 1977				
W-1	23	55	9	29
W-2	22	6	38	56
W-3	18	0.30	31	68
W-4	18	0.29	51	.48
W-6	18	0.50	40	59
W-7	18	0.57	39	61
W-8	15	0.49	29	71
W-9	13	0.46	29	71
W-10	18	0.12	33	67
W-11	17	0.21	30	70
W-12	17	1	53	46
W-13	18	0.09	28	72
W-14	20	0.34	29	70
W-15	19	0.54	33	66
WR-1	23	52	16	30
WR-2	16	0.48	33	66
WR-3	15	2	19	78
WR-4	18	4	27	68
October 1977				
W-1	23	73	18	9
W-2	22	19	43	38
W-3	18	16	49	35
W-4	18	23	55	22
W-5	18	31	56	13
W-6	18	18	62	20
W-7	18	23	57	20
W-8	15	22	58	20
W-9	13	31	30	39
W-10	18	23	54	23
W-11	17	25	48	27
W-12	17	18	60	22
W-13	18	14	59	27
W-14	20	14	54	32
W-15	19	24	53	23
WR-1	23	73	13	14
WR-3	15	6	33	61
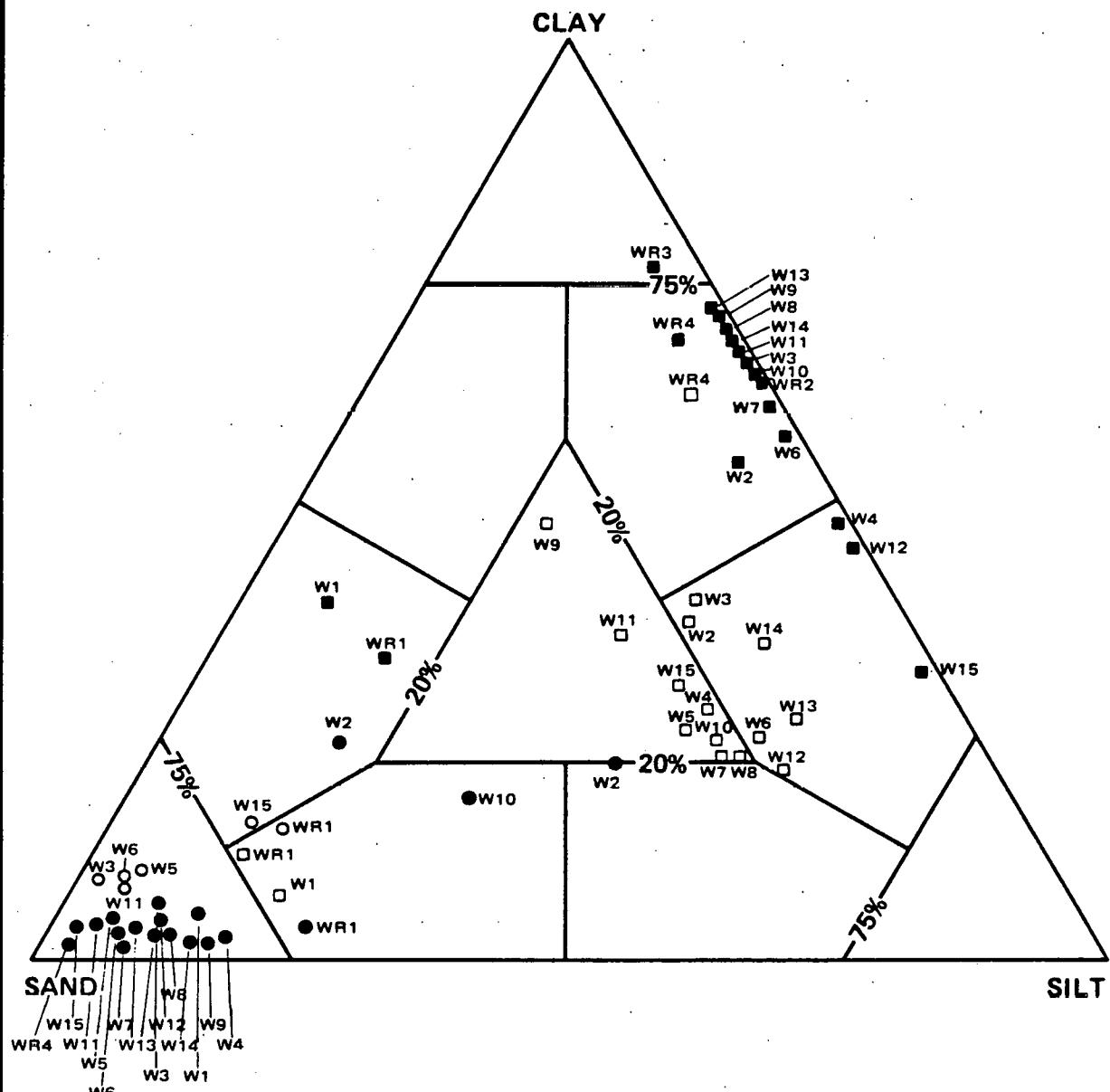
FIGURE 2-5   Sediment composition at Weeks Island Sites A and B.

TABLE 2-10   Particle size characteristics for Weeks Island Site B.

Station	Water Depth (ft)	Percent Sand (>0.06 mm)	Percent Silt (<0.06 mm, >0.002 mm)	Percent Clay (<0.002 mm)
February 1978				
W-3	23	93	0.9	6
W-5	20	87	5	7
W-6	19	89	4	6
W-11	21	90	5	5
W-14	21	71	18	10
WR-1	30	69	15	16
Late March 1978				
W-1	27	87	10	3
W-2	22	63	26	11
W-3	23	90	7	3
W-4	22	85	13	2
W-5	20	94	3	3
W-6	19	94	4	2
W-7	18	94	5	1
W-8	20	91	8	1
W-9	20	87	12	1
W-10	29	32	52	16
W-11	21	95	3	2
W-12	21	91	7	2
W-13	21	92	7	1
W-14	21	89	9	2
W-15	16	96	2	2
WR-1	30	73	23	4
WR-2	44	35	45	20
WR-3	21	93	5	2
WR-4	14	97	2	1

Variation in sediment content at Sites A and B can be attributed to the transport of sediment by the Atchafalaya River system and by offshore currents. The coarsest fraction of the sediment load generally settles out of suspension and is deposited first, with progressively finer fractions deposited away from shore. This distribution pattern is reflected in the sediment map prepared by Uchupi and Emery (1968). Previously deposited deltaic sediments can be redistributed by water currents or storm waves.

Site A probably derives its sediment characteristics from the fine-grained sediments transported westward into the site area from the Atchafalaya Delta. Sediments at Site B would also be expected to be fine grained because of the site's distance from shore. However, sediments at this site as well as at the two offshore stations of Site A are sand sized. This distribution may be due to "strong" currents which cause the silt and clay-sized fractions to remain in suspension at Site B while leaving the sand-sized fractions undisturbed. This suspension is reflected in the high turbidities found in the water column. The depth contours in this region are evenly spaced, paralleling the coastline in a west-northwest to east-southeast direction and sloping to the south-southwest, which suggests that the current follows these contours. Furthermore, the predominant westward drift of the currents along this section of the Louisiana coast is not greatly affected by nearshore shoals.

2.2.3 Water Temperature and Salinity

2.2.3.1 Regional

Coastal Louisiana salinity distributions are mainly influenced by freshwater inflow from the Mississippi and Atchafalaya Rivers (Gagliano et al., 1970b; Nowlin and McLellan, 1967). Geyer (1950) reported that salinity within 5 to 6 miles (8 to 9.5 kilometers) of the Louisiana coast ranges from 15 to 35 ppt as a result of seasonal variations in riverine discharges.

In the region of the proposed diffuser sites, during the summer (Figure 2-6) typical salinities increase from a surface value of 23 ppt to slightly over 36 ppt in the upper 50 feet (15.2 meters), with a

SUMMER PROFILE

TEMPERATURE (°C)

25 25

DEPTH(m)

SALINITY (ppt)

20 25 30 35

DEPTH(m)

SIGMA-T

10 15 20 25
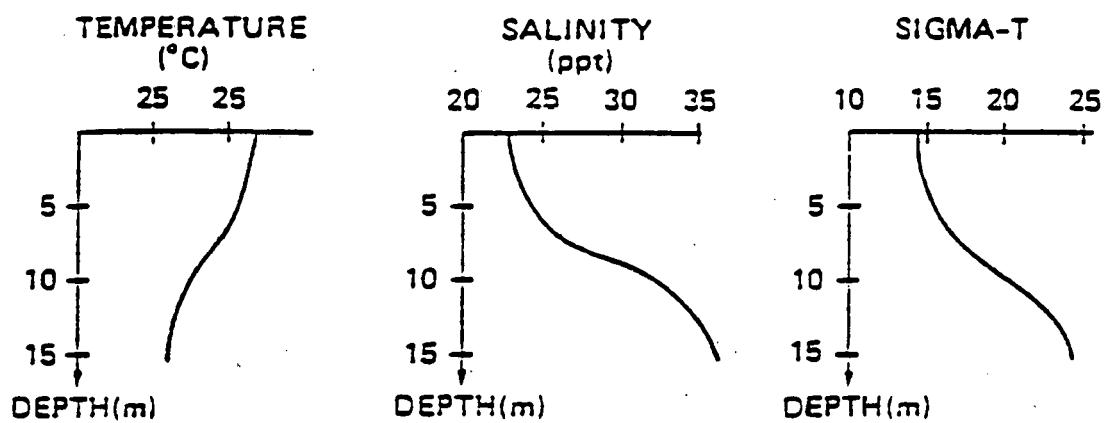
DEPTH(m)

DATE: 6/3/64
LAT: 23°49' N
LONG: 91°21' W
STATION DEPTH: 17 METERS

WINTER PROFILE

TEMPERATURE (°C)

15 20

DEPTH(m)

SALINITY (ppt)

30 34

DEPTH(m)

SIGMA-T

22 24 26
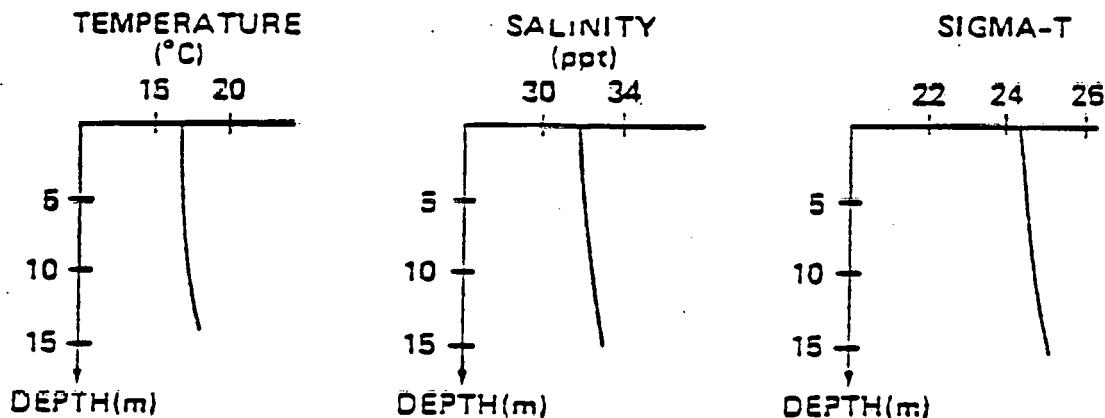
DEPTH(m)

DATE: 12/13/69
LAT: 28°43' N
LONG: 91°18' W
STATION DEPTH: 17 METERS

SOURCE: U.S. Dept. of Commerce, 1977a.

FIGURE 2-6 · Typical hydrographic profiles for summer and winter in the coastal Louisiana Gulf of Mexico.

strong halocline at 23 to 26 feet (7 to 8 meters). Temperatures are nearly isothermal, ranging from 77° to $79^{\circ}F$ (25° to $26^{\circ}C$). The density (sigma-t) profile indicates strong stratification with a pycnocline at 23 to 26 feet. The typical winter profile (Figure 2-6) shows cooler temperatures (61° to $66^{\circ}F$ (16° to $19^{\circ}C$)) and nearly isohaline conditions; salinities range from 32 ppt at the surface to 34 ppt at 49 feet (15 meters). Similarly, the density (sigma-t) shows virtually no stratification (U.S. Dept. of Commerce, 1977a).

Summer and winter vertical cross sections of coastal Louisiana (Figures 2-7 and 2-8) show that during both seasons, fresher, less dense water appears at the surface--probably from the Mississippi River system. The strong vertical density gradient during the summer would tend to inhibit vertical salt diffusion, while the strong horizontal stratification would lead to a strong westerly baroclinic current that would enhance advection. The reduction of horizontal and vertical density gradients during the winter would tend to enhance vertical diffusion and inhibit advection.

2.2.3.2 Diffuser Vicinities

Bottom and surface water temperatures measured at Weeks Island Site A during September through December 1977 showed nearly isothermal conditions with temperatures progressively decreasing during the winter months. Average monthly surface water temperature (Table 2-11) at Weeks Island ranged from $81^{\circ}F$ ($27^{\circ}C$) in September to $55^{\circ}F$ ($13^{\circ}C$) in December. Bottom water temperature closely paralleled surface water temperature and ranged from $81^{\circ}F$ ($27^{\circ}C$) in September to $58^{\circ}F$ ($14^{\circ}C$) in December.

The increase in salinity values measured at Site A (Table 2-11) reflected a decrease in surface runoff from the Atchafalaya and Mississippi Rivers. In October a distinct halocline occurred between the surface and bottom, but it dissipated by November.

Bottom and surface water temperatures measured at Site B (Table 2-11) from February to April 1978 remained nearly isothermal. Average surface temperatures increased from $51^{\circ}F$ ($11^{\circ}C$) in February to $72^{\circ}F$ ($22^{\circ}C$) in April.

TEMPERATURE (°C)

DATE: 6/4/64
STATION LOCATIONS

1. L28°48' N
   λ90°20' W

2. L28°38' N
   λ90°20' W

3. L28°26' N
   λ90°20' W

SALINITY (ppt)

SIGMA-T

MEAN SIGMA-T

$\bar{\sigma}_t(1) = 20.7$

$\bar{\sigma}_t(2) = 22.2$

$\bar{\sigma}_t(3) = 23.8$
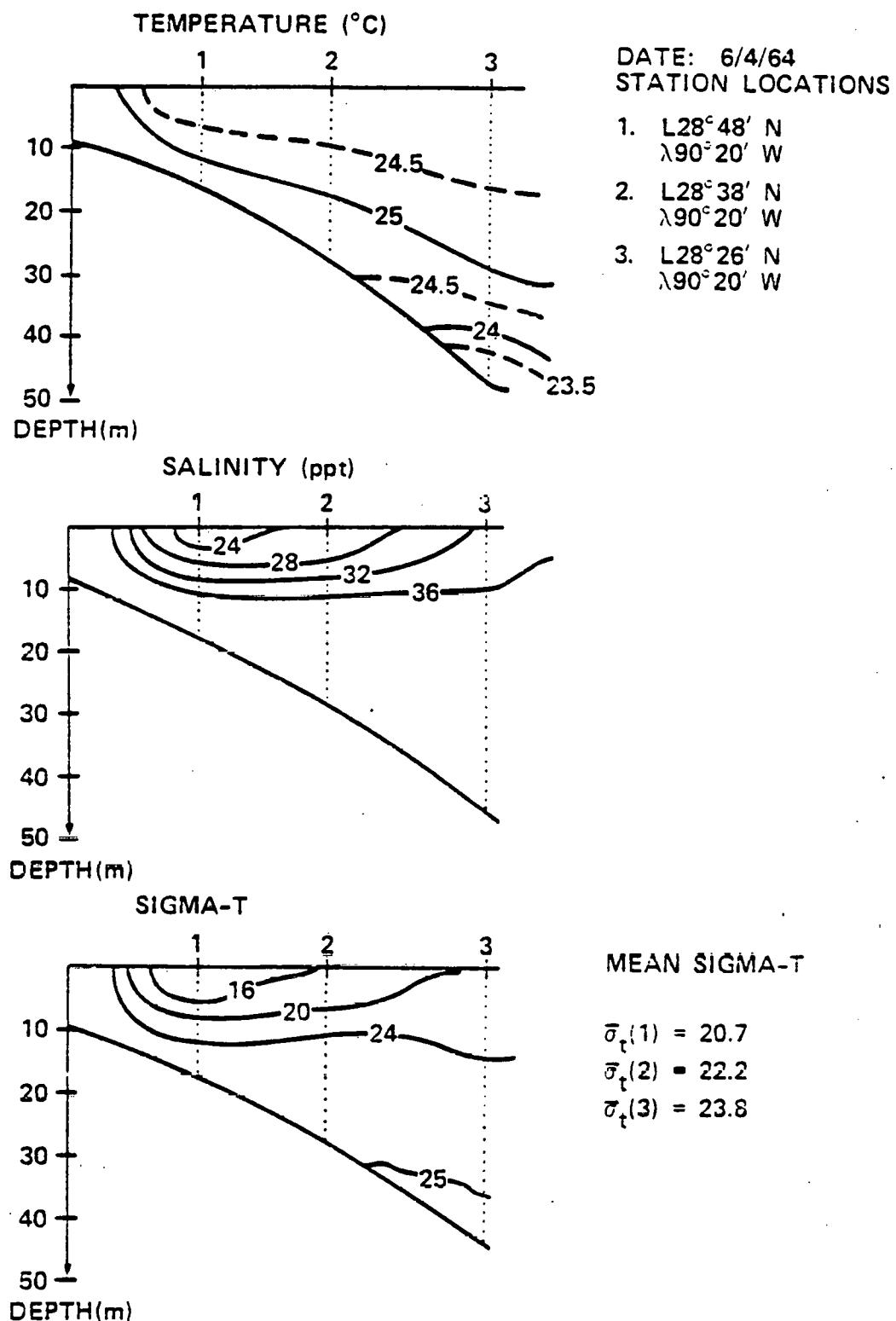
SOURCE: U.S. Dept. of Commerce, 1977a.

FIGURE 2-7   Summer vertical cross-sectional observations of temperature, salinity, and density in the coastal Louisiana Gulf of Mexico.
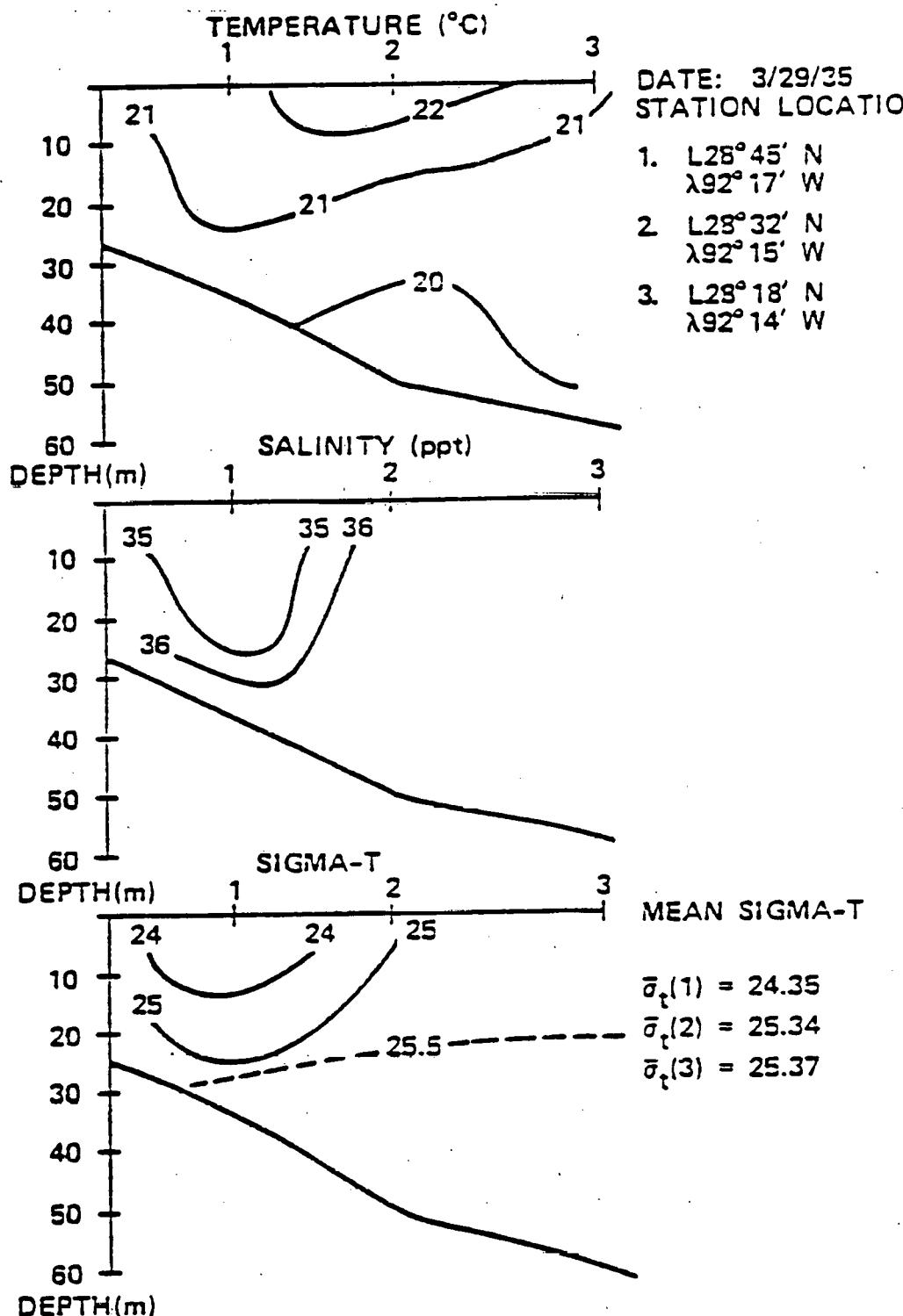
FIGURE 2-8   Winter vertical cross-sectional observations of temperature, salinity, and density in the coastal Louisiana Gulf of Mexico.

TABLE 2-11   Monthly temperature and salinity averages
            for Weeks Island Sites A and B.

	Temperature (°F)		Salinity (ppt)	
	Surface	Bottom	Surface	Bottom
Site A				
September 1977	81.1	80.8		
October	68.5	70.7	15.7	21.9
November	63.3	63.1	26.2	27.1
December	54.9	57.6		
Site B				
February 1978	51.3	51.4	21.2	20.6
Mid-March	60	59.4	24.3	30
Late March	63.3	59.2	17.5	27.2
April	72	71.4	20.6	24.8

Surface salinities at Site B decreased to 17.5 ppt in late March (from 24.3 ppt measured in mid-March), but during April salinity averages increased to 20.6 ppt. Bottom salinity values increased from 20.6 ppt in February to 30 ppt in mid-March, and then decreased to 24.8 ppt in April.

These fluctuations in surface salinity values are primarily attributed to differences in surface runoff from the Mississippi and Atchafalaya Rivers, but localized heavy precipitation could also be a contributing factor. The significant decrease in salinity at the end of March (17 ppt), a reversal of the earlier trend from February to mid-March (21.2 to 24.3 ppt), is probably due to a combination of increased surface runoff and local rainfall.

Bottom salinity values are not as sensitive to the influence from river runoff unless there is complete vertical mixing during storms. The progressive decrease in average bottom salinity values from mid-March (30 ppt) to April (24.8 ppt) reflects a period of increased river runoff and local storms. The dramatic increase in bottom salinity, however, as seen from February (20.6 ppt) to mid-March (30 ppt), probably reflects a wedge-like intrusion of highly saline offshore water.

2.2.4 Tides

The tides of the Gulf of Mexico are predominantly diurnal in character; they are weakly developed with a usual range of less than 2.5 feet (0.7 meter), (Durham and Reid, 1967). The diurnal tides of the Atlantic Ocean also influence the tides in the Gulf through the Yucatan Channel. A single oscillating system with a nodal line extending from western Haiti to Nicaragua is formed by the Gulf of Mexico and the Caribbean Sea. This causes the tides of the Gulf to be simultaneous. The Gulf and the Caribbean Sea are viewed as a single oscillating body with a period of nearly 24 hours (Grace, 1932).

In 1908, C. Wegmann (Defant, 1961) considered the resonance effect of the diurnal components of the Gulf tides and found the period of free oscillation for an east-west movement to be 24.8 hours. According to Grace (1932), the diurnal tide enters through the Florida Straits, progresses counterclockwise around the basin, is refracted by the northwestern and southern Gulf coasts, and egresses through the Yucatan Channel.

When the moon is near its maximum declination, the tide is diurnal and has the greatest range. When the moon is over the equator, the tide has the least range, and there may be several days with two highs and two lows. Although tides in the Gulf have a small range, they are integral in the modification of currents and the acceleration of water movement through narrow passages.

Since the tidal range is small, meteorological effects can sometimes completely mask tidal fluctuations (U.S. Dept. of Commerce, 1967); for example, an onshore wind can increase tides to a height of 4 feet (1.2 meters) above mean sea level. Maximum tidal ranges recur about every 2 weeks (Stone, 1972). Lowest and highest mean water levels occur from December through March and September through October, respectively.

Tidal records from Weeks Island Site A indicate that the area has a mixed tide with variation in successive high and low levels. Site A has a tidal range from 0.1 to 3.6 feet (3 centimeters to 1.1 meters) and averaged 1.6 feet (0.5 meters) for the period from October 13 to November 16, 1977.

Tidal currents apparently are strongest in the deeper water areas off the Louisiana coast. The change in current speed with depth is pronounced and is related to the local water density gradients. The tidal currents have a distinct tendency to rotate clockwise. Near the Mississippi Delta tidal currents are strong (in excess of 0.8 ft/sec (25 cm/sec)), but near Atchafalaya Bay they are relatively weak (less than 0.5 ft/sec (15 cm/sec)). Tidal current speed slackens inshore of the 30-foot (3-meter) isobath and the currents are oriented in the direction of the coastline. Bottom tidal currents are weaker than those at mid-depth or at the surface, but this aspect can be modified by the complex local density gradients. On the inner continental shelf west of the Mississippi Delta, tidal currents are a significant dynamical process and can markedly influence the motion of water in the area. The tidal excursion length (the path that a particle of water would follow if it were carried along by the tidal current alone) is on the order of 1.9 miles (3 kilometers). However, if this particle was under

the influence of the natural tidal forces alone, its track would return
to the starting point one tidal cycle later (LOOP, 1975).

2.2.5 Waves

Waves in the area are a combination of local wind-generated waves
and swell entering from open water. Wave direction generally corresponds
to wind direction and changes according to the season of the year.
Between March and August, waves travel in a northwesterly direction,
while in the fall and winter they shift more to the west. When strong
northers are present, the waves can travel offshore. Wave heights
range from 0 to 20 feet (6 meters), with the smallest waves occurring
in the summer. Data obtained at drilling platforms 15 miles offshore
from Atchafalaya Bay indicate that 95 percent of the time waves do
not exceed 4 feet (1.2 meters), (Horrer, 1951).

Wind and wave data obtained from an offshore platform in the Weeks
Island area during 1978 are presented in Appendix A. Monthly descrip-
tions of these data appear in Section 2.2.6.2.

Significant wave heights measured at Sabine Pass, Texas, and at
Bayou Lafourche, Louisiana (U.S. Dept. of Commerce, 1972), have been
used to estimate wave expectations for the diffuser sites. Significant
wave heights (average of the highest one-third) are similar in both
areas and are closely related to wind speed. On the average, a sign-
ificant wave height of 42 to 43 feet (12 to 13 meters) will occur in
deep water once every 50 years and a height of 30 to 31 feet (9 to
9.5 meters) will occur every 5 years. During a storm, individual waves
may be much greater than the significant wave height.

2.2.6 Currents

2.2.6.1 Regional Historical Data

Current patterns within the area of Sites A and B are the most
significant factor in determining dispersal of brine. The driving
forces of wind stress, local runoff, and density stratification combine
to shape the behavior of nearshore waters along the Louisiana coast.
Wind-driven currents predominate in controlling nearshore circulation
and beach drift, while density gradients and vertical mixing of brackish
and fresh waters have a major effect on tidal passes and estuaries.

Additionally, the Loop Current, a large clockwise current in the eastern Gulf, may occasionally extend into the coastal region of Louisiana and disrupt the normal local current patterns.

The Loop Current is a continuation of the Yucatan Current which enters the Gulf of Mexico through the Straits of Yucatan. Although the current shows great annual and seasonal variability in magnitude and course, it generally penetrates some distance into the Gulf of Mexico, turns clockwise, and exits through the Straits of Florida. Its path appears to be directly influenced by the topography of the Gulf.

Although it fluctuates widely, Leipper (1970) proposed that the Loop Current's degree of intrusion into the Gulf was annually cyclical, based on 1965 to 1966 data. This was confirmed by Ichiye et al. (1973). In winter and early spring, the Loop Current penetrates a maximum of up to 27° N in the Gulf, though it is usually found at lower latitudes. Maximum penetration, at 29° N, occurs in the summer (Figure 2-9). Remnants of the Loop Current off the Louisiana coast are generally identified by their characteristic temperatures of about 71.6^OF (22^OC), maximum salinity values of 36.7 ppt, and dissolved oxygen levels of 5.7 mg/L at the surface and 3.6 mg/L at a 2625-foot (800-meter) depth.

Large eddies frequently separate from the main current, drift into the western Gulf, and decay over a period of 3 to 6 months. Figure 2-9 shows the northerly extent of the current parallel to the continental shelf off central Louisiana, Mississippi, Alabama, and Florida, where an eddy is in the process of being formed on the western loop boundary; this eddy will eventually drift westward. The intensification of the loop can be seen as streamlines constrict, thus causing velocities to increase. The streamlines represent a certain volume passing through a plane perpendicular to the contours at a given time; therefore, velocities must increase to maintain the volume flow as streamlines constrict. Figure 2-10 represents a fully developed eddy with its associated streamlines.

Gulf surface currents in the central Louisiana region have a westerly net annual flow, parallel to the shore, with speeds ranging from 0.2 to 0.4 knots. Shallow water, wind-driven currents, and barotropic slope

STREAMLINES IN AUGUST
APPROXIMATE SPEED IN KNOTS

SOURCE: Eleuterius, 1974.
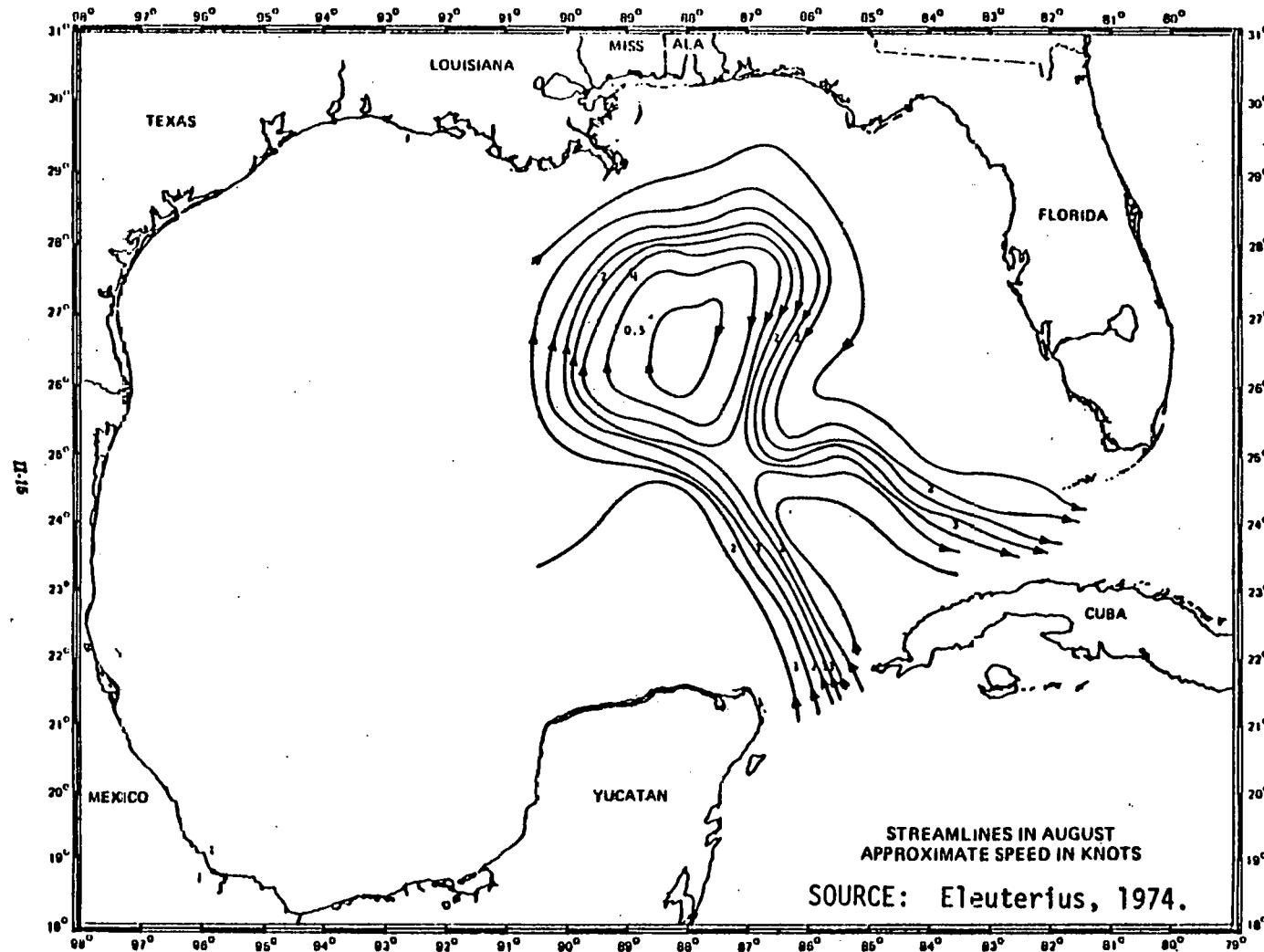
FIGURE 2-9   Loop Current streamlines, August 1966.

STREAMLINES IN JUNE
APPROXIMATE SPEED IN KNOTS

SOURCE: Eleuterius, 1974.
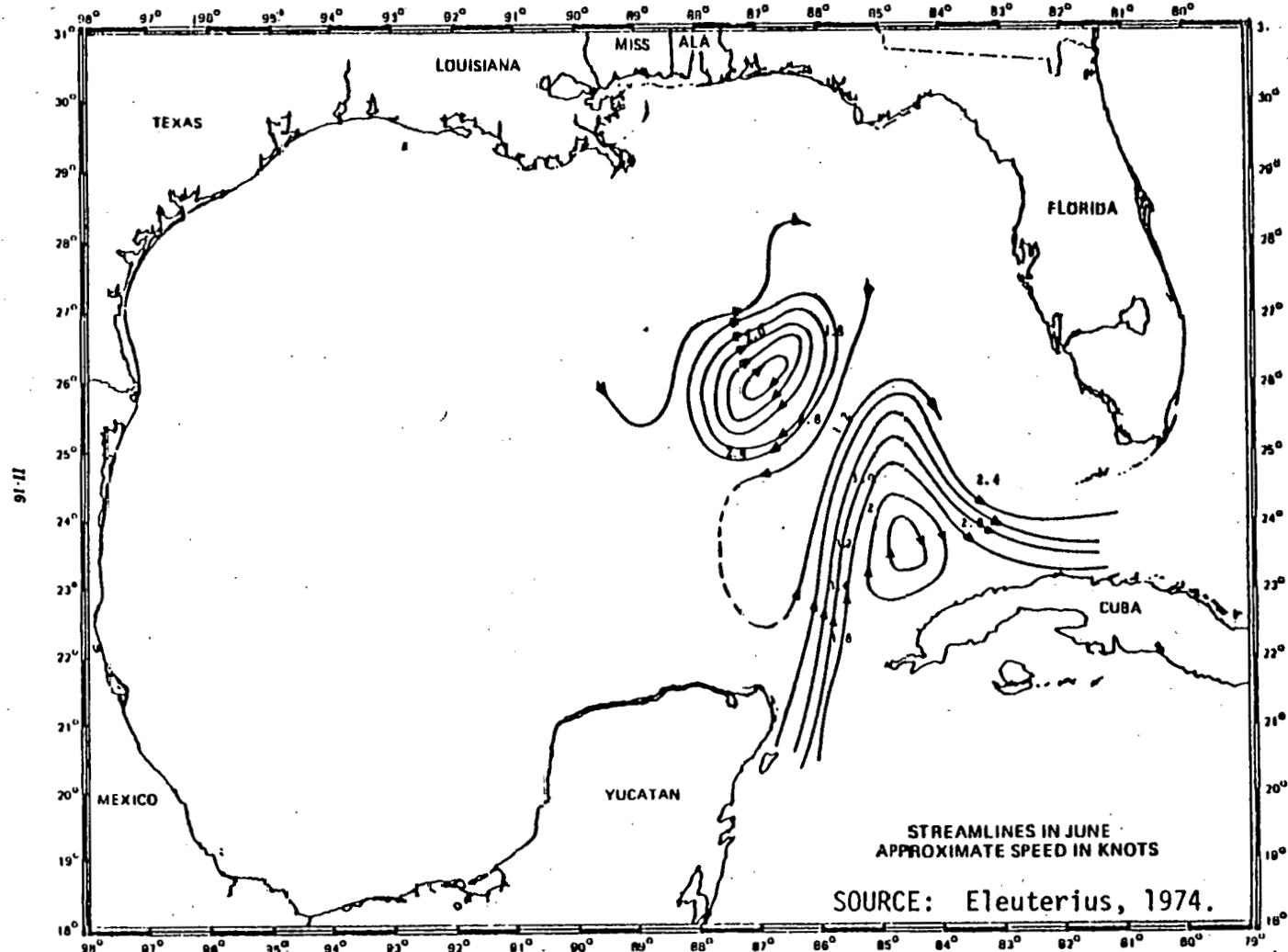
FIGURE 2-10   Loop Current streamlines, June 1967.

11-16

currents, which both parallel isobaths, contribute to the generally west-ward current (U.S. Dept. of Commerce, 1977a). Currents vary seasonally and are controlled by regional wind conditions. An easterly surface flow (0.4 knots) is characteristic in the summer and a westerly surface flow (0.82 knots) persists during the winter and spring. Bottom currents were easterly onshore during the summer, and westerly onshore and offshore during the winter and early spring, respectively (Oetking, 1974b).

Superimposed on the above currents is a rotary tidal current which seldom exceeds 0.3 knots. Generally the tidal heights in the nearshore central Louisiana Gulf range from 1.5 to 2 feet (0.5 to 0.6 meters), and the tide wave moves from west to east. When the moon is at its maximum declination, the tide is diurnal and of greatest range. When the moon is over the equator, the tidal range is lowest and there may be several days of semidiurnal tides (U.S. Dept. of Commerce, 1977a).

2.2.6.2 Observed Currents

Current data at Weeks Island Site A ($29^{\circ}19.5'$ N, $91^{\circ}48.2'$ W) were obtained from October through December 15, 1977. Current data at Site B were obtained from January 7 through April 3, 1978, at a location adjacent to an offshore platform ($29^{\circ}4.95'$ N, $91^{\circ}42.25'$ W), 2.3 miles east of the proposed brine diffuser location. From March 18 through July 10, 1978, current data were collected at another location within the Site B sampling area, 2.2 miles southwest of the proposed brine diffuser location ($29^{\circ}3.1'$ N, $91^{\circ}46.2'$ W).

Current data were analyzed on a monthly basis and a speed histogram and directional records were developed to graphically present raw data. These data (Figures 2-11, 2-15, 2-19, 2-23, 2-27, 2-31, 2-35, 2-39, 2-43, and 2-47) present a vector time series of average velocity using a low pass filter to suppress the high frequencies; for clarity, only every sixth hourly vector is plotted.

The scatter plots developed (Figures 2-13, 2-17, 2-21, 2-25, 2-29, 2-33, 2-37, 2-41, 2-44, and 2-49) present half-hourly alongshore-onshore velocities and visually show an approximate principal axis which corresponds to the mean direction of current flow. The extent of scatter in these diagrams represents differences in speed, and the existence of a "hole"

around the zero speed point suggests high measured speeds at low flow
conditions--that is, high starting speeds or wave-induced contamination
in the measurements (Beardsley et al., 1977). Likewise, the presence
of an arc in the diagrams without any speed and direction measurements
could indicate a directional malfunction. These differences, along
with other factors, will affect the orientation angle of the principal
axis.

Progressive vector diagrams (PVD's) (Figures 2-14, 2-18, 2-22,
2-26, 2-30, 2-34, 2-38, 2-42, 2-46, and 2-50) were constructed by integra-
ting with respect to time each half-hourly current velocity vector.
PVD's best represent the mean direction of current. When a drift current
is absent, tidal forces become a predominant factor, and the diagrams
will show a flow pattern consisting of a series of overlapping loops,
which indicate a condition of little or no net current displacement.
As the strength of the drift current increases, the loops separate
and will disappear entirely if the current drift velocity reaches a
threshold value and prevents a tidal reversal.

A summary of the net current displacement and virtual direction
for each station measured is presented in Tables 2-12 and 2-13. The
virtual current direction is the heading of a line connecting the begin-
ning point on the diagram to the end point. The net displacement is
the length of this line.

2.2.6.2.1 October (Weeks Island Site A)

The speed histogram and directional plot developed for the October
13 to 31 data (Figure 2-11) showed that currents measured at a depth
of 14.5 feet (4.4 meters) were slightly lower than the currents measured
at 11 feet (3.4 meters). This difference suggests that a vertical
shear exists between the surface and bottom waters. Current speeds
were most often in the 0- to 1-ft/sec (0- to 30-cm/sec) range, but
sometimes reached 1.6 ft/sec (50 cm/sec). This distance suggests that
a small vertical shear existed between the surface and bottom waters.
Rotary tidal circulation was apparent throughout most of the record
but was most strongly reflected at the 11-foot (3.4-meter) depth.
In addition, a strong northwesterly current was measured from October
21 to 24.

TABLE 2-12 Progressive vector diagram summary for Weeks Island Site A.

Meter	Current Meter Depth (ft)	Virtual Direction (^{o})	Net Displacement (km)	Period of Record (days)
IA[a]	11	311	19	18
IB[a]	14.5	305	19.5	18
IIB[a]	11	315	70	18
IIB[a]	14.5	322	14	18
WIB[b]	14.5	353	118.5	23

[a] October 13 to 31, 1977.
[b] December 15, 1977, to January 1978.

TABLE 2-13 Progressive vector diagram summary for Weeks Island Site B.

Date	Current Meter Depth (ft)	Virtual Direction (^{o})	Net Displacement (km)	Period of Record (days)
January 7-31	12	276	87	24
February	12	286	98	28
March	12	305	82	31
March 18-31	17	265	9	14
	21.5	252	30	14
April	17	305	248	30
	21.5	297	207	30
May	17	310	299	31
	21.5	304	196	31
June	17	326	206	30
	21.5	328	158	30
July	17	127	30	10
	21.5	135	22	10
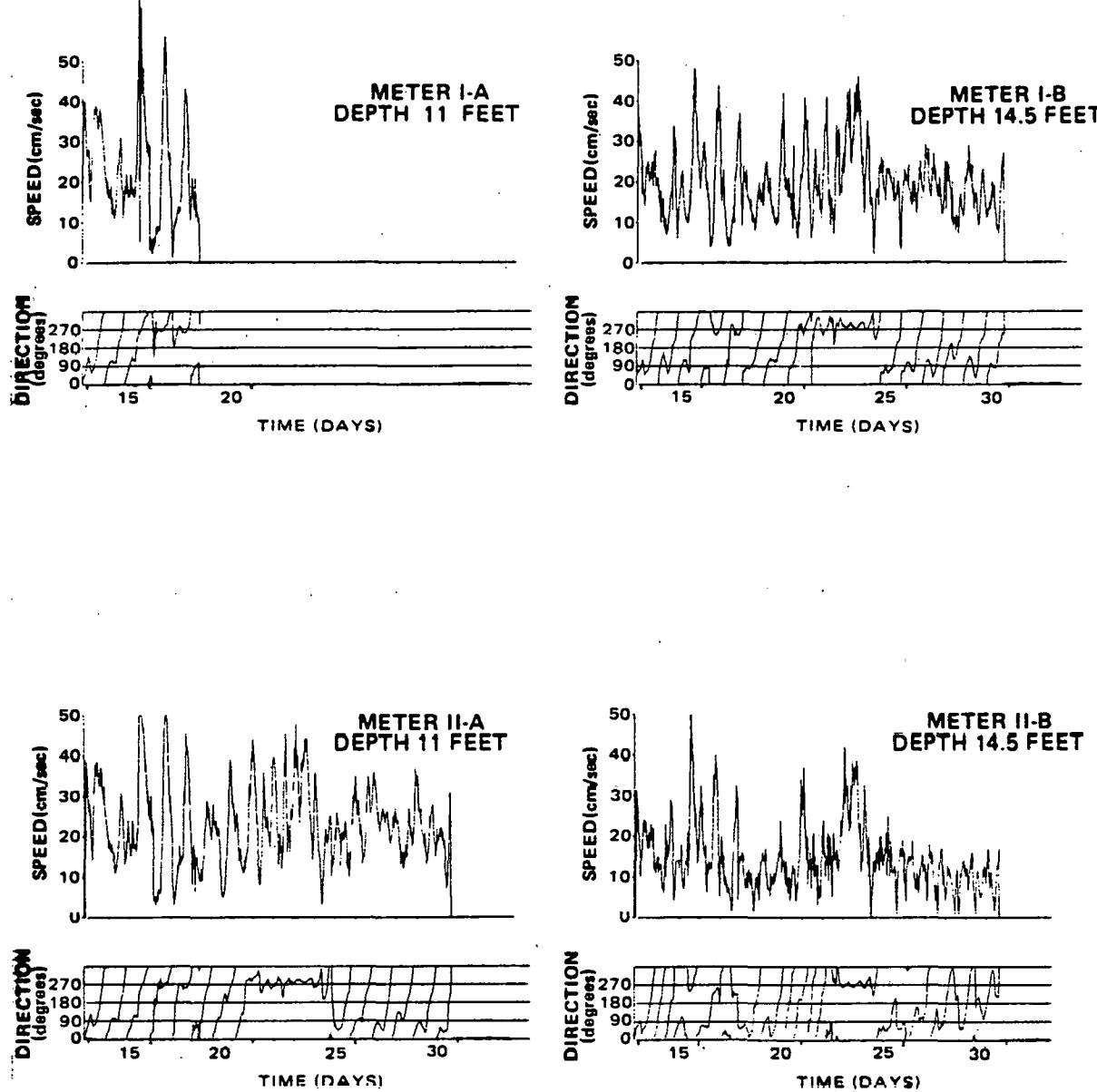
FIGURE 2-11   Speed histograms and directional plots of currents measured at
Weeks Island Site A, October 13-31, 1977.

TABLE 2-14 Offshore wind and wave data collected at West Cameron Block
No. 328, October 20-25, 1977.

Date	Time	Wind Speed (kn)	Wind Direction	Wave Height	Wave Direction	Period (sec)
Oct 20	0000	0	E	0	E	
	0400	10	E	1	E	4.3
	0800	15	E	1	E	4.3
	1200	15	SE	1	SE	4.5
	1600	20	SE	1	SE	4.7
	2000	25	SE	1	SE	4.4
Oct 21	0000	27	E	1	E	4.7
	0400	27	E	1	E	4.7
	0800	25	E	3	E	4.2
	1200	25	E	3	E	4.6
	1600	33	SE	4	SE	5.4
	2000	33	SE	4	SE	5.7
Oct 22	0000	30	E	6	E	3.8
	0400	23	E	6	E	5.5
	0800	23	E	5	E	4.7
	1200	27	SE	5	SE	5
	1600	15	SE	6	SE	5.6
	2000	15	SE	6	SE	6.1
Oct 23	0000	30-35	ESE	5	ESE	5
	0400	43	SE	5	SE	4.5
	0800	40	SE	9	SE	4.6
	1200	13	SE	9	SE	6
	1600	13	SE	10	SE	6
	2000	13	SE	8	SE	6.1
Oct 24	0000	20-25	E	6	E	4.1
	0400	20	ESE	7	ESE	3.8
	0800	5-10	E	12	E	3.9
	1200	5-10	SE	8	SE	3.1
	1600	5-10	NNE	7	NNE	4.8
	2000	5-10	N	6	N	6

SOURCE: Transworld Drilling Co., 1977.

The October vector time-series data (Figure 2-12) show that average current velocities ranged from less than 0.15 ft/sec (5 cm/sec) to approximately 1.1 ft/sec (33 cm/sec). These currents showed variable flow directions at similar depths between the two current meter arrays and at different depths within the same array. A pronounced northwestward drift from October 21 to 24, however, is reflected in all figures.

Minor directional differences were observed between the currents measured at the two 14.5-foot (4.4-meter) depths, but a large directional variation was apparent between the 11- and 14.5-foot (3.4- and 4.4-meter) depths at Array No. 2 (Meters IIA and IIB, respectively), especially on October 21 and 30. At this time current direction differed by as much as 180^{0}--suggesting that a two-layered flow system was operating. The broad ellipse ((Meters IA and IIA) Figure 2-13) plotted for the two meters at 11 feet (3.4 meters), shows that the measurements are similar, but the diagram for Meter IIB exhibits a vague low-speed hole. The data are insufficient to determine if this pattern was duplicated by Meter IA. Both diagrams, however, show close agreement with regard to the orientation of the principal axis, which lies in an east-west direction.

Current velocities measured at 14.5 feet (4.4 meters), (Meters IB and IIB) during October exhibited a broad ellipse; a distinct low speed hole was apparent at Meter IB. Overall, there was less scatter at this depth than at 11 feet (3.4 meters), possibly due to the decreased effect of changing wind direction and tides at deeper water levels. However, the most prominent difference between these two stations was the mean direction of current flow as shown by the variation in the orientation of the principal axis (Figure 2-13). The principal axis at Meter IB lies in an east-west direction, whereas that of Meter IIB lies northeast-southwest. It is believed that this variation could be caused by a nonhomogenous flow field at the site.

Comparison of velocities at each array shows that for the first array (Meters IA and IB), there was a wider scatter in the plot at the surface. However, the principal axes are nearly identical and lie in an east-west direction. At the second array, the broader ellipse at the upper water level is much more evident. The difference in the orientation of the principal axes may be due to nonhomogeneity in the

METER I-A
DEPTH 11 FEET
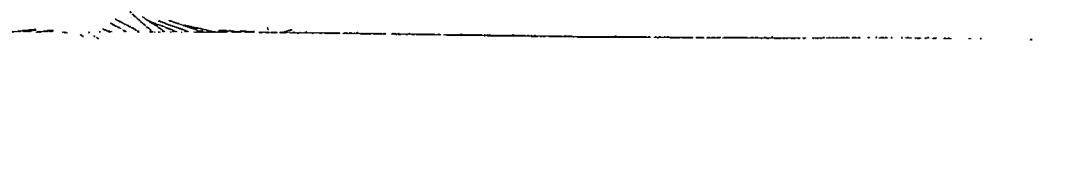
METER I-B
DEPTH 14.5 FEET
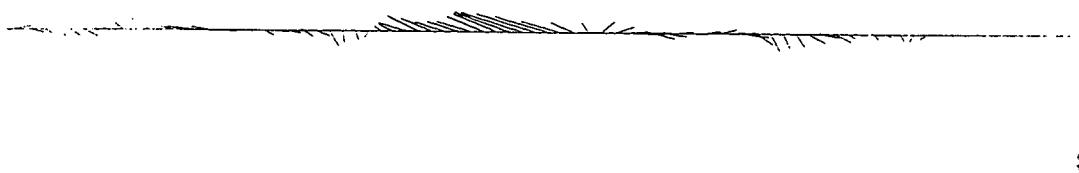
METER II-A
DEPTH 11 FEET

METER II-B
DEPTH 14.5 FEET

15   20   25   30

TIME (DAYS)

NORTH

ONSHORE

.00   25.00   50.00

SPEED SCALE (cm/sec)
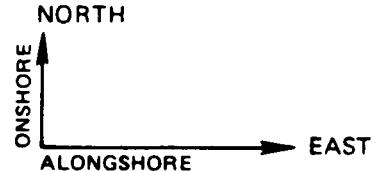
ALONGSHORE   EAST

FIGURE 2-12   Averaged vector time series for Weeks Island Site A,
               October 13-31, 1977.

METER I-A
DEPTH 11 FEET
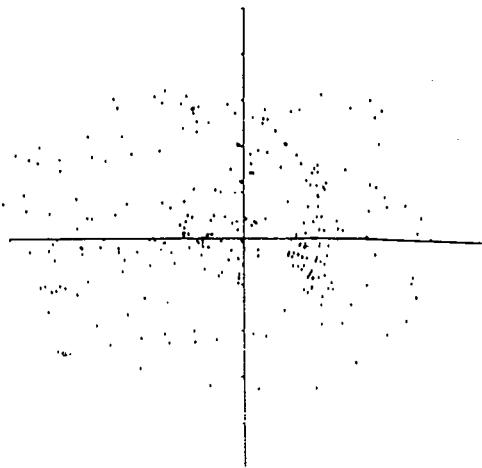
METER II-A
DEPTH 14.5 FEET
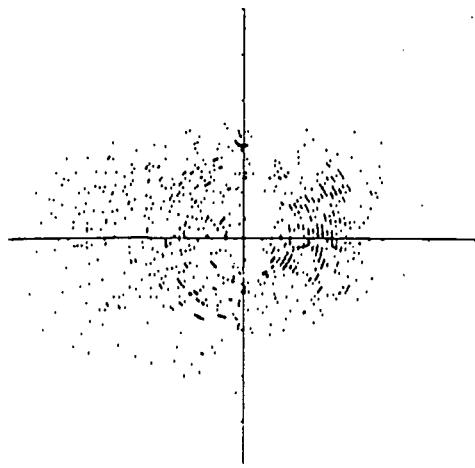
METER I-B
DEPTH 11 FEET
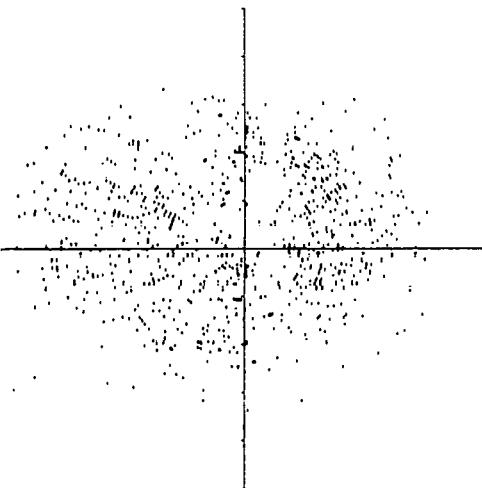
METER II-B
DEPTH 14.5 FEET
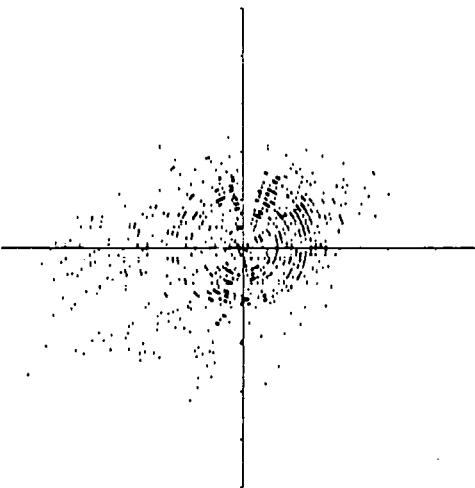
0 10 20 30 40

SPEED SCALE (cm/sec)

NORTH

ONSHORE

ALONGSHORE

EAST

FIGURE 2-13   Velocity scatter plots for Weeks Island Site A, October 13-31, 1977.

water column, possibly induced by vertical shear stresses in the two-layered flow system.

The PVD's developed from the October data (Figure 2-14) show a large discrepancy in the net current displacement for the two meters at 11 feet (3.4 meters) due to the limited operational time of Meter IA. Drift during the first 6 days, however, was nearly identical. Meters IA and IIB had a consistent net displacement of 12 and 8.7 miles (19.5 and 14 kilometers), but varied in direction from 305° to 322°, respectively. Less directional variation in the currents was apparent when the data from the meters in each array were examined. The directional uniformity throughout the water column at each array suggests that the currents at the sites were driven by a common mechanism; but differences between each array could be caused by variations in local topography or a nonhomogenous flow field. These PVD's illustrate that a tide-dominated circulation pattern occurred in the area between October 13 and 23 and show that tidal effects on bottom waters occurred 1 or 2 days after they were apparent in the surface waters. A pronounced northwest drift occurred during the next 2 to 4 days, which was followed by an easterly drift from October 29 to November 3.

Wind and wave data measured at an offshore platform (Table 2-14) showed that easterly and southeasterly winds prevailed during this time interval, with speeds ranging from 5 to 45 knots. Wave heights were from 4 to 6 feet (1.2 to 1.8 meters) and wave direction corresponded to that of the wind.

2.2.6.2.2 December-January (Weeks Island Site A)

Current speeds from December 15 to January 7, 1978 (Figure 2-15) ranged from 0.06 to 2.7 ft/sec (2 to 83 cm/sec and were slightly higher than those found during the October interval. A rotary current was noted during the first 4.5 days of the record. The easterly-southeasterly flow from December 20 to 22 corresponds to the period of maximum current speeds. Winds during this interval (Table 2-15) generally were from the northwest at speeds ranging from 5 to 55 knots. An 8-day period of predominantly northward flow (December 23 to 30), for which there are only partial meteorological data, was followed by a slightly irregular but tidal-dominated flow pattern for the remainder of the current record (December 31 to January 7).
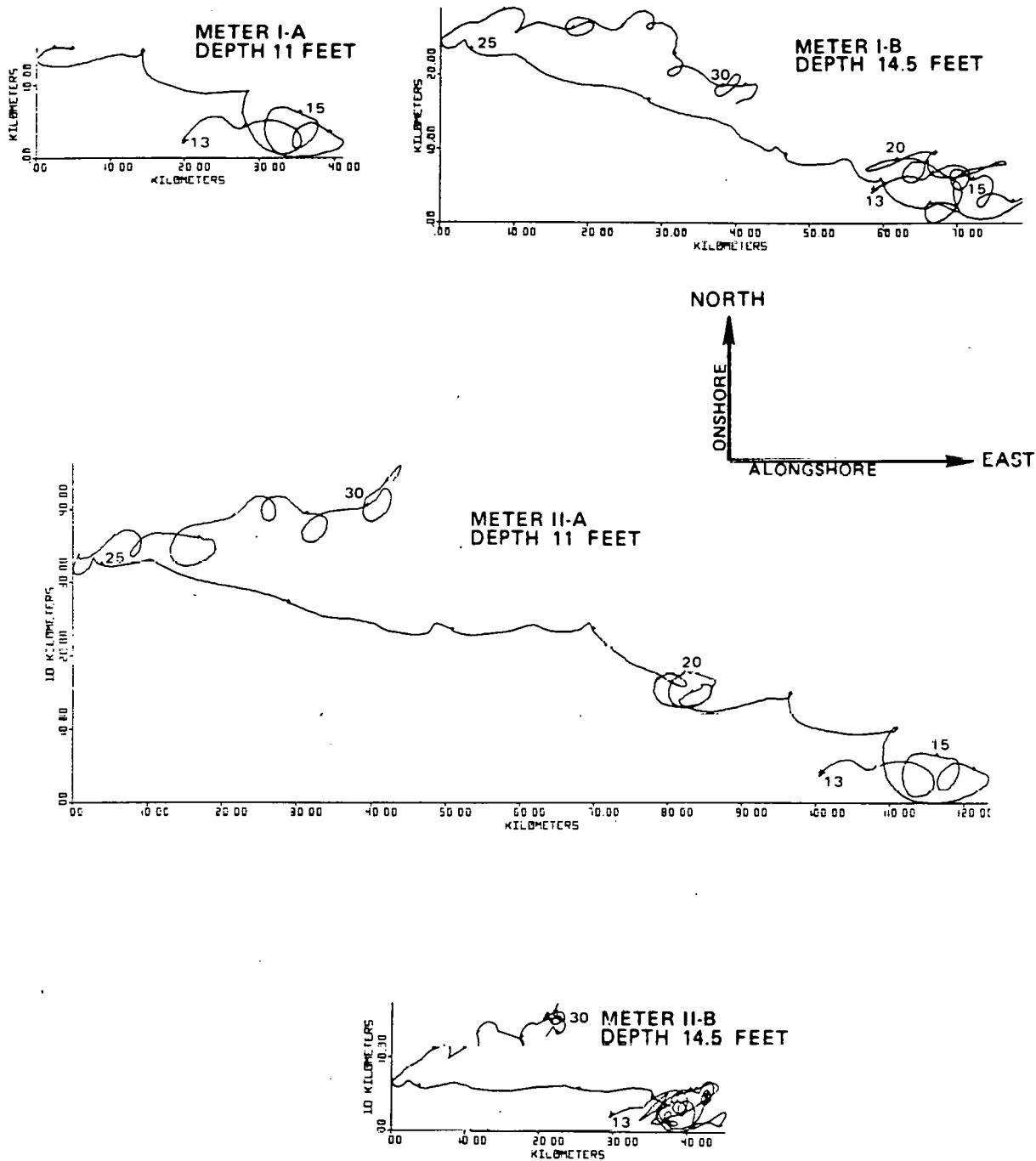
FIGURE 2-14   Progressive vector diagrams for Weeks Island Site A, October
13-31, 1977 (numbers represent days of the month).

STATION W-1-B
DEPTH 14.5 FEET

SPEED (CM/SEC)

DIRECTION (DEGREES)

TIME (DAYS)

2-45
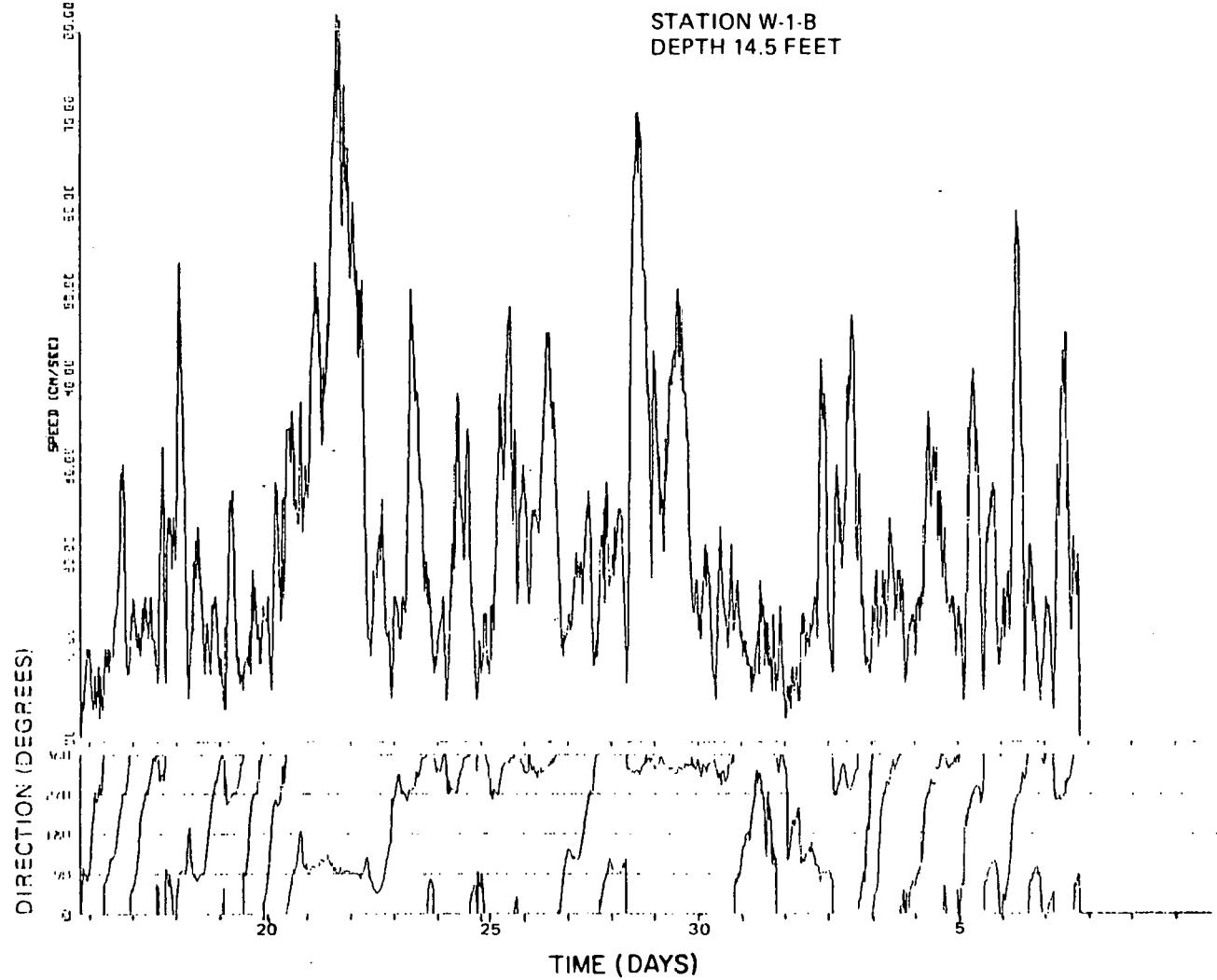
FIGURE 2-15   Speed histogram and directional plot of currents measured at Weeks Island Site A,
December 15, 1977 to January 7, 1978.

TABLE 2-15 Offshore wind and wave data collected at Eugene Island Block
Nos. 350 and 361, December 20-25, 1977.

| Date | Time | Wind | | Wave | | Period (sec) |
		Speed (kn)	Direction	Height	Direction	
Dec 20	0000	15-19	SSW	5	SSW	
	0400	24-30	SSE	5- 7	SSE	
	0800	30-35	N	7- 9	N	
	1200	35-40	N	10-11	N	
	1600	40-44	N	13-15	N	
	2000	40-44	N	15-16	N	
Dec 21	0000	44-50	NNW	16-17	NNW	
	0400	40-45	NW	16-19	NW	
	0800	40-45	NW	18-19	NW	
	1200	40-44	NW	20	NW	
	1600	48-55	NW	18	NW	
	2000	46-50	NW	19	NW	
Dec 22	0000	26-32	NW	10	NW	
	0400	16-22	N	6	N	
	0800	15-20	NE	5	NE	
	1200	4-10	S	6	S	
	1600	4-10	SE	6	SE	
	2000	16-18	S	6	S	
Dec 23	0000	30	S	6	S	5.8
	0400	30-35	SW	9	SW	6
	0800	33-35	SW	9	SW	5.5
	1200	30	SW	8	SW	6.3
	1600	30	SE	7	SE	6
	2000	30	SE	7	SE	5.8
Dec 24	0000	30-35	SE	7	SE	5
	0400	30	S	9	S	5.5
	0800	30	S	8	S	5.7
	1200	28-30	S	8	S	6
	1600	30-40	SE	9.5	SE	5.7
	2000	30-35	SE	9.5	SE	6.1
Dec 25	0000	14-22	SW	8-11	SW	5.1
	0400	28-30	W	9-11	W	5.3
	0800	18-22	N	7	N	5.6
	1200	21	NW	8	NW	6.2
	1600	30	NW	8	NW	6.9
	2000	38-42	NW	8-10	NW	7.3

SOURCE: Transworld Drilling Co., 1977.

The vector time-series shows that average current velocities in this December-January interval ranged from less than 0.15 ft/sec (5 cm/sec) to 1.7 ft/sec (53 cm/sec). Peak velocities occurred from December 20 to 22, when a strong easterly-southeasterly flow was present. The dominant direction of current during December, however, was to the north-northwest (Figure 2-16).

The scatter diagram for the December-January data (Figure 2-17) forms an irregular ellipse which is broadened in the westerly and north-westerly direction. The predominant principal axis is in a northwest-southeast direction and a high percentage of flow with a northward (onshore) component is apparent. A slight instrument malfunction in directional sensitivity is indicated by the two holes at 18° and 346° (Figure 2-17).

Compared with the October data, the currents in December-January show less coherence (i.e., greater scatter)--particularly in the onshore direction. The orientation of the principal axis, has shifted from an east-west direction to the southeast-northwest.

Currents at the beginning of the December-January period (Figure 2-18) were tidal-dominated and little net drift was present; this flow was followed by 2.5 days of strong eastward drift (December 20 to 22). During the next 8 days, there was a strong, nearly continuous northward onshore drift. A rotary tidal flow was superimposed on a net northwest-ward current drift in the last part of the study period.

2.2.6.2.3 January (Weeks Island Site B)

In January, current speeds at Site B generally ranged from 0.3 to 1.3 ft/sec (10 to 40 cm/sec), (Figure 2-19). Maximum current speeds occurred on January 8 and 9 at 1.5 to 2.8 ft/sec (46 to 86 cm/sec) and on January 25 and 26 at 1.7 to 4.6 ft/sec (54 to 139 cm/sec). During both episodes current flow was to the southeast and appeared to be wind-driven. On January 8, wind from the northwest exceeded 50-mph, and the accompanying wave heights were 24 feet (7.3 meters).

On January 25, northwesterly winds varied from 27 to 70 mph, and wave heights ranged from 12 to 15 feet (3.7 to 4.6 meters). Currents

STATION W-1-B
DEPTH 14.5 FEET

20   25   30   5

TIME (DAYS)

OU   25.00   50.00

SPEED SCALE (cm/sec)

NORTH

ONSHORE

EAST

ALONGSHORE
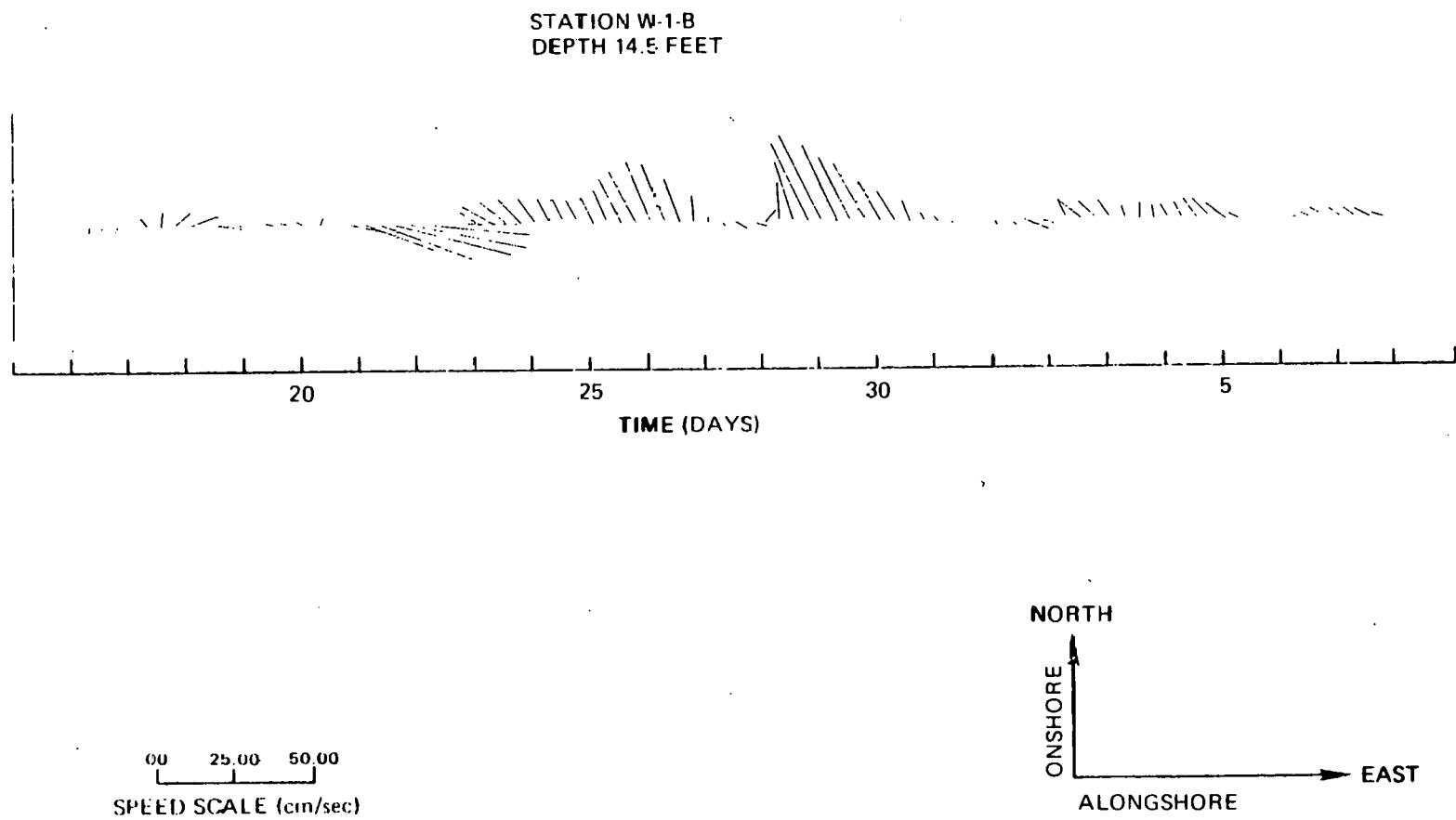
FIGURE 2-16   Averaged vector time series for Weeks Island Site A, December 15, 1977 to
January 7, 1978.
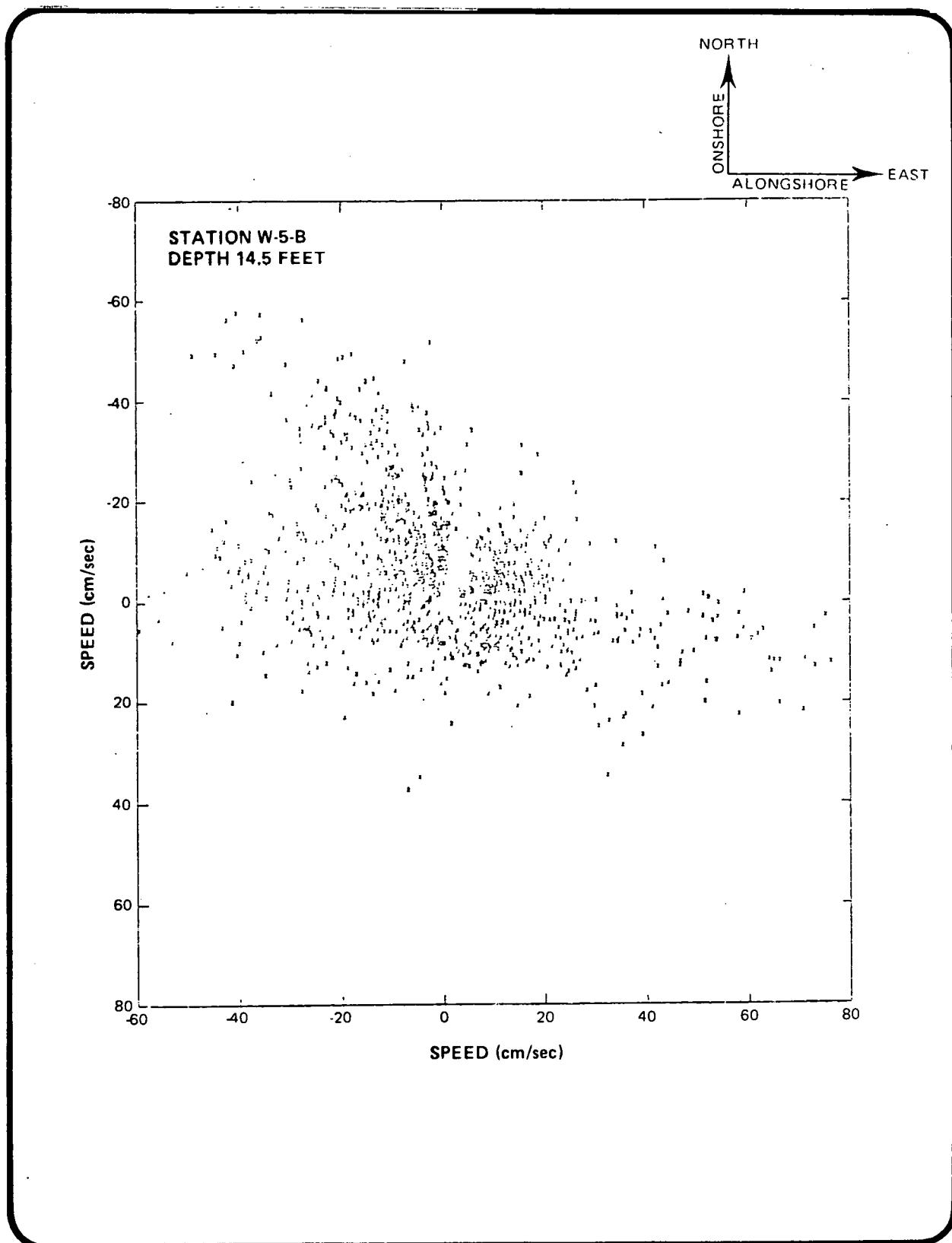
FIGURE 2-17   Velocity scatter plot for Weeks Island Site A, December 15, 1977 to January 7, 1978.
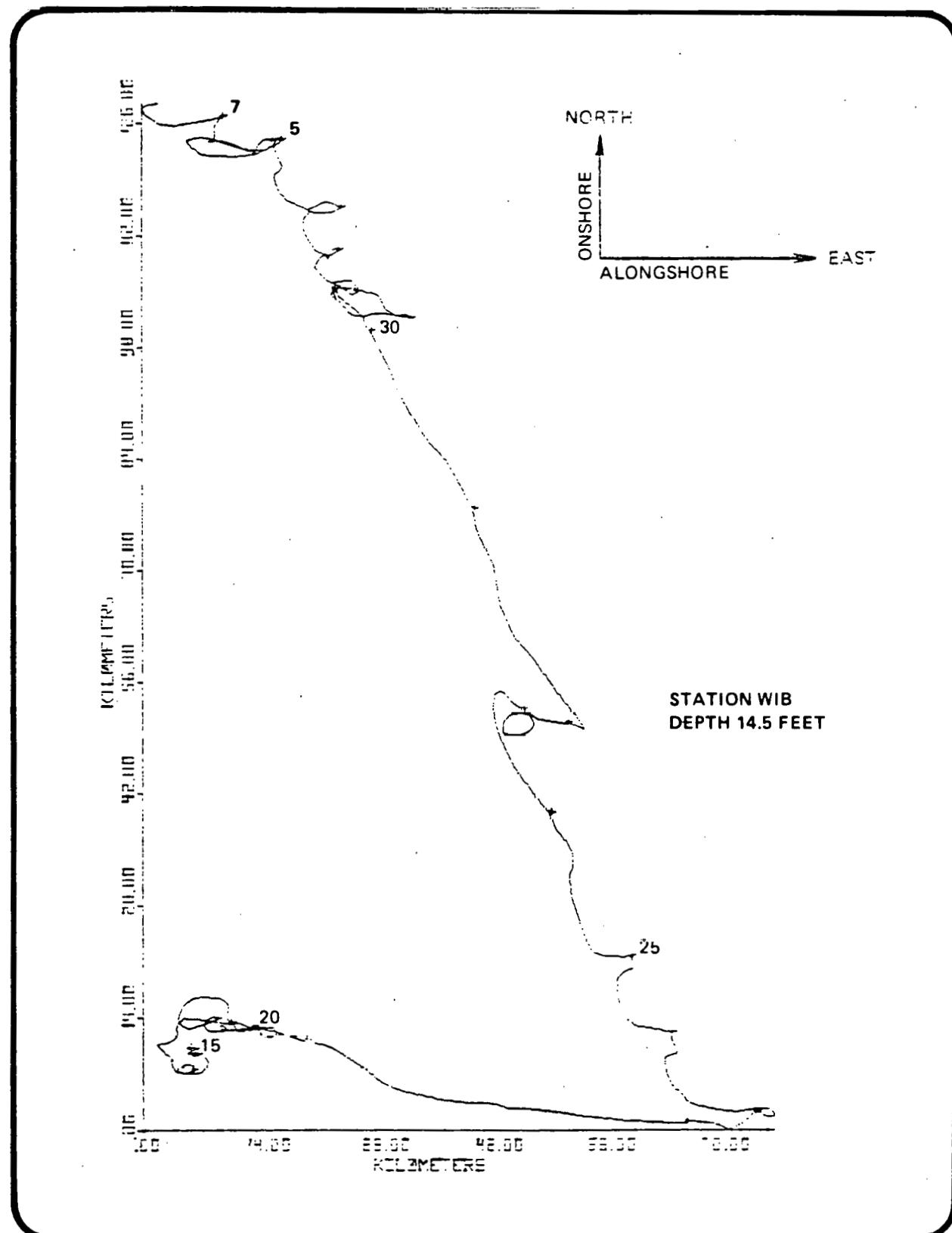
FIGURE 2-18   Progressive vector diagram for Weeks Island Site A, December 15, 1977 to January 7, 1978 (numbers represent days of the month).
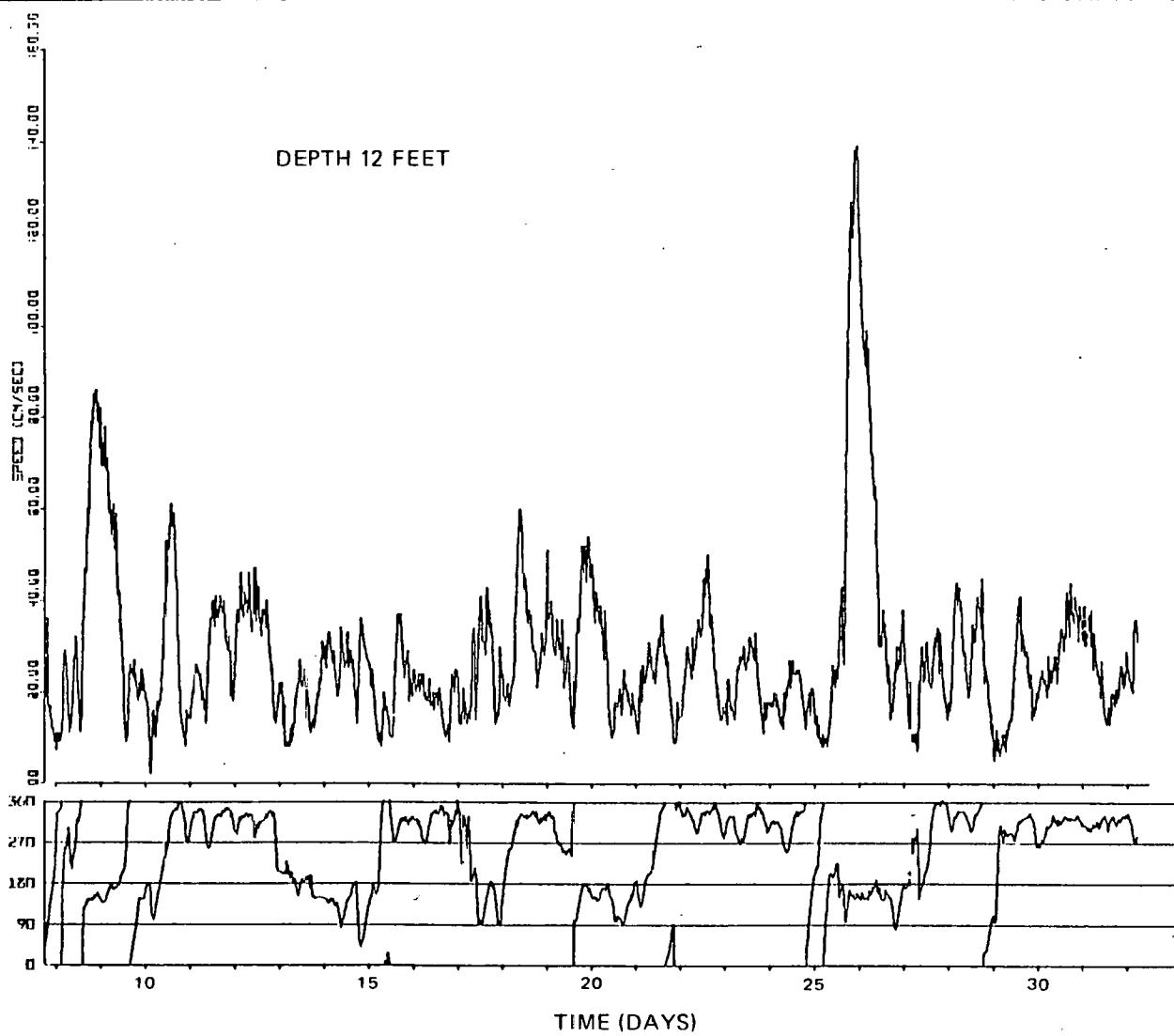
FIGURE 2-19   Speed histogram and directional plot of currents measured at Weeks Island Site B, January 7-31, 1978.

at Site B continued to flow to the southeast on January 26, even though the wind had changed to northeasterly speeds of 6 to 20 mph.

Because of the strong winds, little rotary tidal circulation was evident at the site during January. Most of the current record was dominated by short (1 to 3 days) but continuous episodes of northwesterly or southeasterly flow. This periodic fluctuation of current flow is illustrated in Figure 2-20.

The alongshore-onshore velocity scatter diagram (Figure 2-21) is a crescent-shaped ellipse with its two principal axis directions to the north and to the southeast and with a "hole" around the zero speed point. This hole could be induced by large surface waves such as those observed on January 8 and 25 at Site B.

The currents during January show a net displacement of 54 miles (87 kilometers) to the west (Figure 2-22), with alternating periods of southeastward and northwestward drift.

2.2.6.2.4 February (Weeks Island Site B)

During February current speeds attained a maximum of 2.4 ft/sec (75 cm/sec), but generally ranged between 0.3 to 1.3 ft/sec (10 to 40 cm/sec), (Figure 2-23). Current patterns were dominated by rotary tidal circulation. Two storm events, on February 6 to 8 and on February 21, resulted in current speeds of 1 to 1.7 and 1 to 2.4 ft/sec (30 to 52 and 30 to 75 cm/sec) with current flow to the northwest and south-east, respectively.

During this same period, wind and wave data collected on an offshore platform showed that 6- to 50-mph winds occurred in this area and were predominantly from the north and east. Easterly winds at 16 to 50 mph set up the northwesterly flow on February 6 to 8. Wave heights during this storm increased from 3 to 16 feet (1 to 5 meters). Similarly, the southeasterly flow on February 21 coincided with 20- to 50-mph winds from the northwest and waves of 4 to 17 feet (1.2 to 5.2 meters).

The velocity vector time series for February (Figure 2-24) show a pattern similar to that for January (Figure 2-20), with alternating northwesterly and southeasterly flow. However, in February the magnitude of the vectors is reduced.
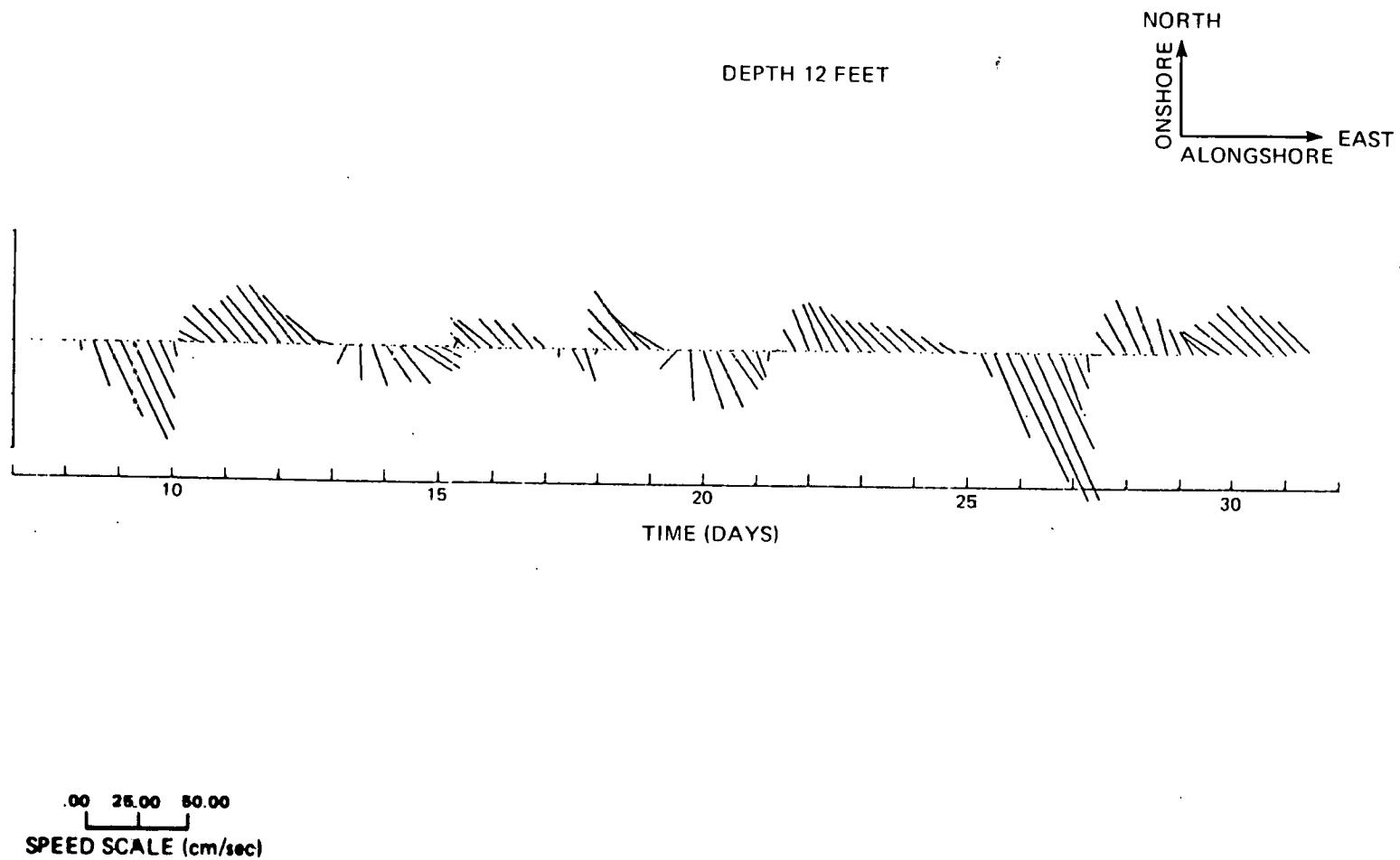
FIGURE 2-20   Averaged vector time series for Weeks Island Site B, January 7-31, 1978.
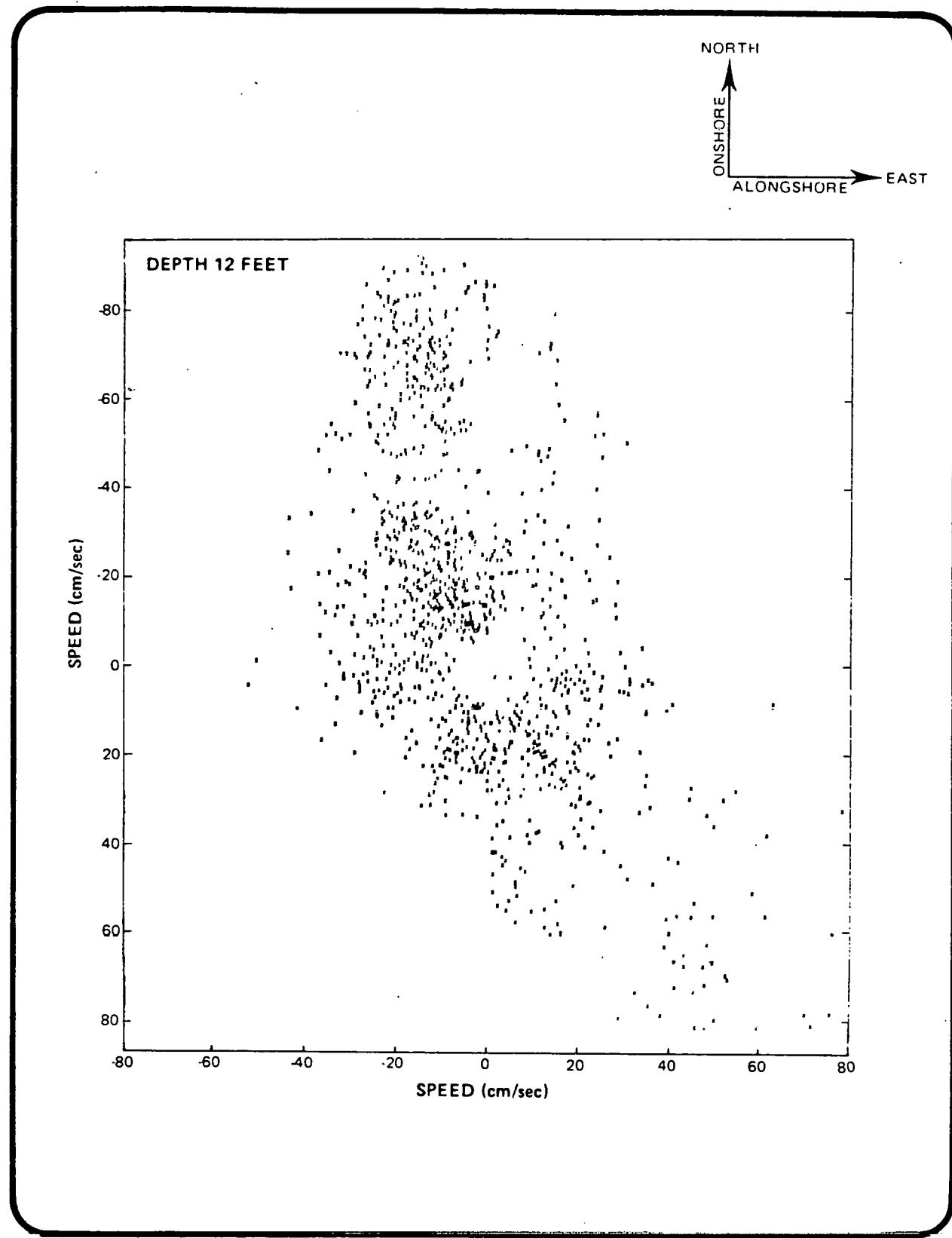
FIGURE 2-21   Velocity scatter plot for Weeks Island Site B,
               January 7-31, 1978.
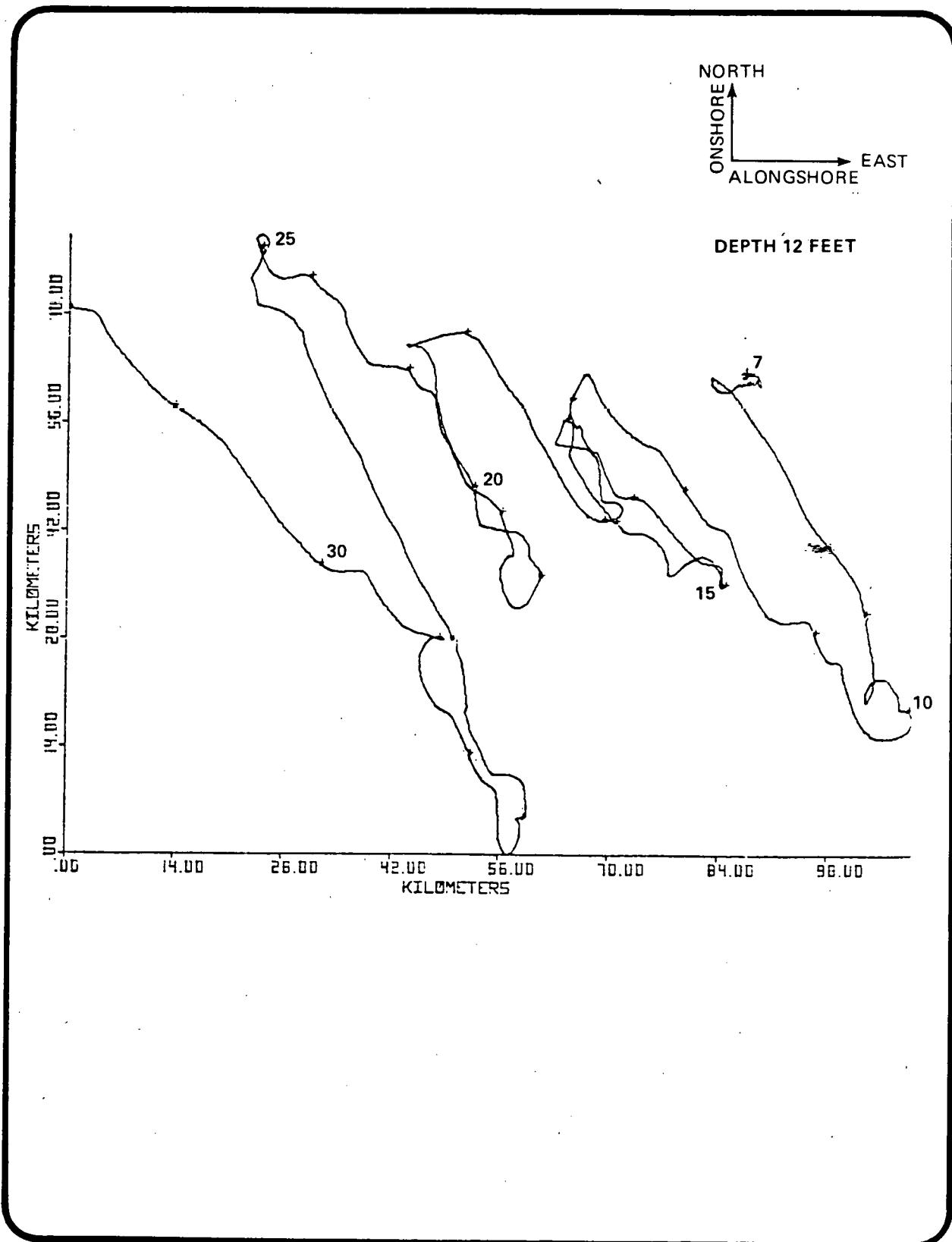
FIGURE 2-22   Progressive vector diagram for Weeks Island Site B, January 7-31, 1978 (numbers represent days of the month).

DEPTH 12 FEET

TIME (DAYS)
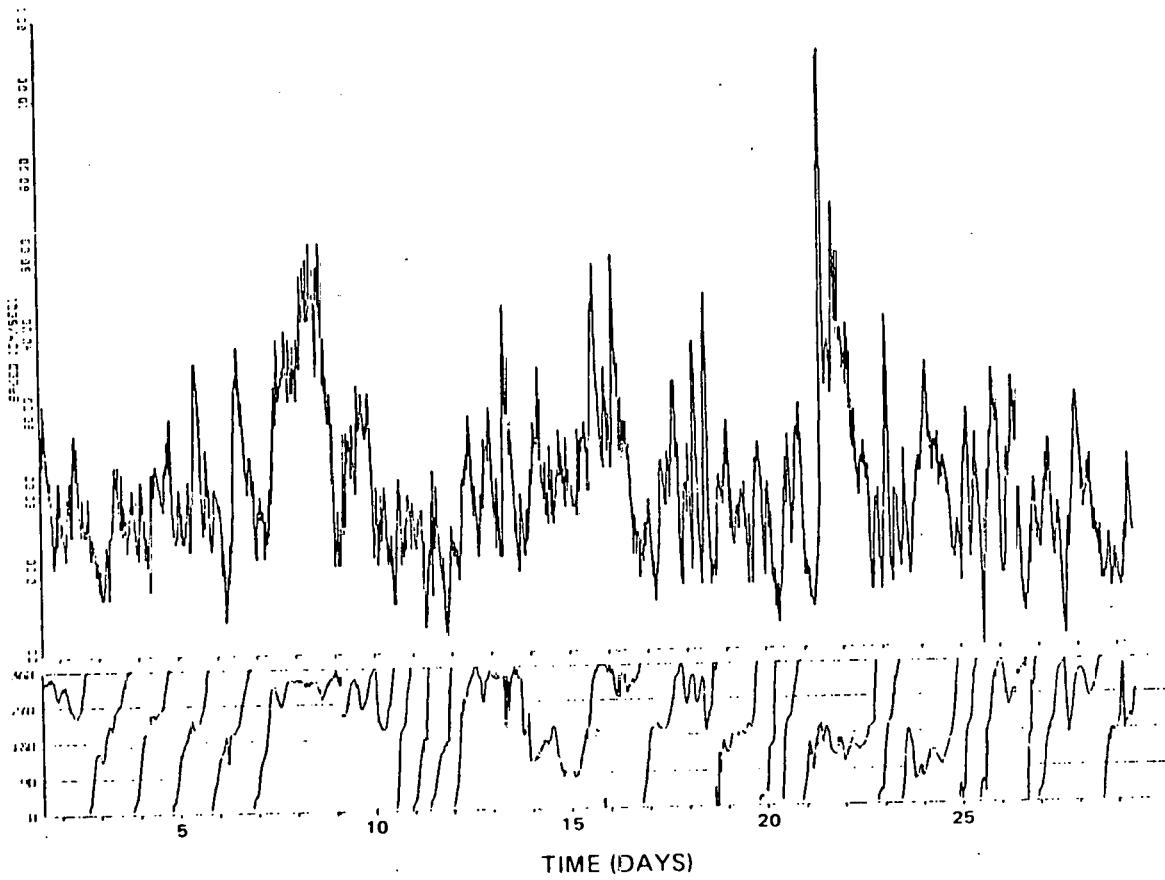
FIGURE 2-23   Speed histogram and directional plot of currents measured at Weeks Island Site B,
February 1978.
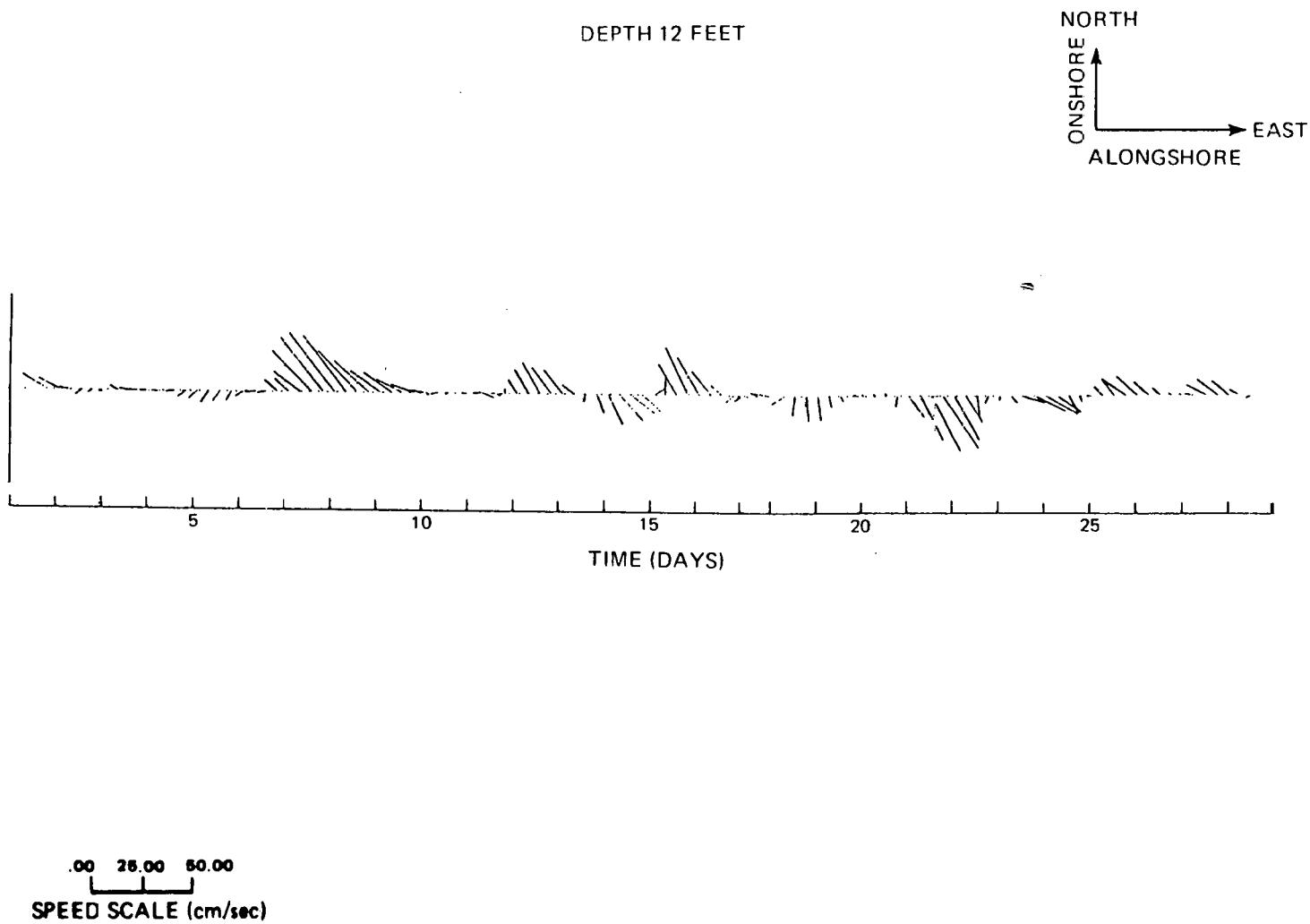
FIGURE 2-24   Averaged vector time series for Weeks Island Site B, February 1978.

The alongshore-onshore scatter diagram for February 1978 formed a regular-shaped ellipse with a northwest-southeast trending principal axis (Figure 2-25). The size of the ellipse was smaller than that for January due to a reduction in the current speeds. The hole around the zero speed point is believed to be caused by the large waves associated with winter storms.

The PVD for February shows a net drift to the west-northwest (Figure 2-26); the net displacement is 61 miles (98 kilometers). Superimposed on the overall drift pattern are the tidal-dominated portions of the record with little or no net displacement (February 2 to 7, 10 to 12, 19 to 20, and 25 to 27).

2.2.6.2.5 March (Weeks Island Site B)

Currents measured during March were similar to those measured in February. The maximum measured speed was 2.9 ft/sec (89 cm/sec), but currents generally ranged from 0.3 to 1.3 ft/sec (10 to 40 cm/sec). Most of the circulation during March was tidal-dominated, but one major storm event was recorded on March 9 when the current attained a speed of 2.9 ft/sec (89 cm/sec) and flowed to the southeast for nearly 2 days (Figure 2-27).

Northwesterly winds with speeds of 20 to 40 mph occurred on March 8 and 9, and are believed to be the driving mechanism of the southeasterly current measured during this interval; accompanying wave heights ranged from 4 to 9 feet (1.2 to 2.7 meters). During the remainder of the month winds were variable at 10 to 25 mph.

The vector time-series for March (Figure 2-28) show a further reduction in average current velocities and a predominant flow direction to the northwest. Several episodes of southerly to southeasterly flow are evident; the most sustained occurred on March 8 to 10. The scatter diagram for March is a rounded ellipse with a northwest-southeast principal axis (Figure 2-29); it is smaller than the February ellipse due to the overall lower current speeds in the early spring.

The PVD developed for the March data shows a net displacement of 51 miles (82 kilometers) to the northwest (Figure 2-30). The predominant
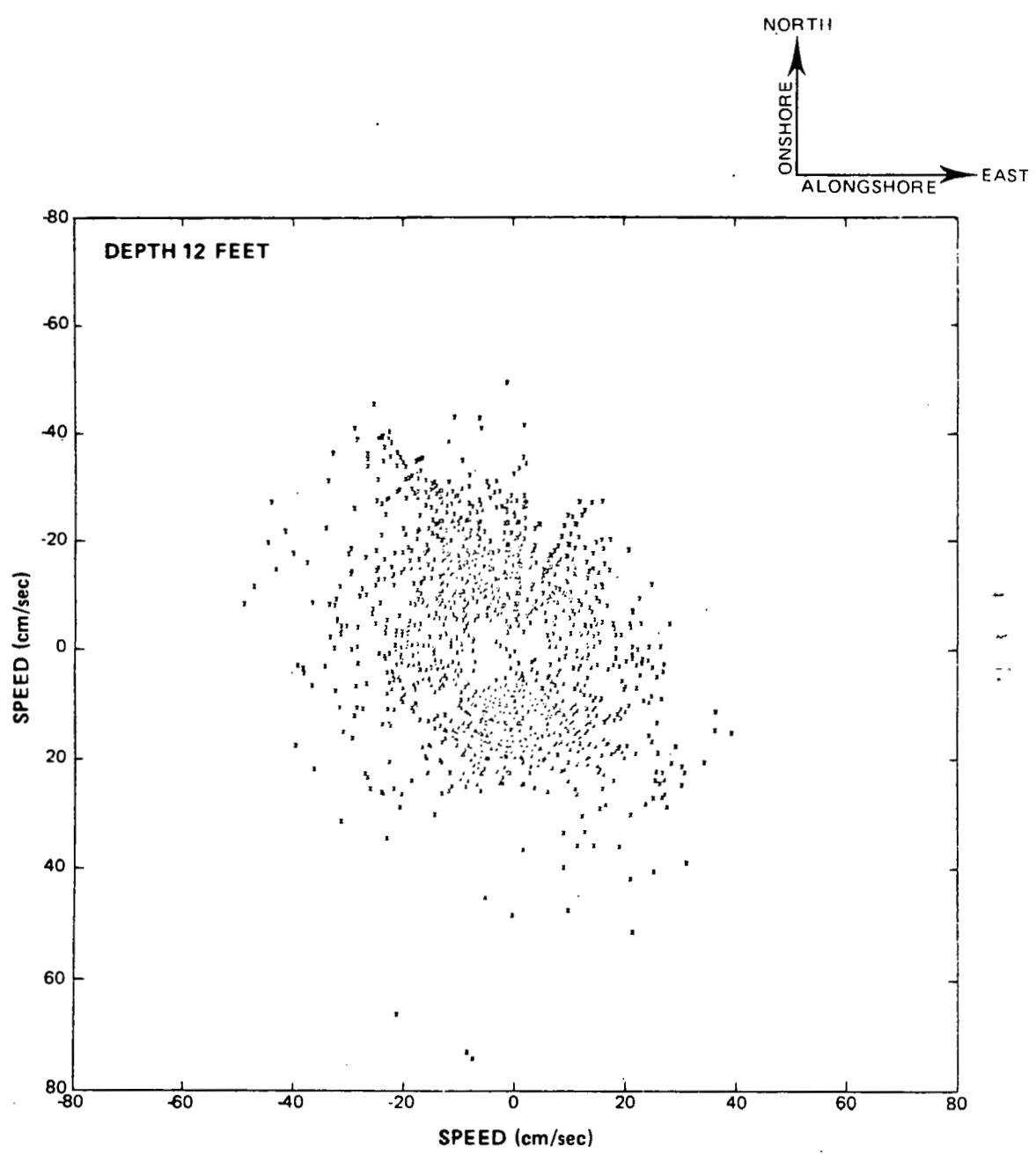
FIGURE 2-25   Velocity scatter plot for Weeks Island Site B, February 1978.
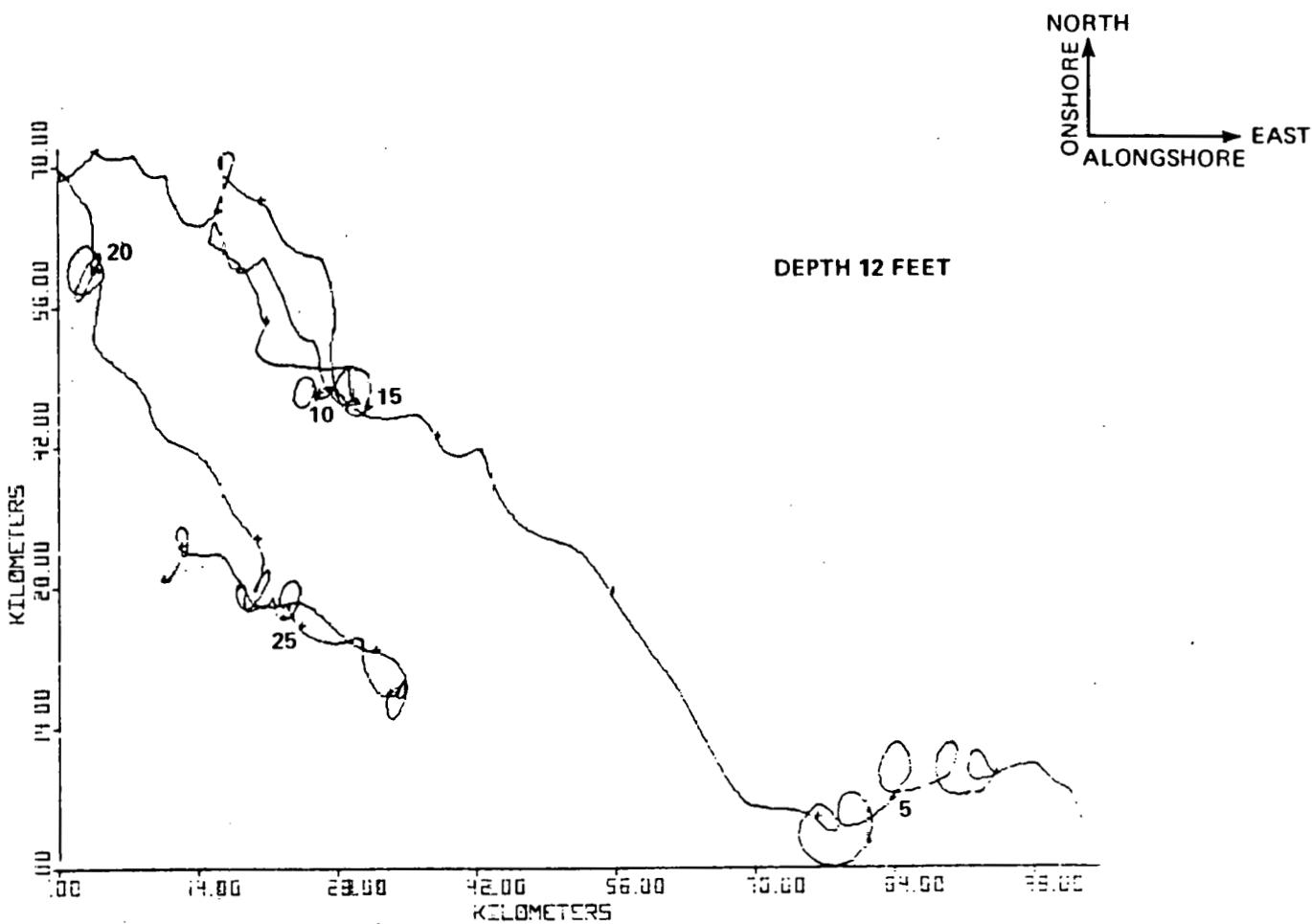
FIGURE 2-26   Progressive vector diagram for Weeks Island Site B, February 1978 (numbers represent days of the month).
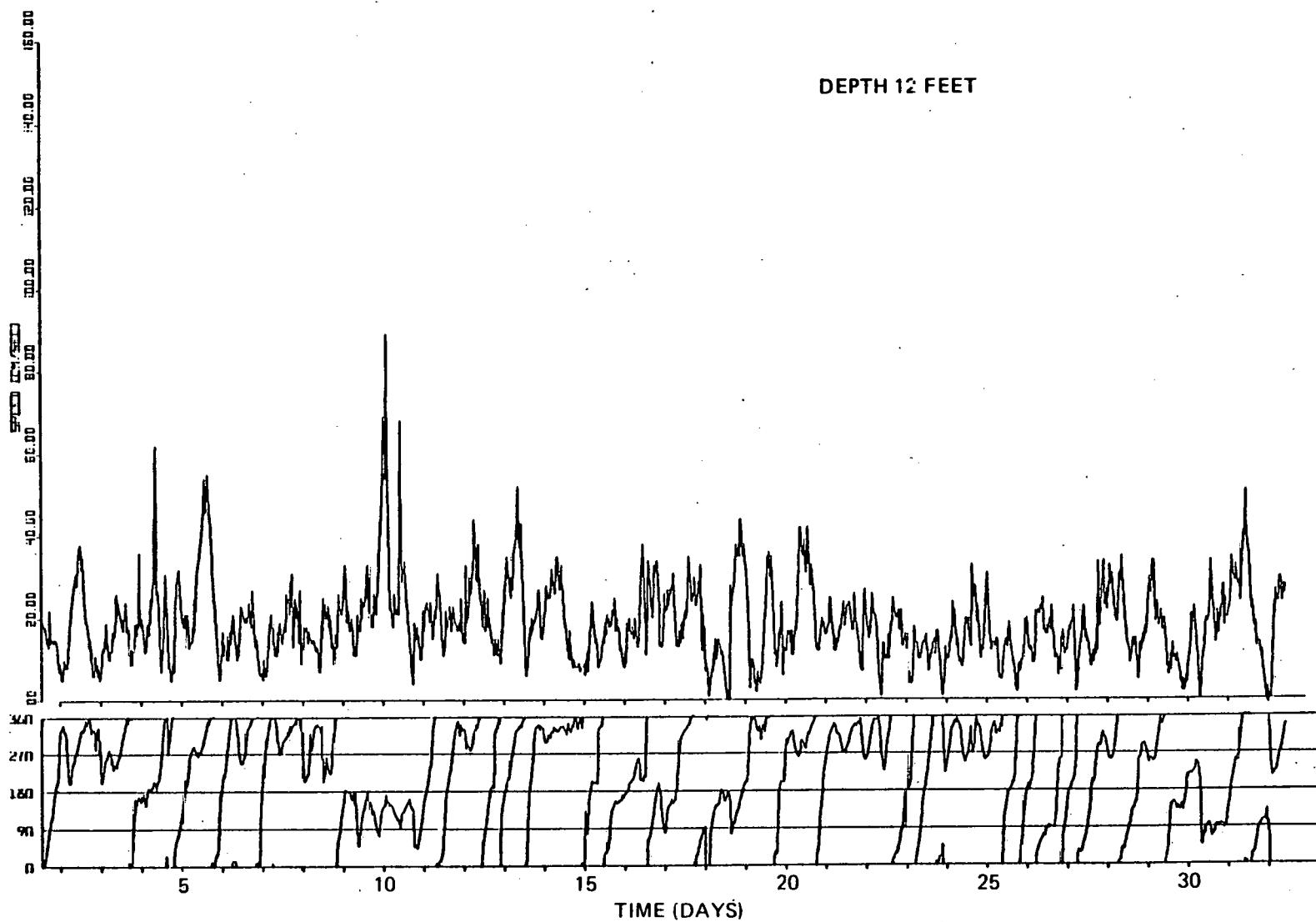
FIGURE 2-27   Speed histogram and directional plot of currents measured at Weeks Island Site B, March 1978.

DEPTH 12 FEET

NORTH

ONSHORE

EAST

ALONGSHORE

TIME (DAYS)

.00   25.00   50.00

SPEED SCALE (cm/sec)
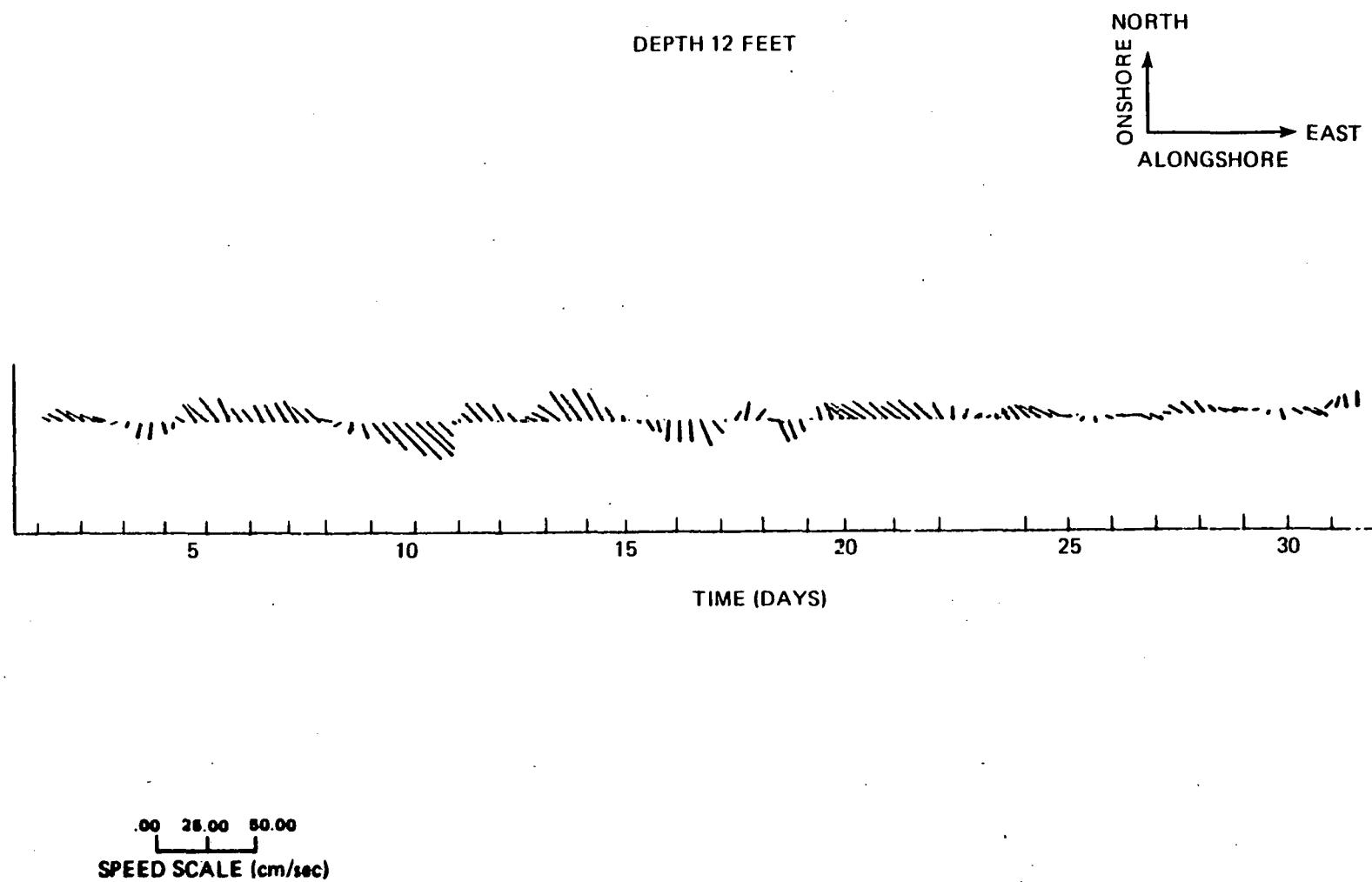
FIGURE 2-28   Averaged vector time series for Weeks Island Site B, March 1978.
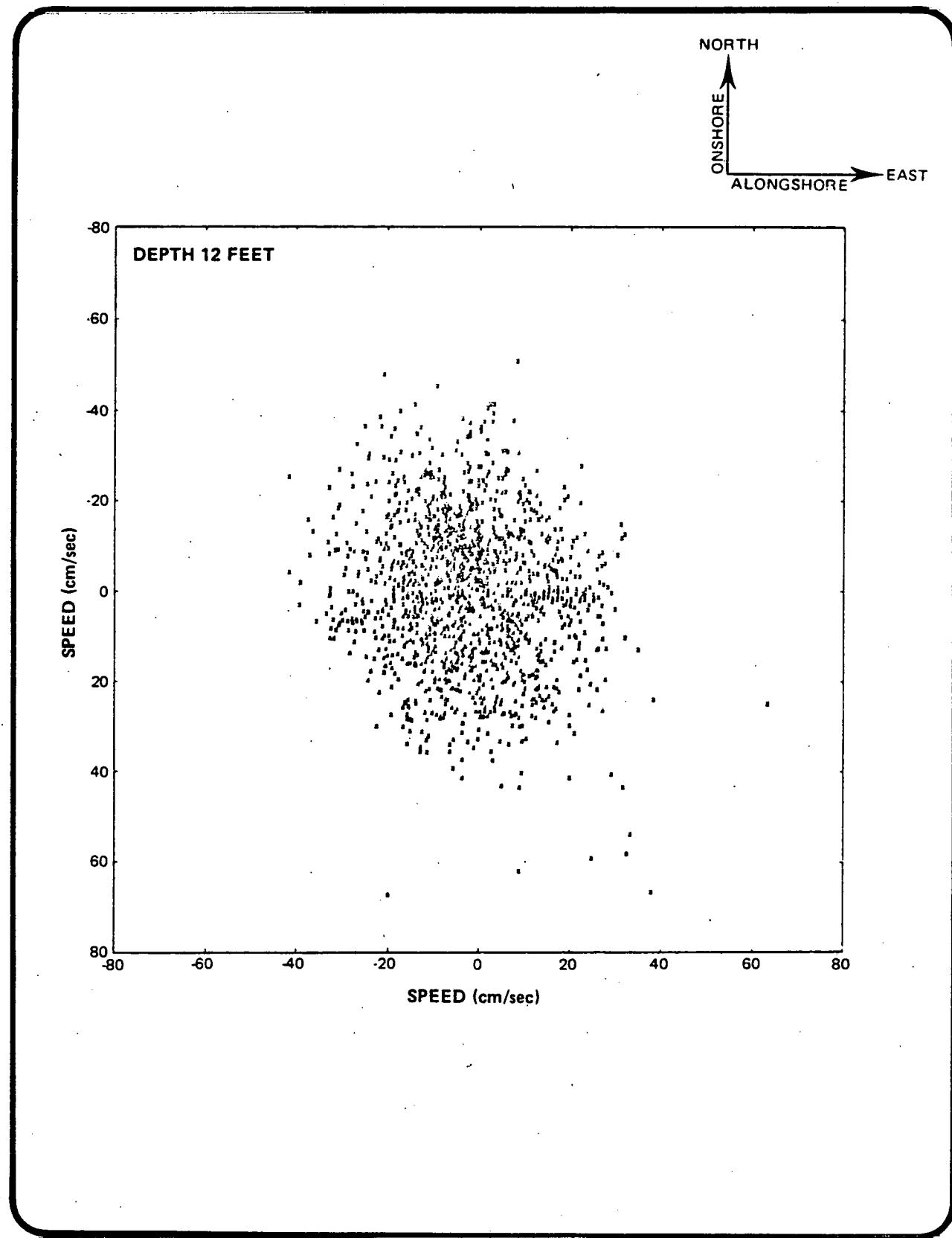
FIGURE 2-29   Velocity scatter plot for Weeks Island Site B, March 1978.
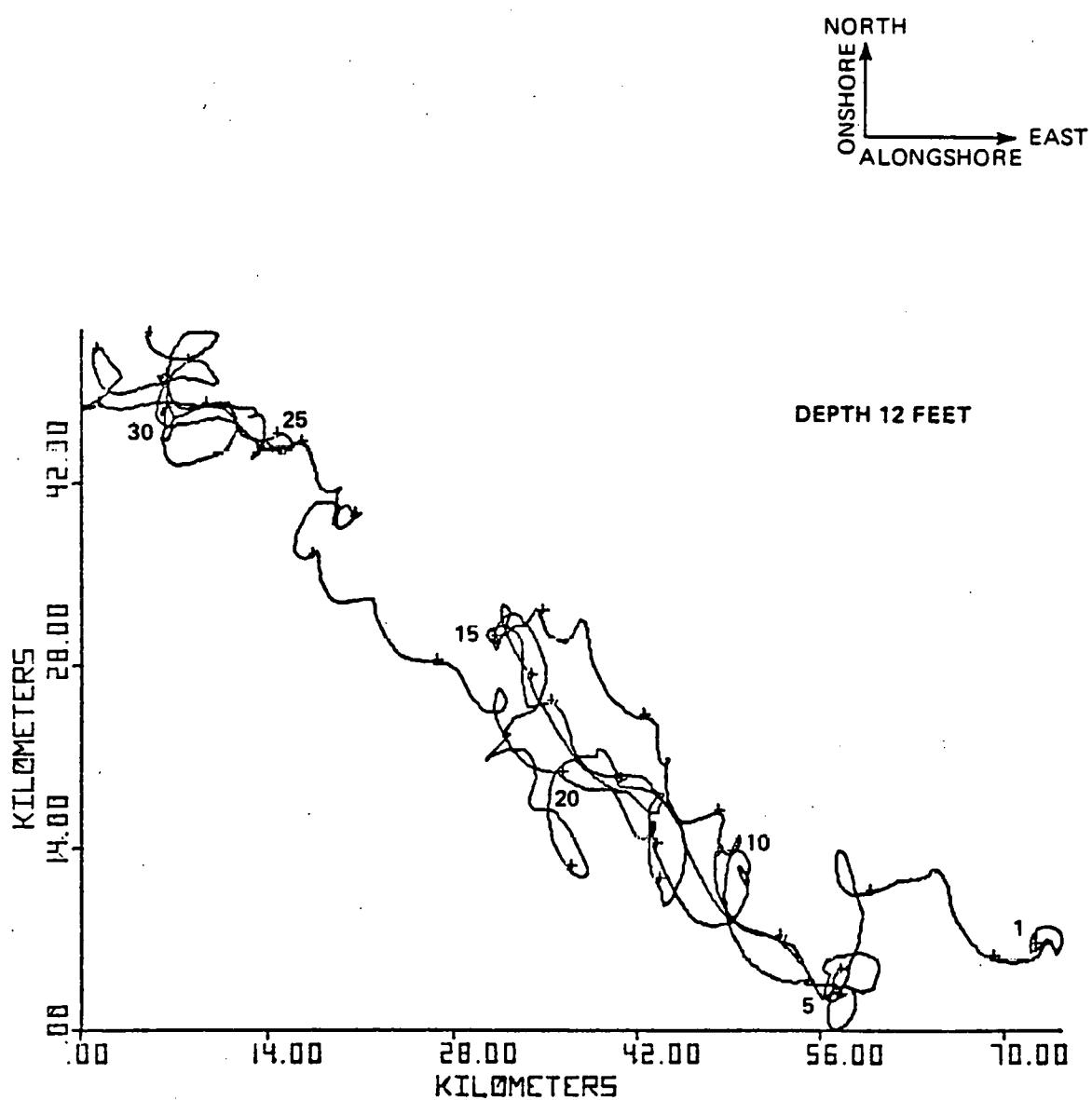
FIGURE 2-30   Progressive vector diagram for Weeks Island Site B, March 1978 (numbers represent days of the month).

rotary tidal circulation tends to obscure some of the fine detail of the record.

Current data collected from March 18 to 31 showed a very homogenous flow field between the 17- and 21.5-foot (5.2- and 6.6-meter) water depths (Figure 2-31). Current speeds were generally less than 1.3 ft/sec (40 cm/sec). The beginning of the record is dominated by alternating periods of generally southeasterly flow on March 19, 25, and 26, and westerly flow from March 20 to 24. The latter portion of the month was dominated by rotary tidal circulation.

Wind data obtained during late March showed that the southeasterly and westerly flow intervals discussed above coincided with sustained winds (10 to 30 mph) from the northwest and east, respectively. The vector time-series (Figure 2-32) show the southeasterly and northwesterly flow patterns during the month. There is a close correlation between the currents measured at the two depths--17 and 21.5 feet (5.2 and 6.6 meters). The scatter diagrams for this portion of the month, however, are slightly different. The regular-shaped ellipse at the 17-foot depth has a northwest-southeast trending principal axis; however, the broad rounded ellipse at the 21.5-foot depth has a principal axis that is not easily discernible (Figure 2-33). From this diagram, it appears that the westerly components of the currents at 21.5 feet were stronger than those at 17 feet.

The PVD also indicates stronger westerly flow at 21.5 feet (6.6 meters), though both records show a net drift to the west-southwest (Figure 2-34). The net displacement at 17 feet (5.2 meters) is only 5.6 miles (9 kilometers); the net displacement at 21.5 feet is 18.6 miles (30 kilometers). Examination of the record shows consistent current patterns until March 27. A stronger westerly drift superimposed on the tidal circulation at 21.5 feet during the last 4 days of the month caused the greater net displacement. One possible explanation for this behavior would be the light (10 mph) variable winds measured from March 27 to 31. They could have reduced or reversed the surface currents while the deeper waters continued to flow westward, initiating a short two-layer flow regime.
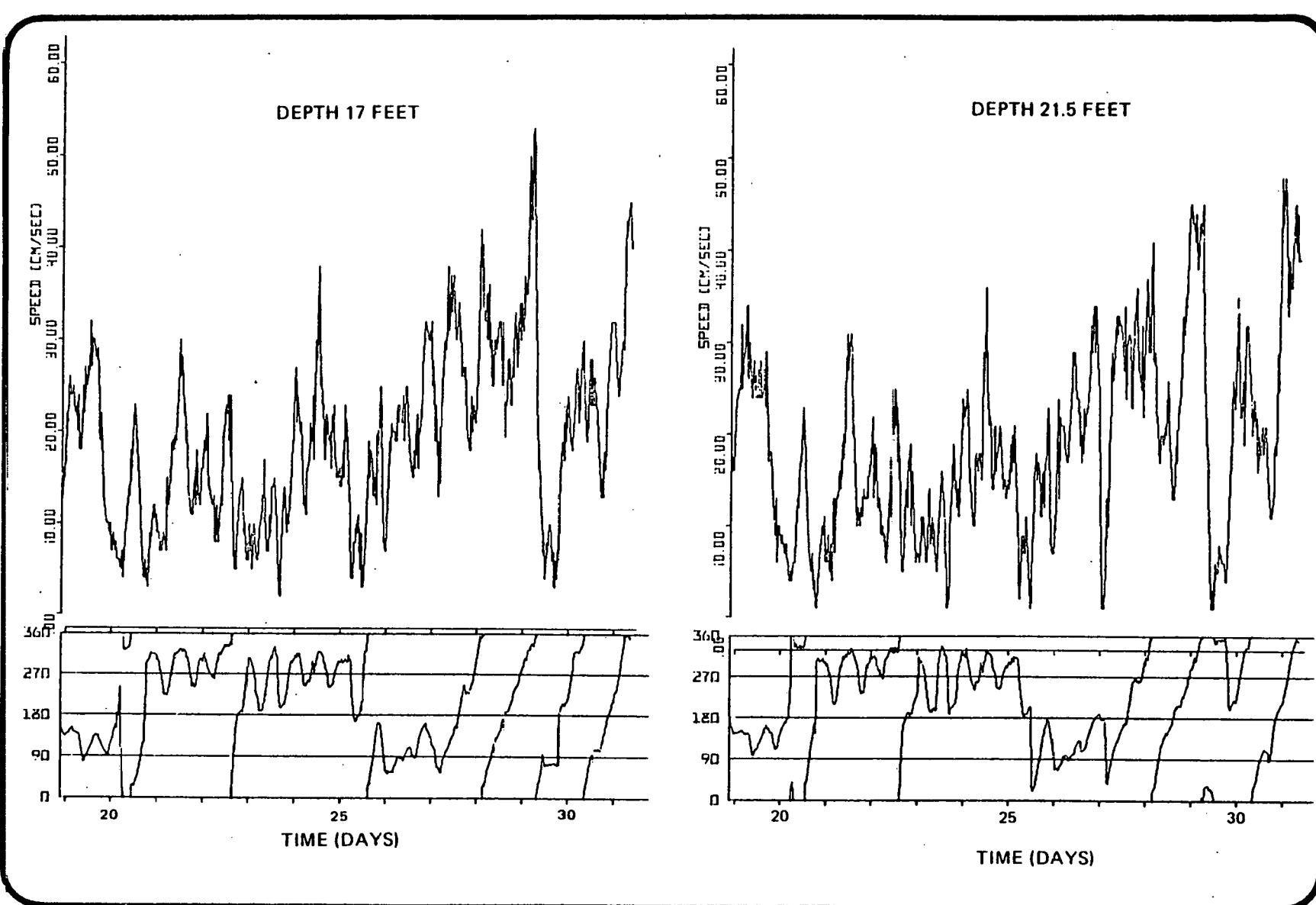
FIGURE 2-31   Speed histograms and directional plots of currents measured at Weeks Island Site B, March 18-31, 1978.
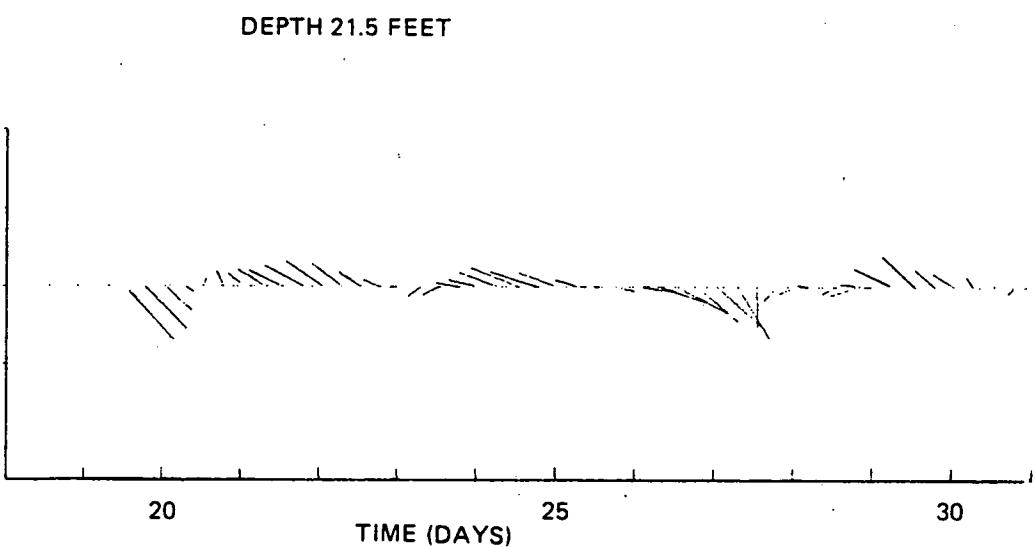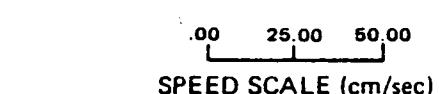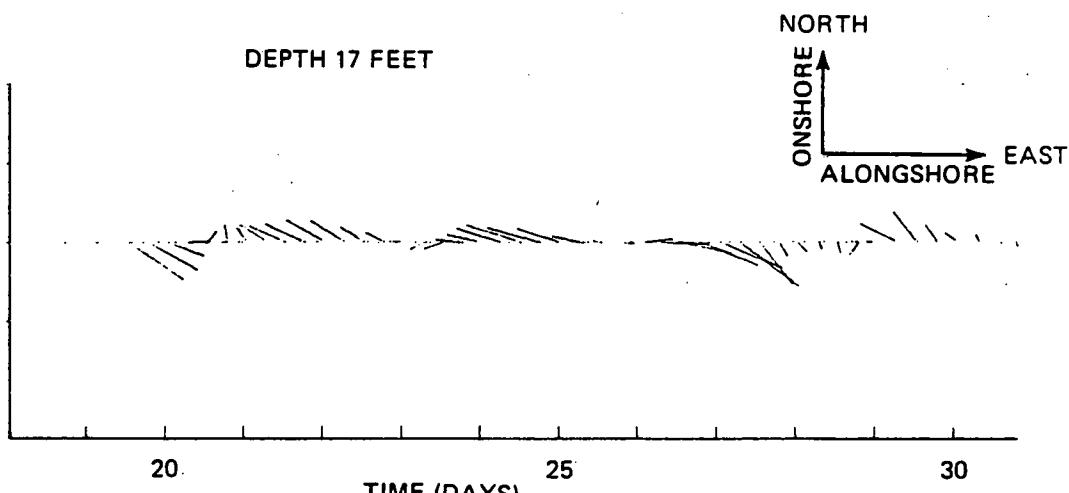
FIGURE 2-32   Averaged vector time series for Weeks Island Site B,
               March 18-31, 1978.
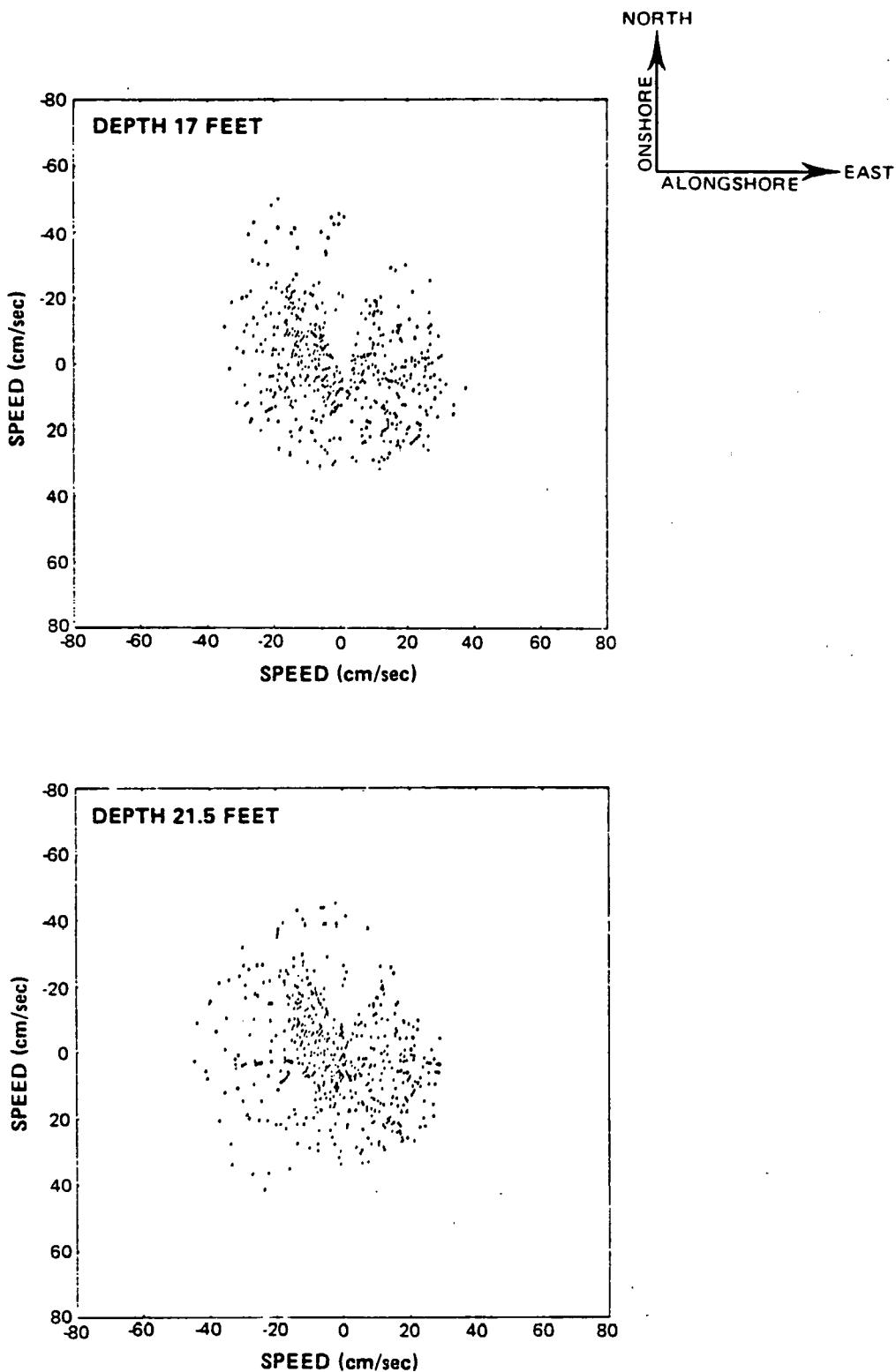
FIGURE 2-33   Velocity scatter plots for Weeks Island Site B, March 18-31, 1978.
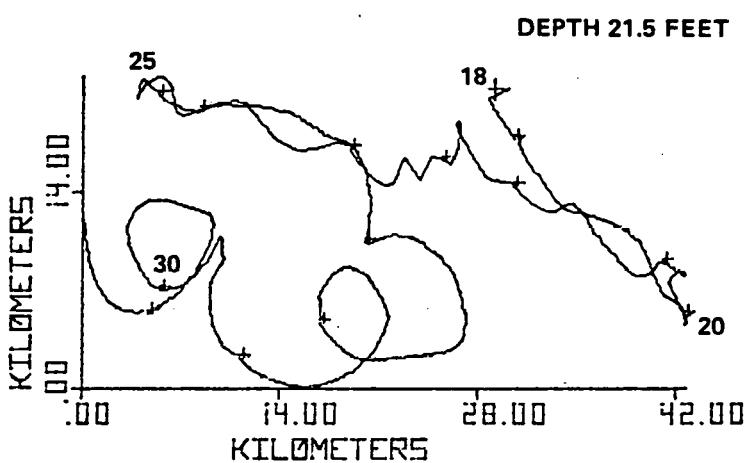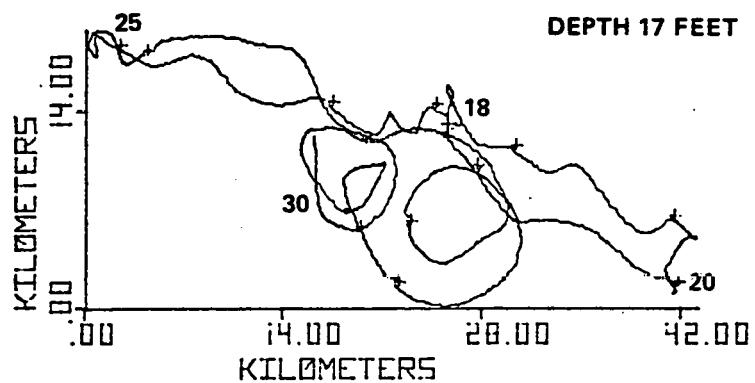
FIGURE 2-34   Progressive vector diagrams for Weeks Island Site B, March 18-31, 1978 (numbers represent days of the month).

2.2.6.2.6 April (Weeks Island Site B)

Relatively calm conditions existed during April. Current speeds attained a maximum of 2 ft/sec (60 cm/sec) on April 22, but generally ranged from 0.15 to 1.3 ft/sec (5 to 40 cm/sec), (Figure 2-35). Comparison of the two records shows slightly lower current speeds at 21.5 feet (6.6 meters) than at 17 feet (5.2 meters). Variations in current direction are insignificant, suggesting that the flow field is homogenous and that the speed attenuation is due to shear stress and does not represent two-layered flow. . The majority of the record shows northwesterly flow which is interrupted several times by rotary tidal circulation. The brief anomalous break in the record on April 21 represents a current meter servicing interval. Monthly wind data show predominantly southeast winds at an average speed of 10 to 20 mph. Therefore, the northwesterly drift appears to be wind-driven.

The vector time-series for April (Figure 2-36) reflects the slightly lower current velocities at 21.5 feet (6.6 meters) and very good directional correlation. The only major deviation in direction occurs on April 22, when the water is moving northwestward at 17 feet (5.2 meters) and west-northwestward at 21.5 feet. The April scatter diagrams (Figure 2-37) exhibit broad rounded ellipses, both with a greater concentration of data points in the northwest quadrant--which also appears to be the direction of the principal axis. An arc 33° to 35° wide, with very few data points, is discernible in the northerly direction. This could represent a magnetic disturbance affecting both meters or an instrument malfunction. It is not likely that it would represent actual current behavior.

The two PVD's show a net displacement of 154 and 128 miles (248 and 207 kilometers) to the northwest (Figure 2-38). There is a steady northwesterly drift during the first 18 days of the month. The direction reverses to the southeast from April 18 to 20, before continuing again to the northwest (April 21 to 25). From April 26 to 30, the drift direction varies slightly between the two water depths, but generally reverses to the southeast and again to the northwest.
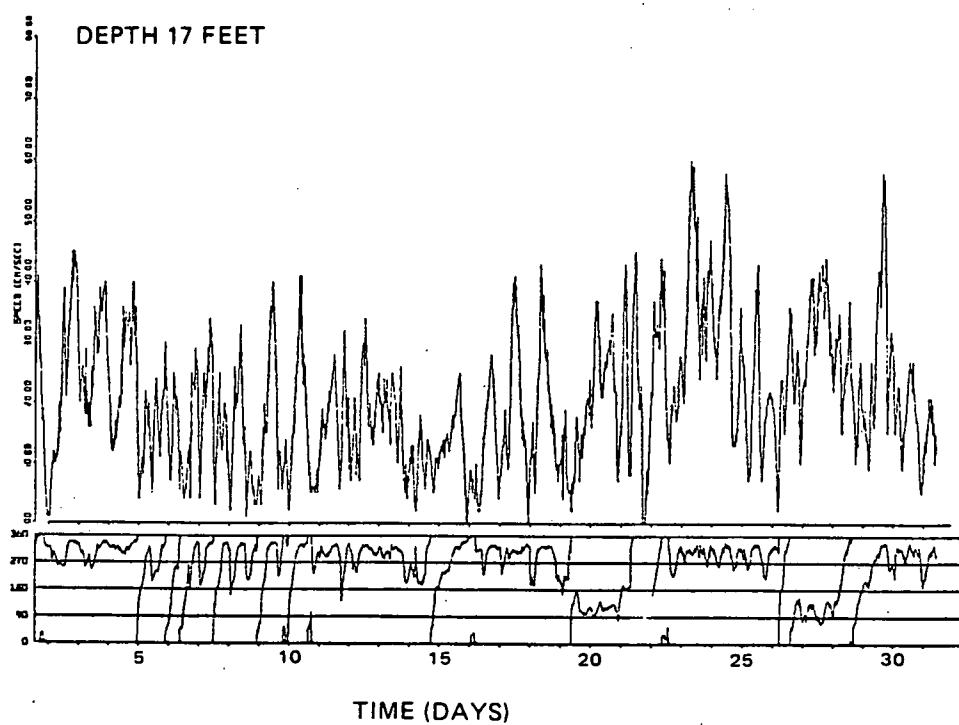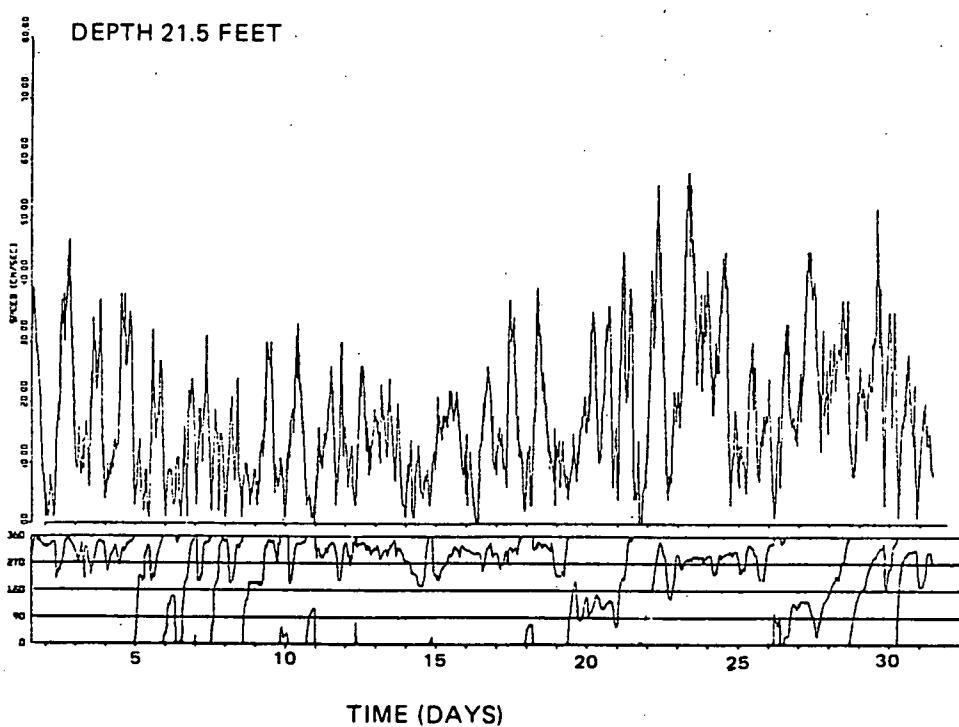
FIGURE 2-35   Speed histograms and directional plots of currents measured at
Weeks Island Site B, April 1978.
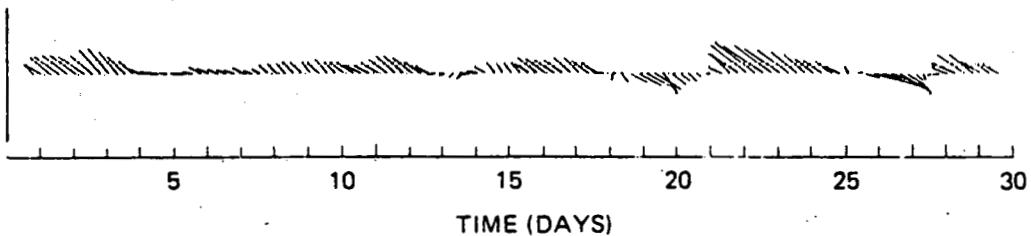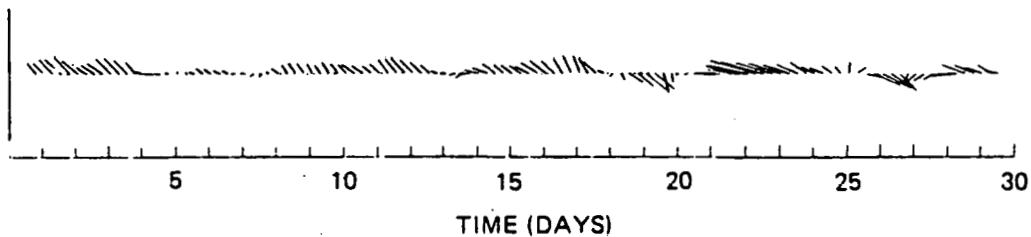
FIGURE 2-36   Averaged vector time series for Weeks Island Site B,
April 1978.

2-72
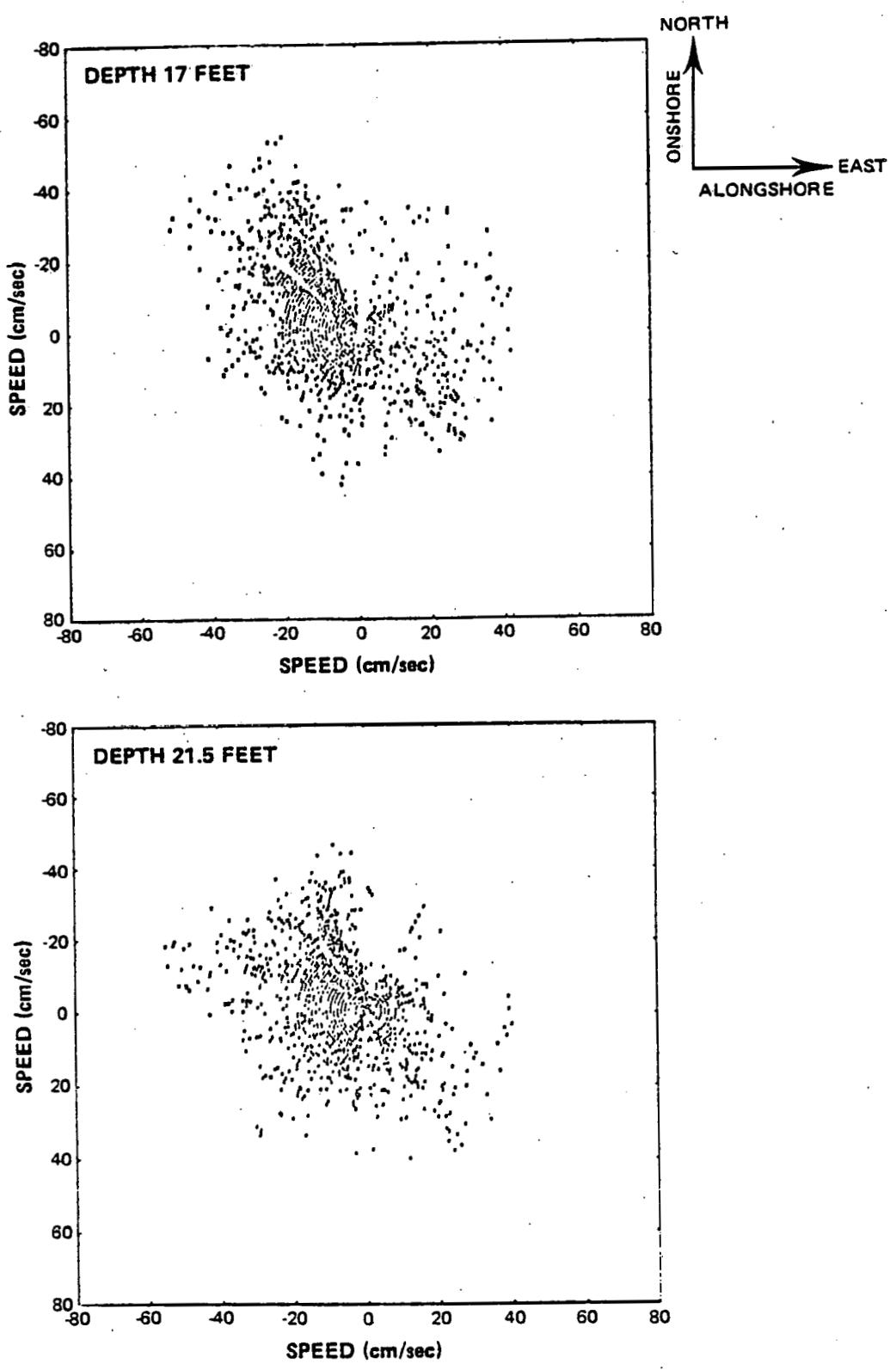
FIGURE 2-37   Velocity scatter plots for Weeks Island Site B, April 1978.
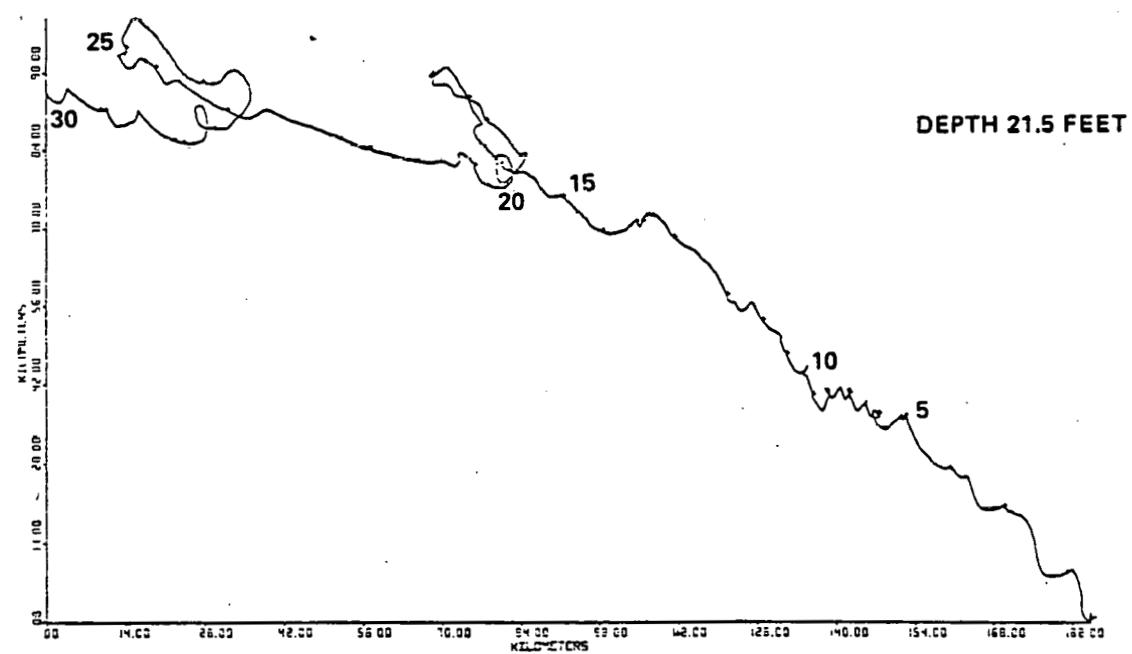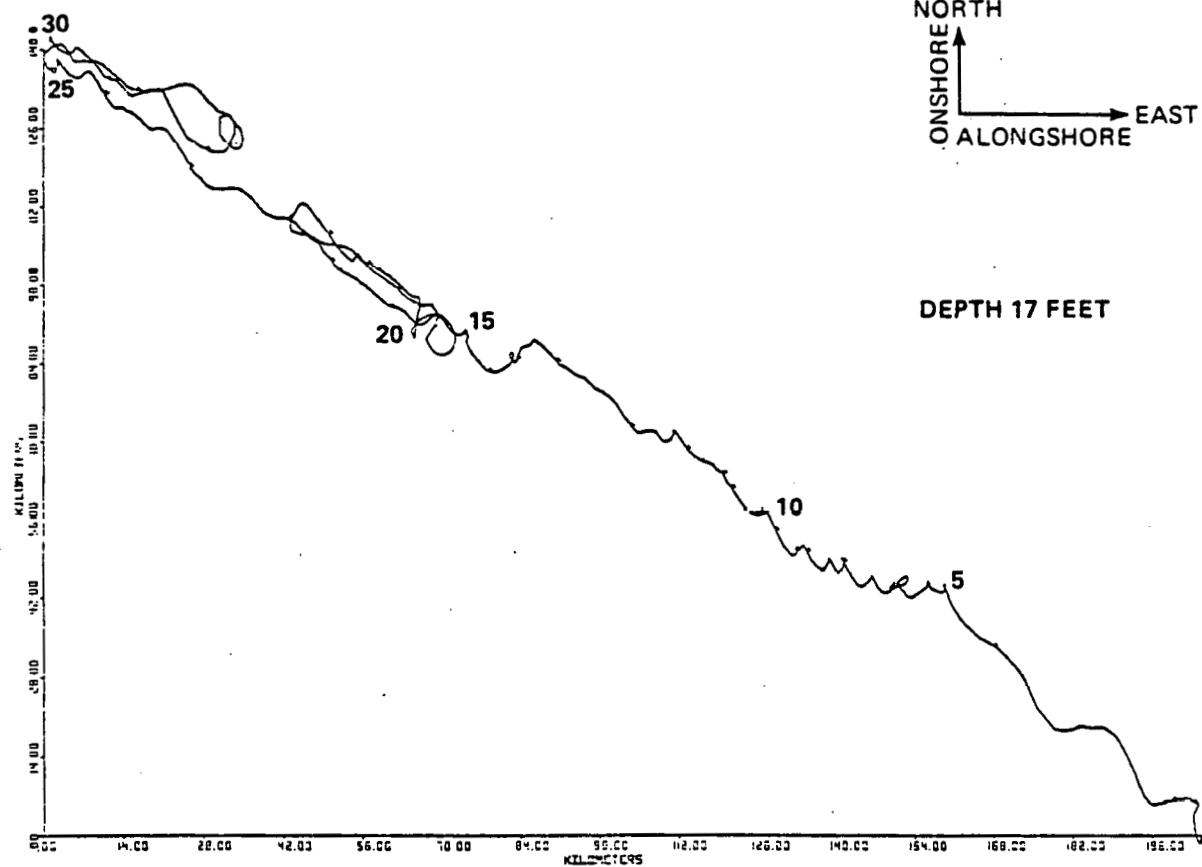
FIGURE 2-38 Progressive vector diagrams for Weeks Island Site B, April 1978 (numbers represent days of the month).

2.2.6.2.7 May (Weeks Island Site B)

The relatively calm conditions that existed in April continued throughout May. Current speeds generally ranged from 0.15 to 1.3 ft/ sec (5 to 40 cm/sec) with slightly higher speeds at 17 feet (5.2 meters) than at 21.5 feet (6.6 meters), (Figure 2-39). The maximum recorded current speed was 2.03 ft/sec (62 cm/sec) on May 7. Two extended periods of northwesterly flow were measured at 17 feet (May 6 to 13 and 23 to 31). The current at a depth of 21.5 feet shows an overall northwesterly flow, but is not as consistent as the record at 17 feet-- possibly because of shear stresses within the water column.

The general circulation in May also appears to be wind-driven. Although there was no data for the immediate site vicinity for the month of May, wind and wave data obtained further west from the site showed that wind speeds ranged from 20 to 30 mph and were consistently from the southeast. Wind speeds at Site B, however, may have differed slightly. Historical data for the vicinity showed a mean monthly wind speed of 10.4 knots and wave heights which generally ranged from 2 to 12 feet (0.6 to 3.7 meters).

The vector time-series (Figure 2-40) illustrates the speed and directional differences at the two water depths. There is a significant reduction in current speed at 21.5 feet (6.6 meters), but the directional differences are minor.

The two scatter-diagrams (Figure 2-41) exhibit regular ellipses with a northwest-southeast trending principal axis. Two arcs 22° to 24° wide, with a northeast orientation and few data points, indicate a possible malfunction. The PVD's developed for May (Figure 2-42) show net displacements of 186 and 122 miles (299 and 196 kilometers) to the northwest (Table 2-13). During the month, there were two episodes (May 4 to 6 and 13 to 17) of reversing drift direction to the east and southeast that are reflected at both depths.

2.2.6.2.8 June (Weeks Island Site B)

The current record during the month of June shows a significant reduction in current speeds, which were slightly higher at 17 feet (5.2 meters) than at 21.5 feet (6.6 meters), but generally ranged from

DEPTH 17 FEET
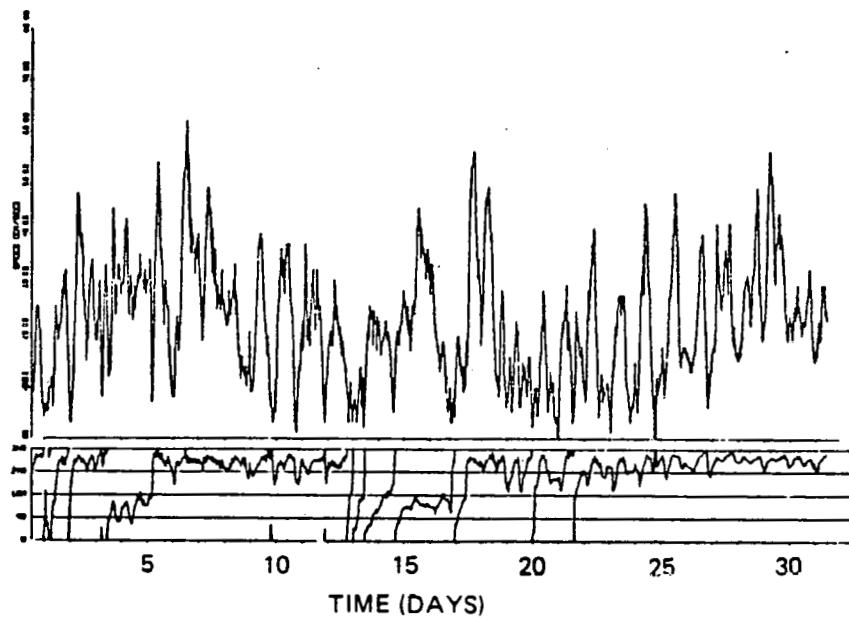
TIME (DAYS)

DEPTH 21.5 FEET
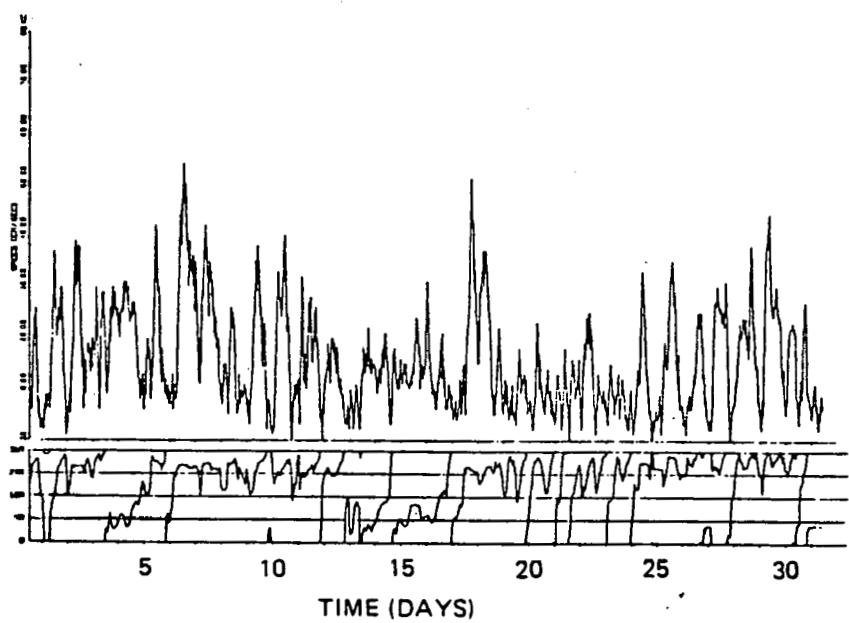
TIME (DAYS)

FIGURE 2-39   Speed histograms and directional plots of currents measured at
Weeks Island Site B, May 1978.

NORTH

ONSHORE

EAST

ALONGSHORE

DEPTH 17 FEET

5   10   15   20   25   30

TIME (DAYS)

DEPTH 21.5 FEET

5   10   15   20   25   30
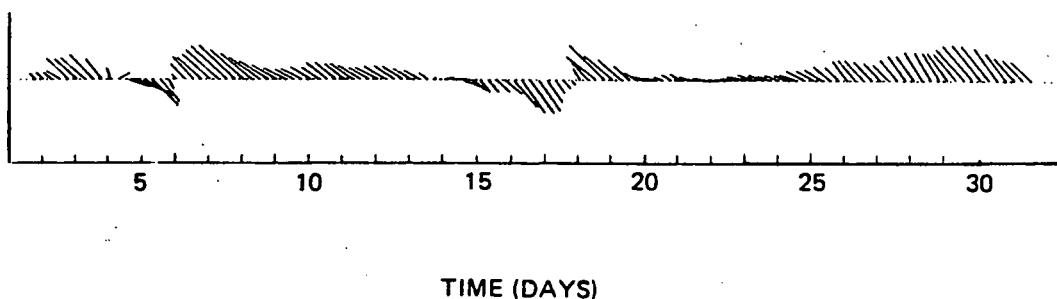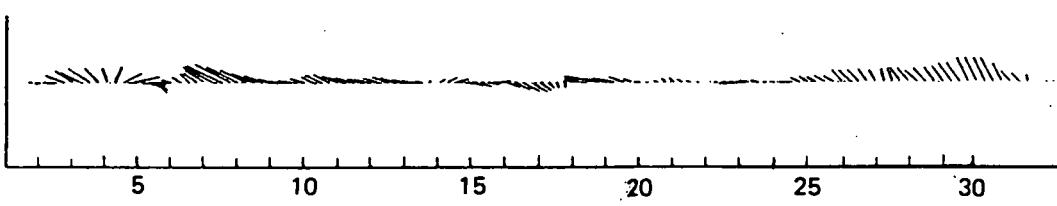
TIME (DAYS)

0 25 50

SPEED SCALE (cm/sec)

FIGURE 2-40   Averaged vector time series for Weeks Island Site B, May 1978.

2-77
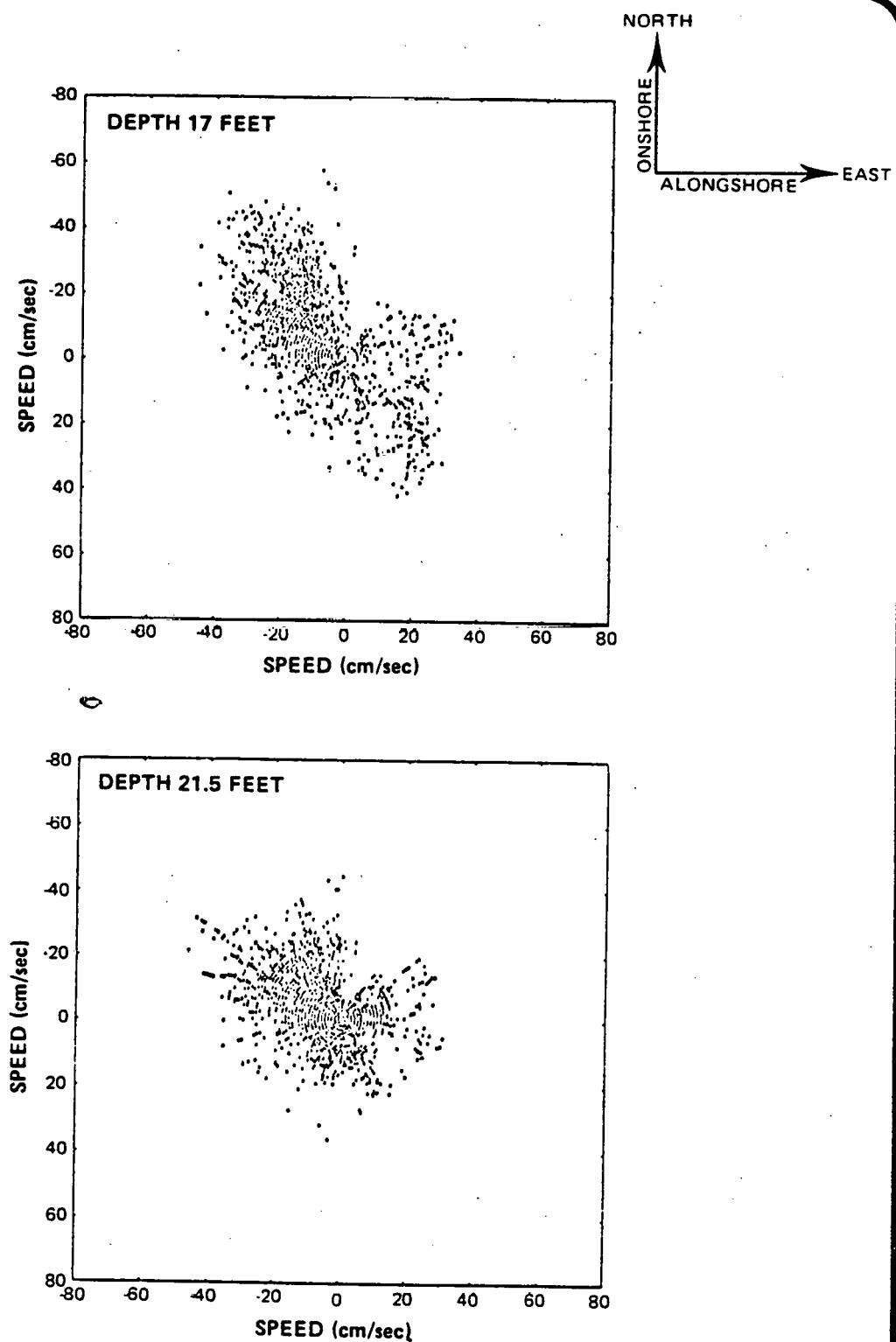
FIGURE 2-41   Velocity scatter plots for Weeks Island Site B, May 1978.
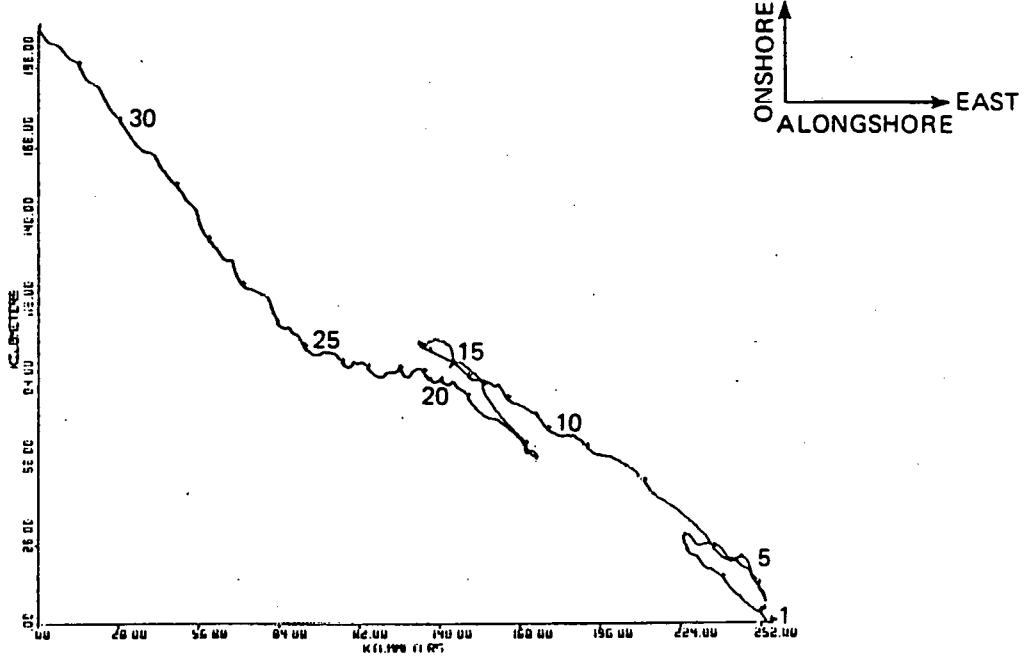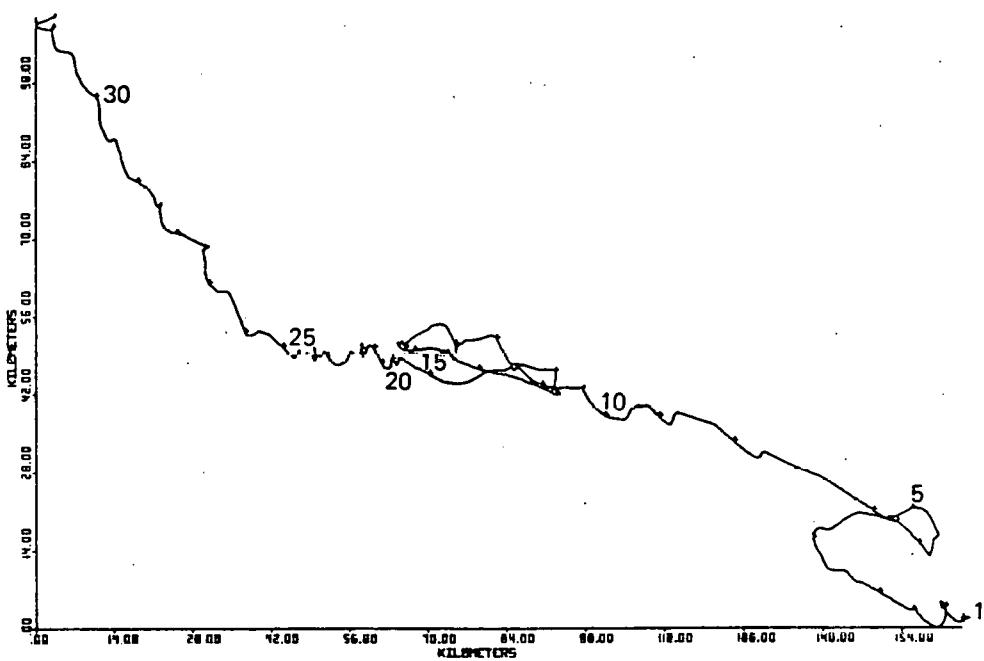
FIGURE 2-42   Progressive vector diagrams for Weeks Island Site B, May 1978
(numbers represent days of the month).

DEPTH 17 FEET

TIME (DAYS)

DEPTH 21.5 FEET

TIME (DAYS)
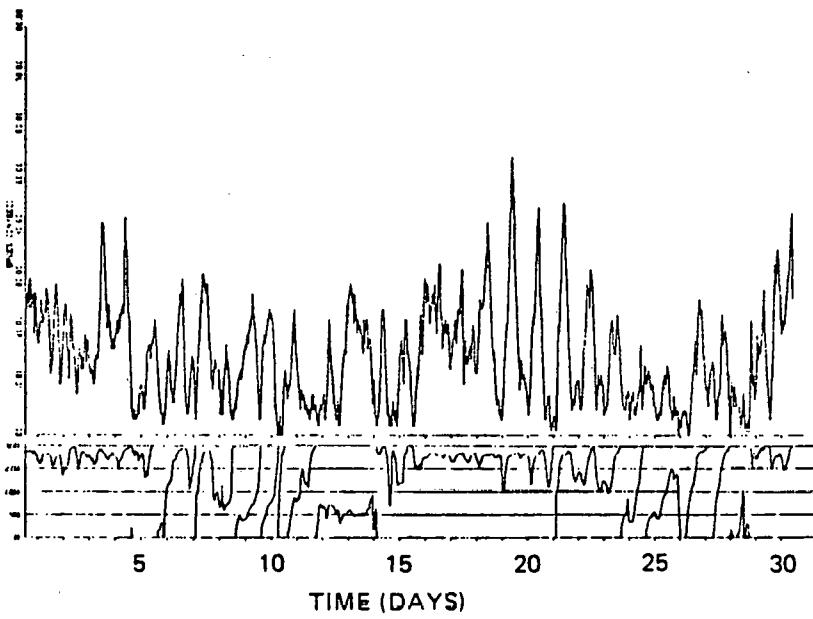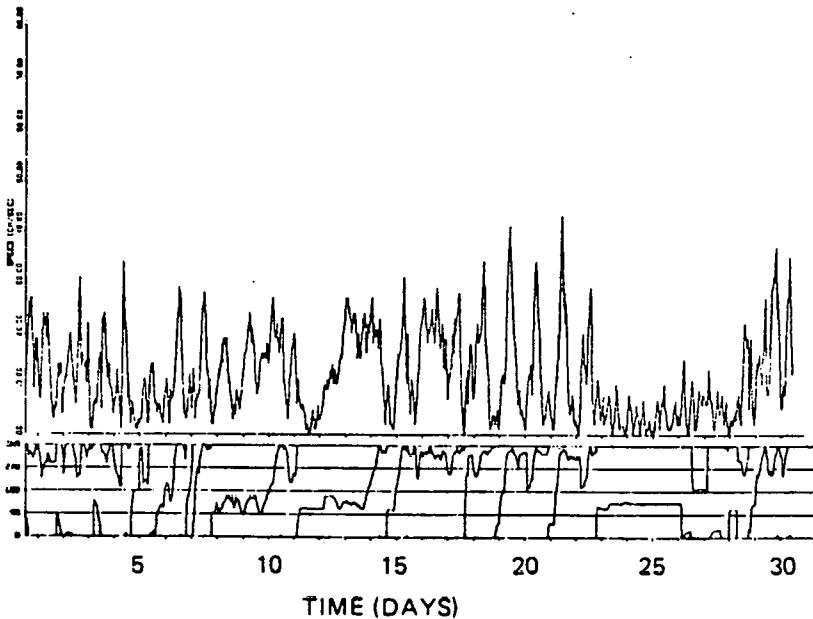
FIGURE 2-43   Speed histograms and directional plots of currents measured at
Weeks Island Site B, June 1978.

less than 0.15 to 1 ft/sec (5 to 30 cm/sec), (Figure 2-43). There are several differences in measured direction between the two water depths. On June 9 and 10, the record at 17 feet reflects rotary tidal circulation; the record at 21.5 feet, however, reflects southeasterly flow. The anomalous directional readings at 21.5 feet from June 24 to 28 could be caused by a compass malfunction, or the extremely low current speeds (0 to 0.15 ft/sec (0 to 5 cm/sec)) recorded during this time interval may not have been sufficient to orientate the current meter into the direction of flow. On June 28, the current meters were serviced and replacement meters were installed.

Wind speeds were generally less than 20 mph. Wind direction varied but most frequently was from the west. This differs from the normal monthly mean direction (southeast) as listed in Table 2-3. The most significant event during the month was very low current speeds < 0.3 ft/sec (< 10 cm/sec)) measured from June 24 to 29. Wind speed during this interval was usually less than 10 mph. Wind direction was variable, but did not coincide with current flow direction. Currents were largely influenced by tides.

Although the range of current speeds was greater at 17 feet (5.2 meters), the vector time-series (Figure 2-44) show uniformly higher average velocities at 21.5 feet (6.6 meters), particularly in the southeasterly direction (Figure 2-45). The comparative size of the two ellipses shows a small dense ellipse at the 17-foot level and a much broader ellipse at the 21.5-foot level. The orientation of the principal axis of both ellipses trends northwest-southeast.

The PVD's (Figure 2-46) for June show net displacements of 128 and 98 miles (206 and 158 kilometers) to the northwest (Table 2-13). The reversal in drift direction to the southeast (June 10 to 16), as recorded by the current meter at the 21.5-foot (6.6 meter) depth, is much greater (due to the stronger currents as discussed above) than the easterly flow recorded by the meter at the 17-foot (5.2-meter) depth.

2.2.6.2.9 July (Weeks Island Site B)

The current monitoring program was terminated at Weeks Island on July 10. Current speeds during the previous 10 days rarely exceeded

NORTH

ONSHORE

EAST

ALONGSHORE

DEPTH 17 FEET

5   10   15   20   25   30

TIME (DAYS)

DEPTH 21.5 FEET

5   10   15   20   25   30

TIME (DAYS)
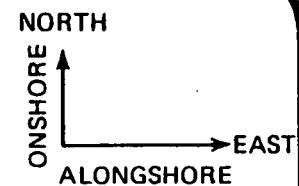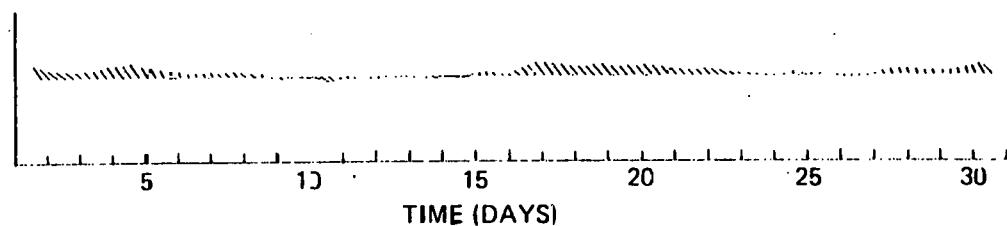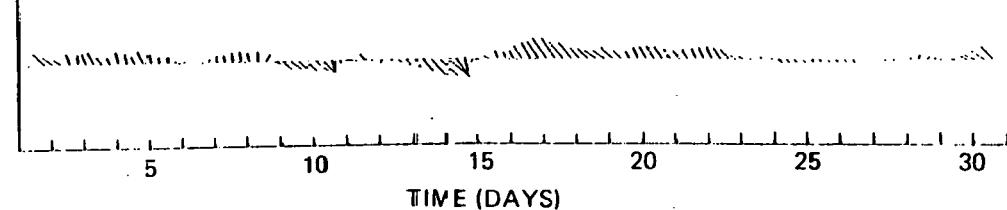
0 25 50

SPEED SCALE (cm/sec)

FIGURE 2-44   Averaged vector time series for Weeks Island Site B, June 1978.
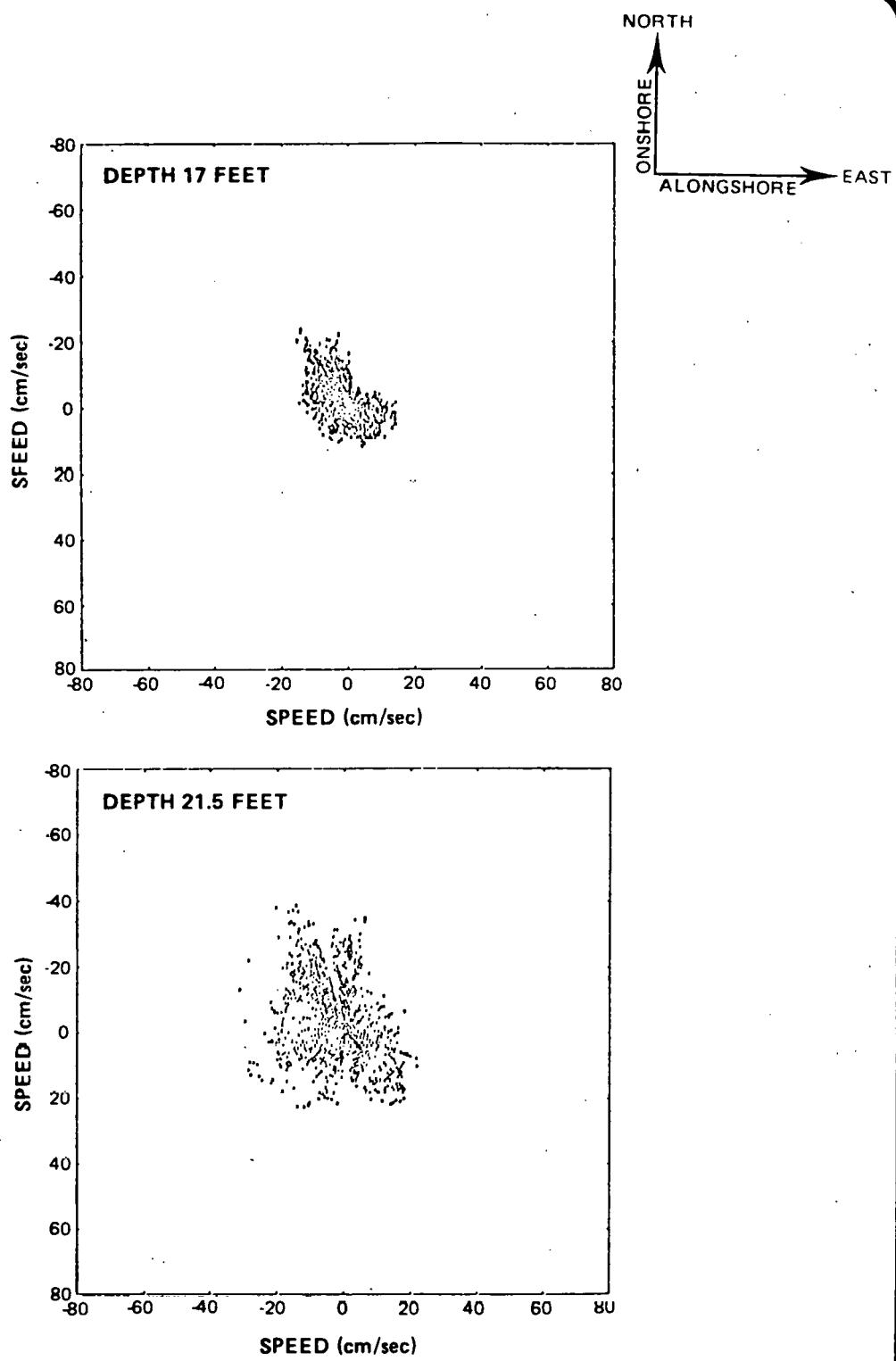
FIGURE 2-45   Velocity scatter plots for Weeks Island Site B, June 1978.
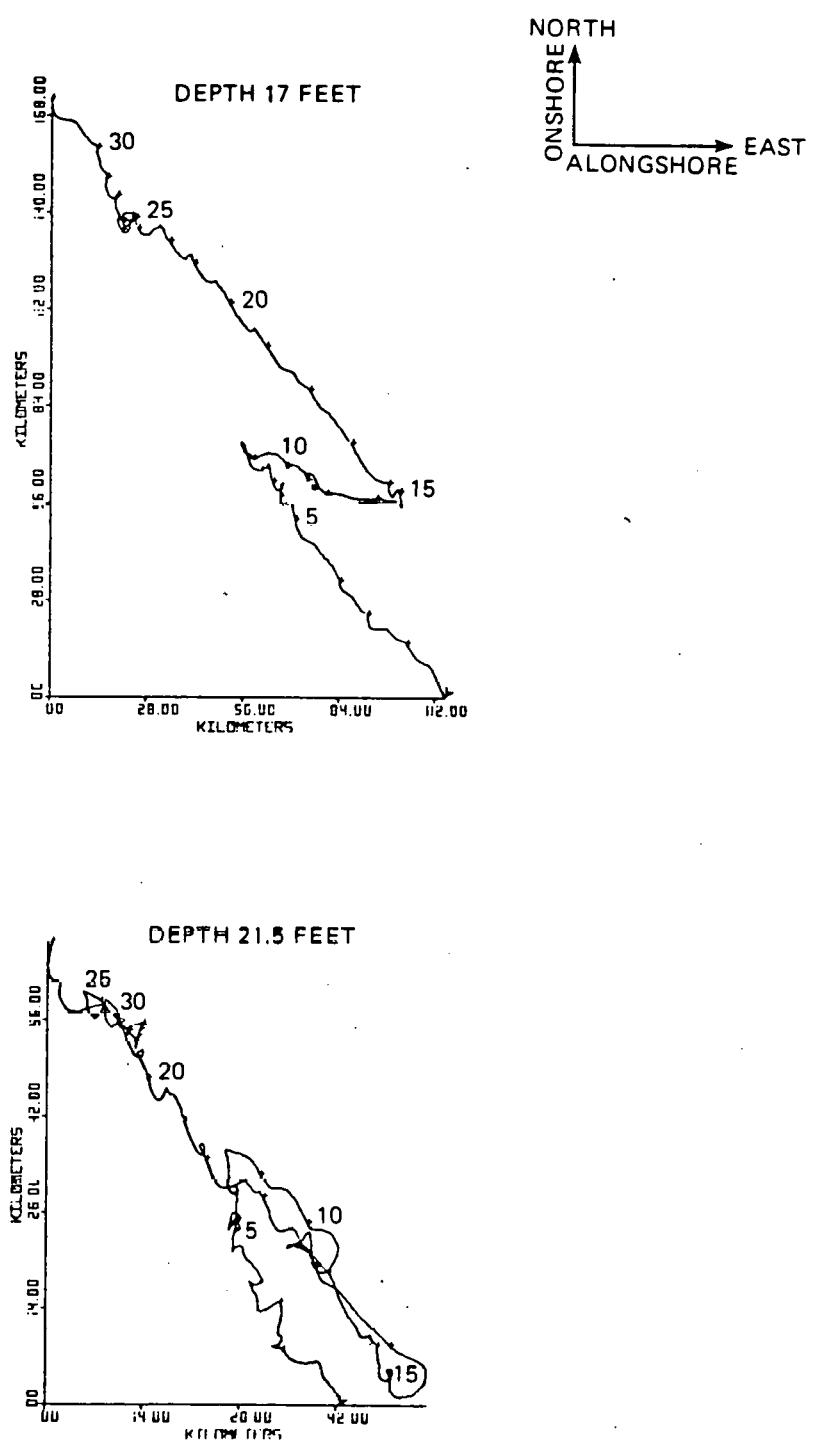
FIGURE 2-46   Progressive vector diagrams for Weeks Island Site B, June 1978
(numbers represent days of the month).

DEPTH 17 FEET

SPEED (CM/SEC)

TIME (DAYS)

DEPTH 21.5 FEET

SPEED (CM/SEC)

TIME (DAYS)
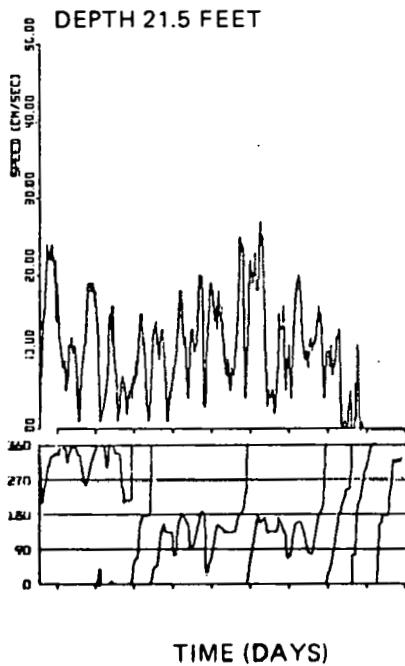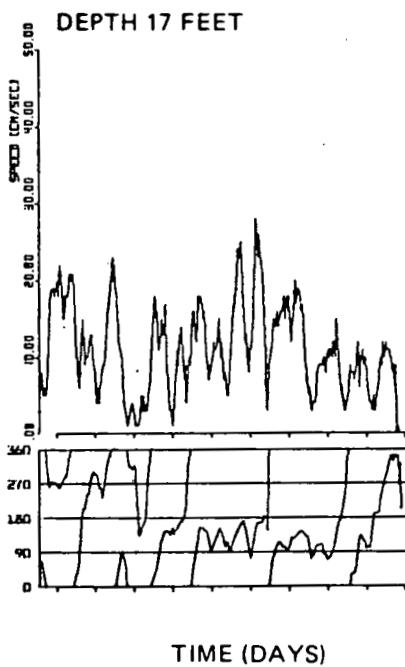
FIGURE 2-47   Speed histograms and directional plots of currents measured at
Weeks Island Site B, July 1-10, 1978.

0.6 ft/sec (20 cm/sec), (Figure 2-47). Southeasterly flow dominated the current record from July 4 to 6 and from 7 to 8.

Wind data collected at the site indicate that light winds, generally less than 10 mph prevailed. Wind direction was from the northeast until July 6; then it shifted to the southeast for 2 days and to the west-north-west for 2 days. Therefore, the July circulation does not appear to be wind-driven.

For example, the vector time-series (Figure 2-48) shows that the currents had consonant current behavior at the two depths, with a predominant southeasterly flow. The magnitude of the vectors at 21.5 feet (6.6 meters), however, was slightly less than that at 17 feet (5.2 meters) depth. The two scatter diagrams form regular-shaped ellipses (Figure 2-49). The principal axis at the 17-foot depth is oriented north-northwest/south-southeast; at the 21.5-foot depth, the principal axis trends northwest-southeast. Figure 2-50 shows the currents had net displacements of 19 and 14 miles (30 and 22 kilometers) to the southeast.

Therefore, the reversal in the net drift direction to the southeast from the northwest in early July may be due to a detached eddy of the Loop Current which has migrated into the study area. It could also mark the transition to a summertime easterly drift current as reported by Murray (1976).

2.2.6.3 Drogue Study

A cursory drogue study was undertaken on November 16 and December 2, 1977. The mean current drift on November 16 was consistently west-northwest. On December 2, the drift direction varied from southwest to west-northwest. Neither of these studies was of long enough duration to distinguish acute tidal influences from long-term drift.

2.2.6.4 Summary

A 10-month program (October 1977 to July 1978) to measure water current velocities at Week Island Sites A and B located on the inner continental shelf of southwestern Louisiana has shown that a prevailing northwesterly drift occurred throughout most of the year. Maximum current speeds of 2.6 to 4.6 ft/sec (80 to 140 cm/sec) were measured during winter storms. Minimum current speeds of 0.0 to 1.0 ft/sec (0 to

DEPTH 17 FEET

NORTH

ONSHORE

EAST
ALONGSHORE

5
TIME (DAYS)

10

DEPTH 21.5 FEET

5
TIME (DAYS)

10

.00   25.00   50.00

SPEED SCALE (cm/sec)
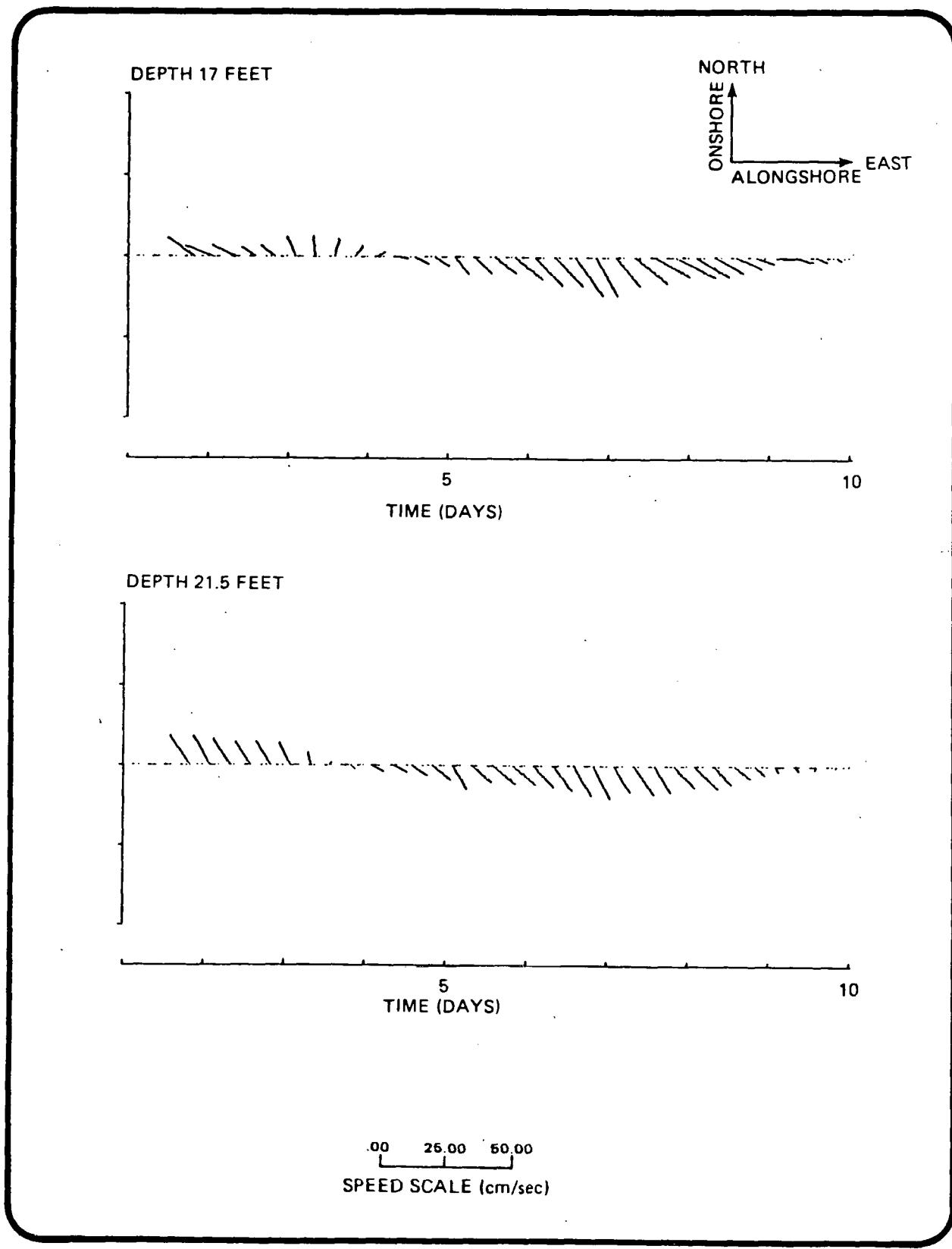
FIGURE 2-48   Averaged vector time series for Weeks Island Site B,
                July 1-10, 1978.
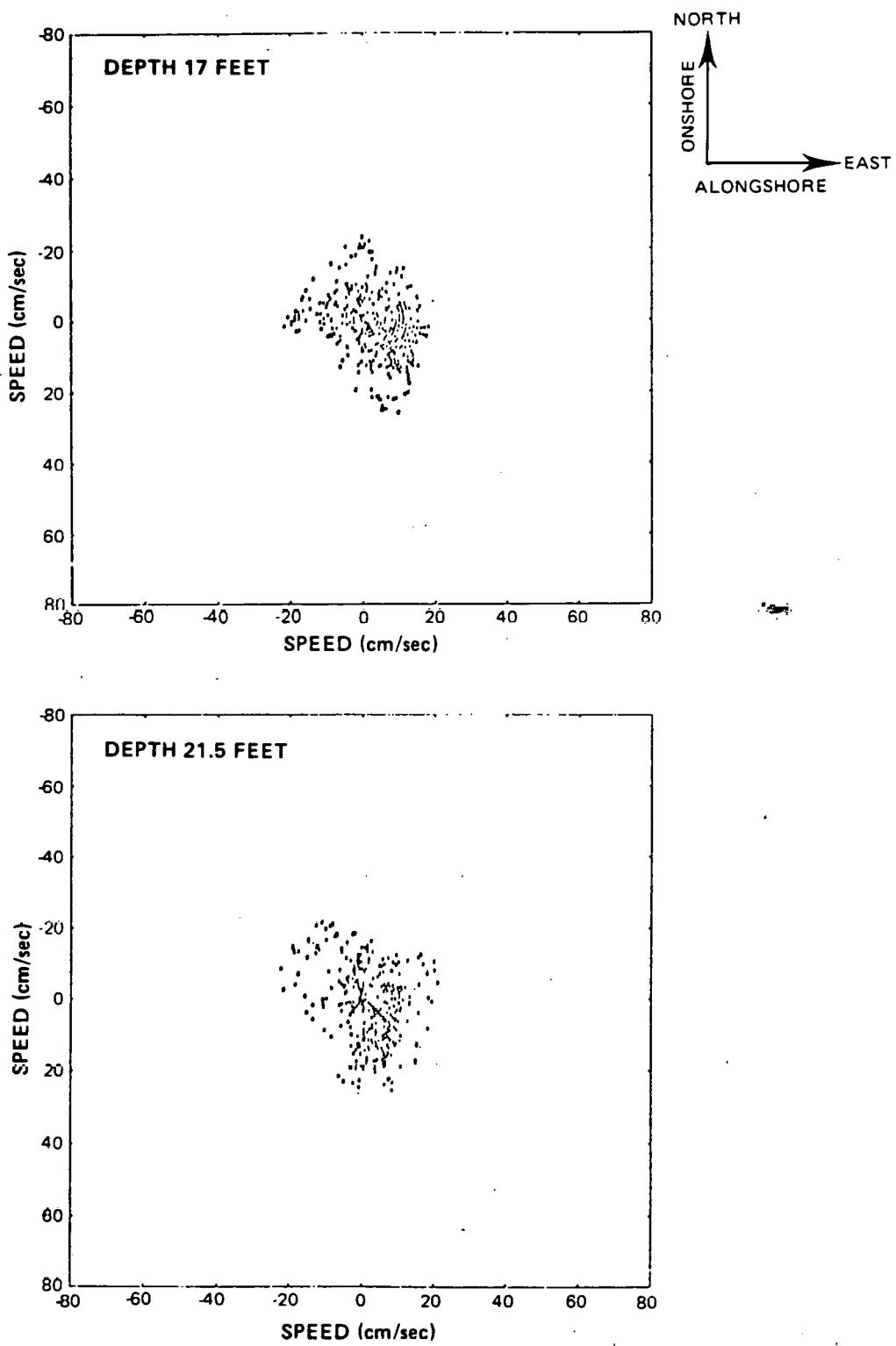
FIGURE 2-49   Velocity scatter plots for Weeks Island Site B, July 1-10, 1978.
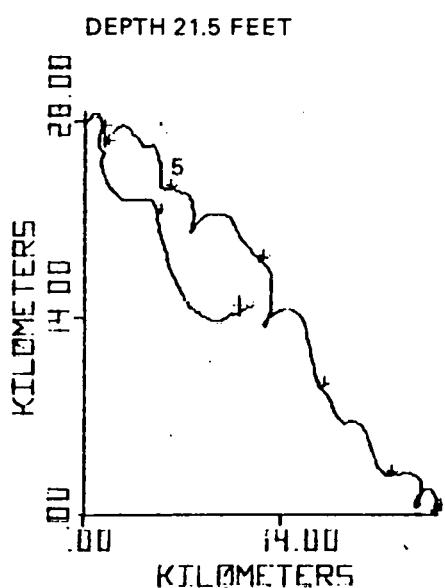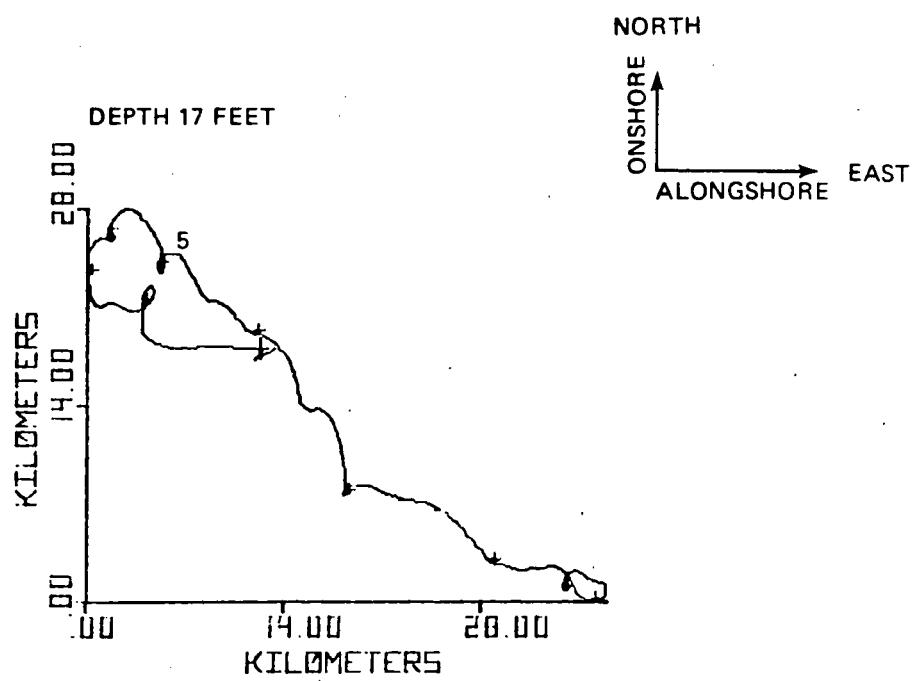
FIGURE 2-50   Progressive vector diagrams for Weeks Island Site B,
July 1-10, 1978 (numbers represent days of the month).

30 cm/sec) were measured during June and early July. Current speeds dur-
ng most other times of the year ranged from 0.3 to 1.3 ft/sec (10 to 40
cm/sec).

Although there was a predominant northwesterly drift throughout
most of the year there were significant secondary trends in the overall
circulation pattern. During the months of October, February, and March
the circulation was tidally dominated which may be due to the decreased
effects of the Loop Current, lower precipitation and runoff, and lower
wind speeds. Brief periods of stagnation associated with low current
speeds and little or no net drift were observed to occur during the
months of May, June, and July. Detached eddies from the Loop Current
may be primarily responsible for this type of behavior. Stagnant-type
conditions also occurred following the passage of a storm front in
January. Storm activity during the study period was limited to the
months of December and January; however, this geographical area is usually
subject to hurricanes and tropical storms from late summer through early
fall.

Local winds have a major influence on the nearshore circulation
pattern. For example, easterly to southeasterly winds during most of
the year cause a westerly to northwesterly drift current. Strong
southerly winds along the Texas coast during the summer are believed
to initiate a reversal in the net drift direction from the west to the
east (Murray, 1976). However, it is not known if the net southeasterly
drift during the early part of July marked the beginning of this transi-
tion. Other factors which could affect the circulation pattern are the
Loop Current, barotropic slope currents, and the tide.

Current speeds generally decrease with depth due to shear stresses
and may vary slightly in direction. Some instances of a two-layered
flow regime were recorded at the site but, were of short duration and
may have been induced by local wind effects.

Temperature profiles reflected nearly isothermal conditions when
measured during the fall, winter, and early spring. Salinity profiles
showed nearly isohaline conditions during the winter months of November
and February. Average salinity gradients of 4 to 9 ppt between the
surface and bottom waters are induced by river runoff, precipitation,
and the intrusion of offshore saline water.

2.3 Chemical Oceanography

The characteristics of the chemical factors (such as oxygen, pH
balance, nutrients, organic carbon, trace metals, hydrocarbons, and
suspended matter) near the diffuser sites in the nearshore Gulf of
Mexico waters are highly dependent on the seasonal discharges of the
Mississippi and Atchafalaya Rivers (Figure 1-1) and the intrusion of
deep marine waters. In general, the upper water layers are highly
influenced by the less saline, less dense riverine waters, while the
bottom water layers are affected by the more saline, denser Gulf water.
The seasonal changes in climatological conditions, however, markedly
affect the mixing and diffusion characteristics of these two water
layers.

2.3.1 Dissolved Oxygen and pH Balance

The primary sources of oxygen in coastal waters are the atmosphere
and the photosynthetic activity of marine plants. Surface dissolved
oxygen (DO) values in the northern Gulf are generally high and average
8 mg/l. Low DO values are found in bottom waters, especially during
the warm summer months. Near Marsh Island (Figure 1-2) DO values averaged
8.2 mg/l from April 1972 to March 1974 (Juneau, 1975); the lowest concen-
tration was 7.1 mg/l and the highest was 8.9 mg/l. There appeared
to be no depth-related trend. DO levels reported for the inshore areas
and marshes of Caillou Bay (Figure 1-2) were highest in March (11.4
mg/l) and lowest in September (5.8 mg/l); the sample average was 8.6
mg/l (Barrett, 1971).

DO measurements taken during 1973 near the Louisiana Offshore
Oil Port (LOOP) study area, east of the brine disposal sites, showed
that surface DO was uniformly high, with station means from 7.3 to
8.1 mg/l. At mid-depths, values averaged 4.9 mg/l; at the bottom,
values averaged 1.1 to 4.7 mg/l. During December, 27 percent of the
area was almost anoxic and had DO values of less than 2 mg/l; in July,
93 percent of the study area was anoxic. During June and July 1973,
the total anoxic area between the Southwest Pass of the Mississippi
Delta and Ship Shoal was estimated to cover 1000 square miles (Flowers
et al., 1975).

At Weeks Island Sites A and B, between September 1977 and April 1978, DO values ranged from 5.1 to 10.8 mg/l and from 3.8 to 11.4 mg/l, respectively (Figure 2-51). Variations in DO levels at stations occupied within each sampling array were usually small. During September and October, the surface water at Site A had a higher oxygen content than the bottom water. In November and December, as a result of mixing, DO levels in the two layers were similar. DO concentrations at Site B continued to remain high (>5 mg/l) in February, but by late March the bottom water decreased to a value of less than 4 mg/l. In April the bottom layer recovered and was measured at more than 5 mg/l. The low oxygen levels measured at Site B may have been part of a large anoxic layer which was found in the coastal Louisiana Gulf of Mexico during the late spring and early summer of 1978 (personal communication).

The biochemical oxygen demand (BOD) of eastern Louisiana Gulf waters has been reported by Flowers et al. (1975) to be generally low (2 mg/l). Water with a BOD value of about 3 is considered to be of relatively good quality. The average chemical oxygen demand (COD) was 170 mg/l and was within the range found in other similar coastal areas (LOOP, 1975). Because of its high organic load, the Mississippi River system has a major seasonal influence on the BOD and COD values of the area. BOD decreases steadily from May through September; COD increases during summer (Flowers et al., 1975).

2.3.2 Inorganic Nutrients, Ions, and Organic Carbon

The Mississippi and Atchafalaya Rivers have a tremendous influence on the amount of nutrients input to Louisiana coastal waters. Between the Mississippi River and west to Caminada Bay, inorganic nitrogen (nitrate and nitrite) values were reported by Ho and Barrett (1975) to be one to two orders of magnitude greater during periods of high river discharge than during normal flow periods. An inverse relationship was found between nitrate (NO_3) and nitrite (NO_2) and salinity levels-- nitrate and nitrite concentrations decreased seaward while salinity increased in value. Reactive silicate (SiO_2) and orthophosphate (PO_4) showed a similar but weaker relationship to salinity levels. Concentrations of ammonia, organic phosphates, and organic nitrogen remained fairly constant in the coastal waters throughout various river flow periods.
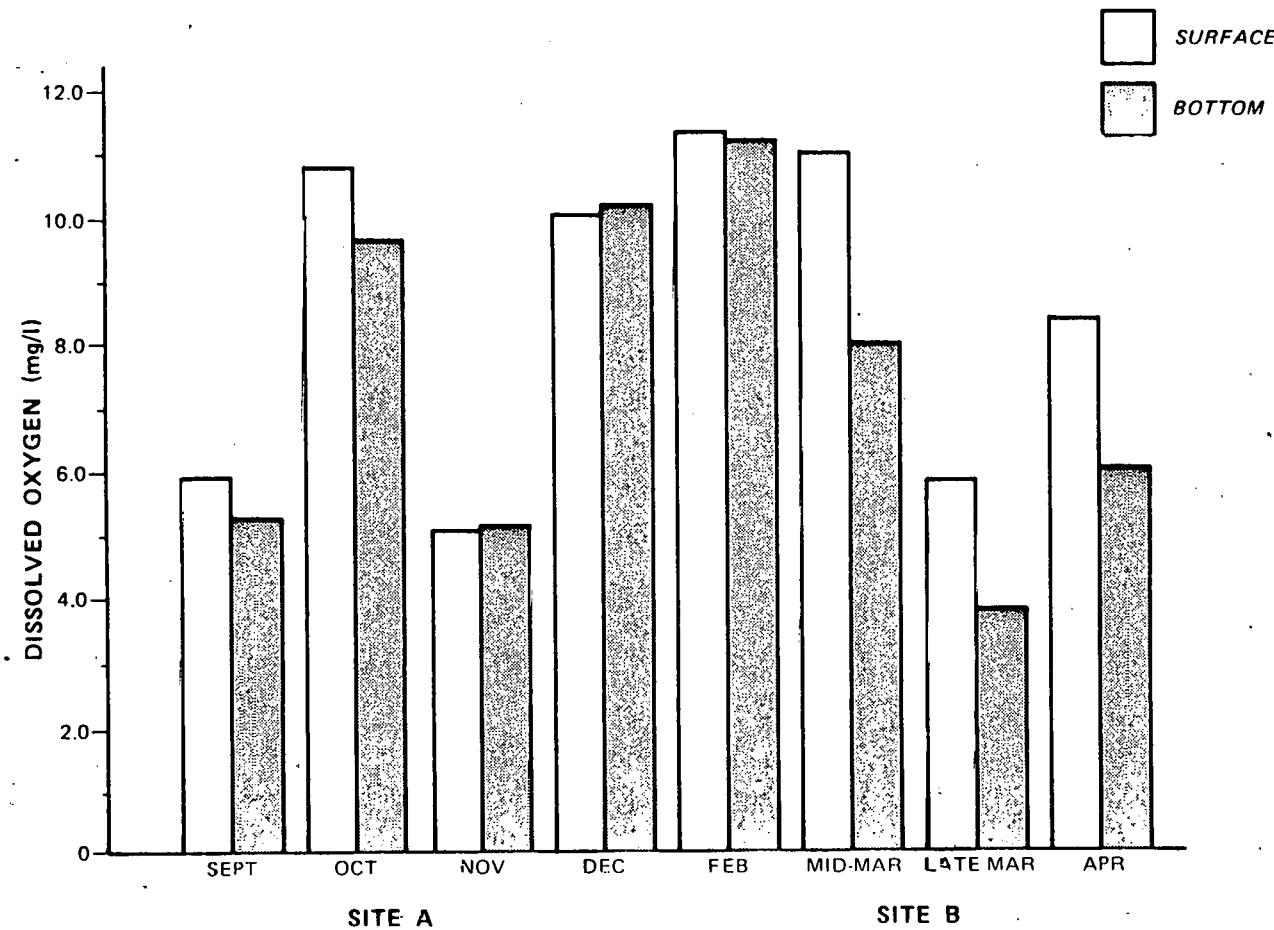
FIGURE 2-51   Mean dissolved oxygen values at Weeks Island Sites A and B.

Assuming that the Atchafalaya River flow is 50 percent of the Mississippi River flow, but that both carry proportionally the same nutrient load, the estimated amount of nutrients discharged into the Louisiana coastal area between January and July 1973 (Ho and Barrett, 1975), during abnormally high water flow, is shown in Table 2-16.

TABLE 2-16   Nutrients discharged into the Louisiana coastal area, January to July 1973 (in billions of pounds).

	$NO_3 + NO_2$	PO_4	Dissolved SiO_2	Organic N	Organic C
Mississippi	1.96	0.08	2.90	1.82	21.70
Atchafalaya	0.98	0.04	1.45	0.91	10.85

In earlier studies (Barrett, 1971; Juneau, 1975), nitrate inshore of the sites averaged 3.5 to 8.4 microgram-atoms per liter (μg-at/l); nitrite averaged 0.6 μg-at/l. Average inorganic phosphate ranged from 0.9 to 2.5 μg-at/l, and total phosphate averaged 4 μg-at/l. Seasonal trends were apparent but varied from station to station and year to year. Sulfate and calcium peaked during October; annual averages were 122 mg/l and 73 mg/l, respectively.

The major ion and nutrient values measured at Weeks Island are consistent with results from previous studies, though seasonality has an influence in the comparison of the September and February sampling. The water column was stratified in September, as reflected by temperature, salinity, dissolved oxygen, ions, and nutrients. This condition is typical of estuarine and coastal systems in late summer; less saline, land-derived water overlies the more saline and dense marine water on the bottom. In February, the system was homogenous.

Based on the mean and range values of nutrients and the major ions (Tables 2-17 and 2-18), freshwater runoff apparently had a greater effect on the more inshore Weeks Island Site A in September than on Site B in February; concentrations of major ions, and thus salinity, were less at Site A than at Site B. This may have been due to two factors--proximity to the shore and the amount of seasonal runoff. Silicate and orthophosphate values were greater at the more inshore Site A, though nitrate levels were similar at the two sites. Nitrite

TABLE 2-17 Organic carbon and nutrients in the water column for Weeks Island Sites A and B.

	Sediments (% TOC)	DOC (mg C/1) S[a]	DOC (mg C/1) B[a]	POC (mg C/1) S	POC (mg C/1) B	PO$_4$ (µM) S	PO$_4$ (µM) B	Pore
Site A (Sept 1977)								
Mean	1.02	1.49	1.30	0.72	0.72	1.20	1.34	0.52
Range	0.72 - 1.37	0.75 - 2.30	1.20 - 1.36	0.44 - 1.54	0.51 - 1.19	0.76 - 1.43	0.93 - 1.77	0.30 - 0.75
Site B (Feb 1978)								
Mean	0.09	1.06	1.37	0.55	0.64	0.57	0.62	13.49
Range	0.05 - 0.19	0.85 - 1.43	1.01 - 1.67	0.31 - 0.94	0.37 - 1.15	0.37 - 0.77	0.42 - 0.81	7.95 -21.3

	NO$_3$ (µM) S	NO$_3$ (µM) B	NO$_2$ (µM) S	NO$_2$ (µM) B	SiO$_4$ (µM) S	SiO$_4$ (µM) B	Pore
Site A (Sept 1977)							
Mean	12.2	10.3			24.2	14.4	108
Range	4.6 - 20.3	3 - 19.9			8.3 - 80.0	9.7 - 21.3	85 - 126
Site B (Feb 1978)							
Mean	10.11	10.25	0.67	0.73	<0.38	<0.38	159
Range	8.34 - 11.80	8.65 - 11.40	0.46 - 0.85	0.48 - 1.01			140 - 178

[a]S = surface; B = bottom.

TABLE 2-18   Major ion concentrations (g/kg) for Weeks Island Sites A and B.

		Cl	SO$_4$	Na	K	Mg	Ca
Site A **(Sept 1977)**							
Surface	Mean	9.77	1.27	5.3	0.19	0.64	0.22
	Range	1.52 - 15.95	0.12 - 2.19	0.7 - 8.9	0.03 - 0.32	0.08 - 1.08	0.06 - 0.34
Bottom	Mean	13.09	1.78	7.1	0.26	0.86	0.28
	Range	7.88 - 15.91	0.96 - 2.23	4.1 - 8.8	0.15 - 0.32	0.5 - 1.07	0.19 - 0.34
Pore	Mean	13.06	2.39	7.4	0.31	0.93	0.31
	Range	7.8 - 15.91	1.42 - 2.74	4.6 - 8.9	0.2 - 0.35	0.5 - 1.11	0.18 - 0.37
Site B **(Feb 1978)**							
Surface	Mean	16.8	2.49	9.42	0.358	1.15	0.371
	Range	16.8 - 16.9	2.45 - 2.52	9.38 - 9.49	0.355 - 0.363	1.14 - 1.16	0.37 - 0.374
Bottom	Mean	17.0	2.54	9.51	0.360	1.15	0.372
	Range	16.6 - 17.3	2.48 - 2.62	9.38 - 9.68	0.356 - 0.365	1.13 - 1.18	0.369 - 0.376
Pore	Mean	13.9	2.05	7.75	0.249	0.99	0.316
	Range	12.7 - 16.2	1.93 - 2.25	7.11 - 9.07	0.238 - 0.258	0.92 - 1.12	0.302 - 0.347

was measured only at Site B. These values are within the ranges expected
and found in the coastal Louisiana Gulf of Mexico, as is the trend
of decreasing nutrients with increasing salinity.

No significant trends were evident for nutrient elements measured
in the sediment pore water samples. Pore water major ion levels are
less responsive than water column ion levels to seasonal and distance-
from-shore changes in salinity. As a result, pore water ion levels
were similar at Sites A and B in September and February, respectively,
and both levels approximated the bottom water levels of Site A during
September. Because of the shallow water depths at Site A and B, these
findings are not unexpected since the sediments at the sites should
be quite transitory. Except for the quiet summer months, the strong
wave activity due to storms or bottom currents often will rapidly redis-
tribute the sediments upward into the water column. The percent total
organic content (% TOC) in the sediment at both sites was low due to
the influx of terrigenous clastic material, which effectively masked
the organic carbon content. Dissolved organic carbon (DOC) and particu-
late organic carbon (POC) levels did not differ between sites or with
depth. These values are close to those reported for other coastal
areas.

2.3.3 Trace Metals

The average values of manganese in coastal Gulf Waters (3.9 µg/l)
are an order of magnitude higher than open Gulf values (0.31 µg/l),
(Slowey and Hood, 1971). The coastal and open sea values for copper
are 1.6 µg/l and 1.3 µg/l, respectively, and for zinc--4.2 µg/l and
3.5 µg/l, respectively. High values in the open Gulf were usually
found at surface and intermediate depths; deep waters had uniformly low
values. High concentrations of metals at intermediate depths seemed
to have originated outside the Gulf of Mexico and may have resulted
from the release of trace metals during organism decomposition. The
riverine input of manganese into coastal waters was significant, but
the input of copper and zinc was negligible.

Except for mercury, the values for dissolved metals collected
west of the Delta (Table 2-19) were within the range of expected values
for coastal marine environments (Flowers et al., 1975). The values

TABLE 2-19   Dissolved metals (ppb) in surface and bottom waters in the LOOP study region.

	Cd		Cr		Cu		Fe		Pb		Mn		Hg		Ni		Zn	
Station Grp III	S^a	B^a	S	B	S	B	S	B	S	B	S	B	S	B	S	B	S	B
19.4 - 20 km, 24.4 m																		
June 1973	1.8	0.9			1	0.8			1.1	ND^b					1.7	0.4	7.6	11.6
July 1973													0.48	0.41				
Aug 1973			ND	10.6	0.6	ND	9	4.3	ND	8.9	2.4	3.1			0.9	ND	2.0	1.1
Oct 1973			21.1	10.5	0.7	4.3	4.3	9.9	ND	3.2	ND	2.1			ND	ND	2.6	3.4
Jan 1974			3.5	ND	1.1	1.4	5.2	2	ND	3.3	1.1	4.1			1.7	ND	5.2	3.9
Range/Level (Surface)	0.3	3.1	ND	55.3	ND	4.9	ND	14.9	ND	3.3	ND	3.8	0.22	0.9	ND	5.2	ND	17
(Bottom)	ND	2.8	ND	21	ND	9	ND	12.8	ND	26.7	ND	7.6	0.22	0.67	ND	2.6	0.2	18
Station Grp IV																		
27.4 - 36.6 km																		
33.5 - 42.6 m																		
June 1973	0.2	0.2			2.8	1.9			ND	ND					ND	ND	5.8	11.9
July 1973													1.03	0.86				
Aug 1973			7.9	4	2.1	2.2	1.4	3.6	17.5	0.8	ND	ND			1.3	ND	0.9	2.8
Oct 1973			6.6	3.3	0.7	1	14.2	8.1	2.5	ND	1.2	ND			0.7	ND	5.6	3.4
Jan 1974			9.2	4.6	2	0.8	3.9	2	8.3	0.8	2.8	3.7			ND	5.5	4.2	1.9
Range/Level (Surface)	ND	0.8	ND	28.9	ND	5.7	ND	18.2	ND	36.7	ND	6.8	0.86	1.36	ND	2.6	ND	8.7
(Bottom)	ND	0.7	ND	13.3	ND	3.1	ND	14.2	ND	3.3	ND	6.3	0.71	1.14	ND	22.1	ND	32.8

[a]S = surface; B = bottom.

[b]ND = not detectable.

SOURCE: Flowers et al., 1975.

TABLE 2-20   Concentrations of trace metals (ppb) in the dissolved and
particulate phases of the water column and in pore water
from Weeks Island Sites A and B.

		Dissolved			
		Site A (September 1977)		Site B (February 1978)	
		Mean	Range	Mean	Range
Al	S[a]			9	3.6 - 15
	B[a]			17	3.8 - 33
	Pore[b]			2503	50 - 8700
Cd	S	0.04	0.03 - 0.06	0.22	0.17 - 0.32
	B	0.05	0.03 - 0.07	0.27	0.22 - 0.31
	Pore	12.5	4.7 - 18	0.26	0.23 - 0.34
Cr	S			2.4	2.2 - 2.8
	B			2.5	<2 - 2.8
	Pore			4.7	3 - 8.4
Cu	S	1.4	0.9 - 1.8	0.6	0.4 - 0.7
	B	1.1	0.9 - 1.5	0.3	0.2 - 0.4
	Pore	55	32 - 83	2.9	1.5 - 4.1
Fe	S	<2		22	<2 - 50
	B	<2		7	<2 - 15
	Pore	86	33 - 245	3297	29 - 8600
Pb	S	0.06	0.02 - 0.09		<2 - 4.4
	B	0.08	0.04 - 0.21	<2	<2 - 2.3
	Pore	1.7	0.8 - 2.2	8.83	<2 - 26
Mn	S	0.8	0.25 - 1.2		<0.5 - 1.3
	B	1.5	0.54 - 2.1	<0.5	
	Pore	1610	150 - 320	20250	19600 - 25500
Hg	S	0.03	0.01 - 0.05		<0.005 - 0.01
	B	0.04	0.03 - 0.04	<0.005	
	Pore			60	
Ni	S	1.3	0.9 - 1.9	<2	
	B	1.2	1 - 1.7	<2	
	Pore	5.7	4.9 - 7.3	6.7	3.1 - 10
Zn	S	<12		1.6	0.5 - 3.4
	B	<12		0.6	<0.3 - 1.1
	Pore	65	22 - 120	14.1	4 - 35

[a]S = surface; B = bottom.

[b]Pore = sediment pore water.

TABLE 2-20   (cont'd).

		Particulate			
		Site A (September 1977)		Site B (February 1978)	
		Mean	Range	Mean	Range
Al	S				
	B				
	Pore				
Cd	S	0.02	0.006 - 0.057	0.007	0.0006 - 0.015
	B	0.59	0.008 - 1.7	0.009	0.0009 - 0.024
	Pore				
Cr	S			0.78	0.28 - 1.55
	B			1.03	0.34 - 2.37
	Pore				
Cu	S	0.68	0.07 - 1.7	0.19	0.019 - 0.44
	B	1.45	0.06 - 3.1	0.27	0.047 - 0.6/
	Pore				
Fe	S	1348	95 - 4200	329	47 - 720
	B	4043	130 - 7800	510	14 - 1200
	Pore				
Pb	S	0.8	0.26 - 2	0.52	0.054 - 1.18
	B	1.97	0.097 - 4.8	0.53	0.13 - 1.3
	Pore				
Mn	S	21	2.2 - 62	5.9	0.4 - 12.5
	B	81	10 - 180	9.4	2.6 - 22.3
	Pore				
Hg	S				
	B				
	Pore				
Ni	S	1.6	<0.126 - 4.3	0.68	0.11 - 1.41
	B	3.8	0.17 - 8	0.96	0.21 - 2.3/
	Pore				
Zn	S	5.6	3.2 - 12	1.47	0.14 - 3.16
	B	31	0.65 - 62	1.94	0.46 - 4.54
	Pore				

for mercury were high, but may have been due to variations in the analytical techniques used.

Heavy metal concentrations at the sites are greatly influenced by sediment input from the Atchafalaya River. In an area with a high amount of suspended matter, it is expected that the particulate phase, onto which metals adhere in the water column, would have a higher trace metal content than the dissolved phase. Generally, this trend is observed at both sites (Table 2-20). Site A is closer to the river and has higher levels of suspended matter (Section 2.3.5) and particulate trace metals than Site B; however, these levels are low compared to those found in other coastal areas of the Gulf of Mexico. Due to sediment resuspension, trace metal levels in the bottom water particulate phase were higher than those measured in surface waters.

A portion of the particulate trace metal phase is weakly attached to suspended matter and may be assimilated by organisms during digestion of particulate matter. The percent leachable fraction is a measure of that portion of the particulate metal content which is soluble in weak acid and may be biologically assimilated. The percent leachable fraction ranged from the typically low iron level to several high values including manganese and cadmium (Table 2-21). Weeks Island Site A, with its high particulate trace metal content, also has a percent leachable particulate fraction higher than Site B.

TABLE 2-21   Percent leachable fraction of particulate trace metals from Weeks Island Sites A and B.

	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn
Site A (September 1977)								
Surface	29.3		14.0	4.5	29.3	62.7	8.9	30.5
Bottom	35.6		22.2	10.5	26.5	59.2	16.9	53.1
Site B (February 1978)								
Surface	22.7	<1.0	8.3	6.0	29.7	46.0	6.7	26.3
Bottom	49.3	<1.0	8.7	6.0	29.0	59.0	7.0	18.3

Concentrations of dissolved heavy metals were higher in the sediment pore water than in the overlying water column. This difference suggests that the metals may be diffusing from the sediments into the interstitial water (Table 2-20). Generally, metals such as manganese and cadmium--with a high percent leachable fraction, and metals such as iron and zinc--associated with the minerals in the sediment, were found in high levels in the pore water. The dissolved heavy metal levels in the water column are well within the range of those expected for coastal environments.

Sediments at site A (Section 2.2.2) are predominantly silts and clays and are characteristically finer than the sands at Site B. As a result, Site A sediments also showed a significantly higher heavy metal concentration (Table 2-22). Because iron, which has properties similar to other trace metals, is not easily altered by anthropogenic effects, it is a good indicator of whether other trace metals have a natural or man-induced origin. Table 2-23 presents the sediment metal/iron ratios for Weeks Island. Manganese, nickel, and chromium are probably exposed to geochemical influences similar to those of iron since their metal-to-iron ratios are constant between the two sites. Unlike iron, zinc, lead, and cadmium may be influenced by other factors since their levels at the two sites change at different rates.

Zooplankton samples, consisting mostly of chaetognaths, had significantly higher levels of trace metals (except for copper) than did croaker or shrimp (Table 2-24). This difference may be due in part to the high surface area-to-mass ratio for zooplankton relative to similar ratios for croaker and shrimp. The trace metal values found in the zooplankton were similar to levels reported in zooplankton collected in the northwest Gulf of Mexico (Sims, 1975). Trace metal levels (except for zinc, nickel, and cadmium) were comparably low in white shrimp collected from Sites A and B. During September, trace metal levels at Site A (except for iron, copper, and aluminum) were low in croakers. Anchovies collected at Site B had trace metal levels higher than those in Site A croakers. This increase was possibly due to the higher surface area-to-mass ratios of the smaller anchovies.

2.3.4 Hydrocarbons

Of the estimated 6 to 12 million metric tons of hydrocarbons entering

TABLE 2-22   Concentrations of trace metals in sediments
(ppm) from Weeks Island Sites A and B.

	Site A (September 1977)		Site B (February 1978)	
	Mean	Range	Mean	Range
Al	1900	1500 - 2000	515	433 - 725
Cd	0.22	0.19 - 0.27	0.130	0.009 - 0.023
Cr	2.7	2.2 - 3.3	1.39	1.28 - 1.69
Cu	11.0	7.8 - 13.0	1.14	0.74 - 2.59
Fe	6000	5700 - 6300	2490	2305 - 3037
Pb	18.7	16.8 - 20.9	5.93	5.27 - 9.26
Mn	555	507 - 627	256	220 - 288
Hg			3.82	2.11 - 6.88
Ni	6.8	5.8 - 7.7	3.44	3.10 - 3.78
Zn	27.8	24.6 - 30.9	14.7	13.0 - 15.2

TABLE 2-23 Sediment metal/iron ratios for Weeks Island Sites A and B.

	Al/Fe $(x10^{-1})$	Cd/Fe $(x10^{-5})$	Cr/Fe $(x10^{-4})$	Cu/Fe $(x10^{-4})$	Pb/Fe $(x10^{-4})$	Mn/Fe $(x10^{-2})$	Hg/Fe $(x10^{-3})$	Ni/Fe $(x10^{-4})$	Zn/Fe $(x10^{-4})$
Site A (September 1977)		3.6	4.6	19.2	31.1	9.3		11.3	46.3
Site B (February 1978)	2.1	5.2	5.6	4.6	23.8	10.3	1.5	13.8	59

TABLE 2-24   Heavy metal contents (ppm) of selected organisms from Weeks Island Sites A and B.

Sample #	Sample Description[a] (Species)/Site Station	Al	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn
	Site A (September 1977)									
1	Croaker (M. undulatus), WT-3	2.52	0.003		1.4	13.3	0.05	3.8	0.01	18.7
2	White shrimp (P. setiferus), WT-3	0.13	0.04		27.3	6.4	0.001	2.2	0.24	56.3
3	Zooplankton (chaetognaths), WT-3	1020	1.56		15.6	692	0.55	21.9	6	162
	NW Gulf of Mexico zooplankton[b]									
	#1	1252	2.4		74	799	15.3	12.6	2	115
	#2	283	1.3		6.3	288	4.3	9.8	1.9	58
	Site B (February 1978)									
4	White shrimp (P. setiferus), WT-1, WT-3	3.12	0.032	0.038	23.6	6.77	0.082	0.696	0.090	49.4
5	Bay anchovy (Anchoa mitchilli), WT-1, WT-3	99.6	0.061	0.122	5.46	102	0.193	10.4	0.401	173

[a]Sample 1 - 4 fish pool, flesh only; Sample 2 - 5 shrimp pool, flesh only; Sample 3 - whole sample, mostly chaetognaths; Sample 4 - n = 10, flesh only; Sample 5 - n = 10, flesh only.

[b]SOURCE: Sims, 1975. #1 - Sample from nearshore off Corpus Christi, Texas.
 #2 - Sample from directly offshore of the Atchafalaya, further from land than the Weeks Island sites.

the oceans yearly, 50 percent are believed to result from organic decay, 17 percent from terrestrial runoff, 8 percent from atmospheric fallout, 4 percent from natural seepage, and 21 percent from oil production and shipping operations (Ahearn, 1974). Hydrocarbon concentrations in the open ocean are generally less than 10 ppb at the surface and much less in deep waters. In the Gulf of Mexico, n-alkane levels were reported to be 0.2 ppb in East Bay, Louisiana; 0.1 ppb 15 miles from Corpus Christi, Texas; and 0.63 ppb near a burning oil rig 15 miles southwest of Point Au Fer Island, in the region of the Weeks Island brine diffuser sites (Parker et al., 1972, as cited in LOOP, 1975). N-paraffin levels of 0.63 ppb were measured in water off Louisiana (IDOE, 1972, as cited in Bishop et al., 1975). The Gulf Universities Research Consortium (1974) detected hydrocarbon levels of 0.5 to 2.1 ppb in a control area, 0.8 to 6.0 ppb near an operating rig, and 3.7 to 11.0 ppb in Timbalier Bay.

Hydrocarbons found in Gulf waters are predominately saturated hydrocarbons; concentrations of aromatics are usually low. Nonvolatile hydrocarbons have a range from 1 to 12 ppb and aromatics range from 1 to 3 ppb, but many samples contain undetectable amounts. Levels of paraffin compounds are high--with single-ring naphthenes the most abundant species. In general, surface waters have a higher content than deeper waters (Brown et al., 1973, as cited in Bishop et al., 1975). Flowers et al. (1975) found that hydrocarbon levels ranged from 17 to 64 ppb and make up 80 to 90 percent of the surface water organic matter in coastal Louisiana. The predominant carbon tetrachloride extractable component in samples was the lipid fatty acid fraction which ranged from 16 to 136 ppb.

Site A sediments (in September) contained nearly three times (14,013 ppb) the hydrocarbon content measured at Site B (in February)--5115 ppb (Table 2-25). This difference may be largely due to Site A's finer grain texture and greater organic carbon content. The same trend was found in the water column, with Site A having a greater hydrocarbon concentration than Site B (10.6 vs 0.36 ppb for surface samples and 9.2 vs 0.24 ppb for near-bottom samples).

Gas chromatographic traces of sediments indicate that Site A (Figures

TABLE 2-25   Gas chromatograph hydrocarbon concentrations (ppb) in water samples and sediments from Weeks Island Sites A and B.

	Hexane Fraction		Benzene Fraction		Total
	Resolved	Unresolved	Resolved	Unresolved	
Site A **(September 1977)**					
Surface (Mean)	0.204	7.906	0.2	2.254	10.56
(Range)	0.003 - 1.027	1.348 - 34.361	0.004 - 0.906	0.193 - 10.447	2.81 - 45.91
Bottom (Mean)	0.155	7.284	0.073	1.737	9.25
(Range)	0.022 - 0.489	1.591 - 8.974	0.017 - 0.347	0.432 - 1.565	2.39 - 26.33
Sediment (Mean)	950	9,625	588	2,851	14,014
(Range)	247 - 1,364	1,640 - 14,327	112 - 1,612	612 - 6,389	2,611 - 20,088
Site B **(February 1978)**					
Surface (Mean)	0.034	0.206	0.017	0.108	0.364
(Range)	0.027 - 0.045	0.084 - 0.349	0.002 - 0.044	0.038 - 0.165	0.051 - 0.547
Bottom (Mean)	0.018	0.116	0.0159	0.09	0.24
(Range)	0.004 - 0.037	0.014 - 0.212	0.0007 - 0.043	0.03 - 0.187	0.103 - 0.363
Sediment (Mean)	612	3,765	198	734	5,115
(Range)	66 - 3,390	473 - 13,770	66 - 855	256 - 2,330	922 - 19,790

2-52 and 2-53) hydrocarbons are predominantly derived from waxes of higher plants with some contribution from petrogenic sources, while the opposite is true at Site B (Figures 2-54 and 2-55). However, Site A had a much higher sediment hydrocarbon concentration and was sampled at a different time of year.

Traces representative of water column hydrocarbons at Site A (Figures 2-56 to 2-58) showed large concentrations of toxic high molecular weight aromatic compounds, but the anomalies in Figure 2-58 may represent contamination in the samples from the ship's bilge. Chromatographs of the water column for Site B (Figures 2-59 to 2-62) suggest that the hydrocarbons represented were of biological origin though the bottom waters contained petrogenic hydrocarbons originating on land.

Gas chromatograph-mass spectrometry analyses (Appendix B) show that the sediment at Site A contained an abundance of sulfur and that petrogenic hydrocarbon content generally increased when grain size decreased. Sediments at Site B contained n-alkanes with no odd carbon preference or olefinic compounds. Surface water fractions at Site B contained n-alkanes, branched alkanes, and biogenic olefins.

Hydrocarbon concentrations in whole white shrimp samples (Table 2-26) were similar at Site A (15.98 ppm) and Site B (14.46 ppm). However, hydrocarbon levels in anchovies (Table 2-26) from Site B were eight times higher (114.5 ppm) than levels in shrimp. Croaker sampled at Site A had a hexane fraction of 8 ppm (Table 2-26).

Chromatographs of hydrocarbons in croakers (Figure 2-63) show a large petrogenic content for Site A, but anchovies at Site B contained hydrocarbons mostly of biological origin. White shrimp contained mainly petrogenic compounds including steranes and triterpanes (Figures 2-64 to 2-67). Traces for shrimp from Site A showed a large polyolefin peak near n-C_{22}, but shrimp from Site B had a prominent pristane peak. Mass spectrometric analyses of shrimp from both sites (Appendix B) show that the aromatic fraction contained a number of potentially toxic aromatic and chlorinated compounds. In particular, shrimp collected from Site B contained at least 13 chlorinated compounds--DDE was most prominent with a concentration of approximately 15 ppb.
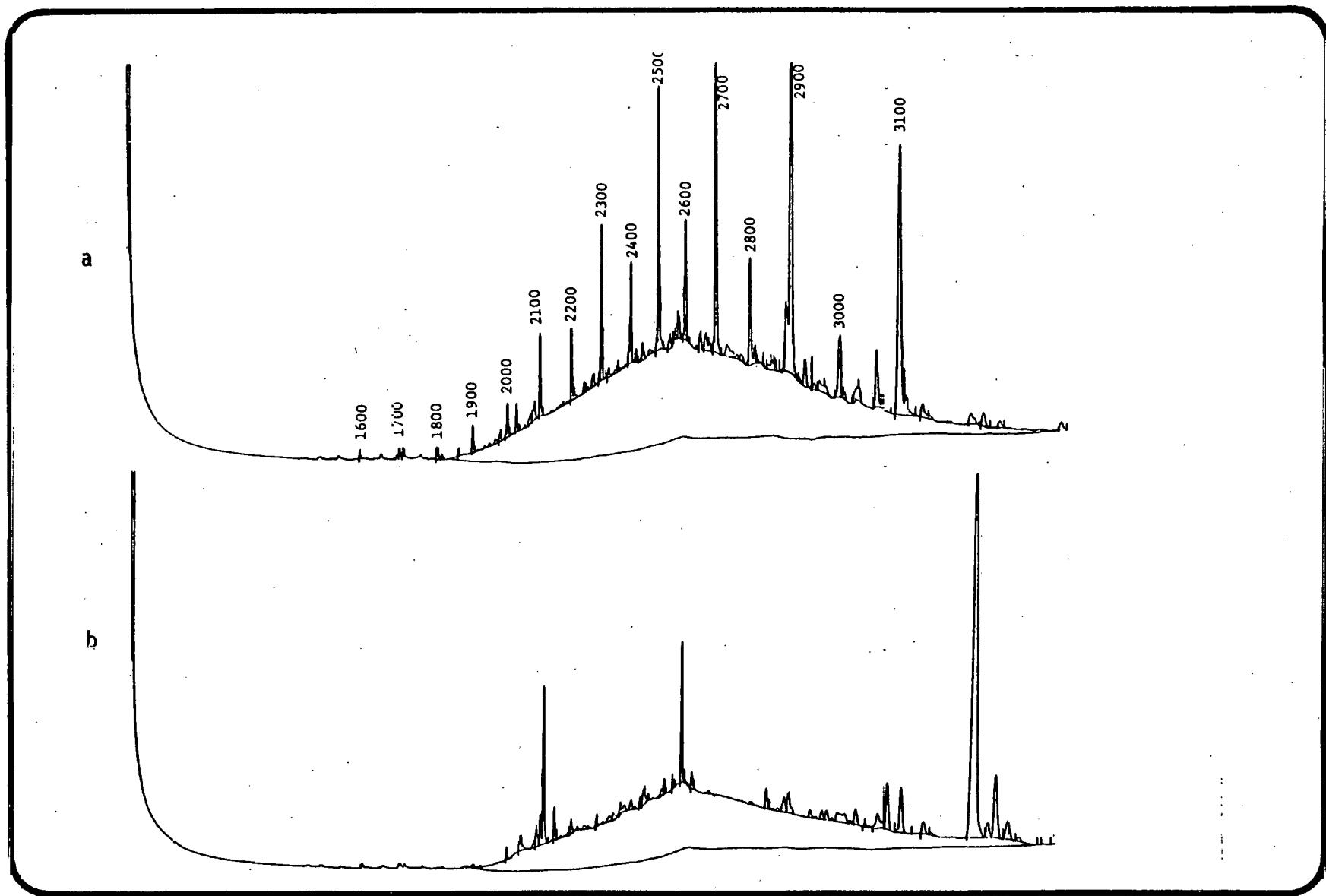
FIGURE 2-52   Gas chromatographic traces of the (a) hexane and (b) benzene fractions of sediment from Weeks Island Site A, station WR-3.
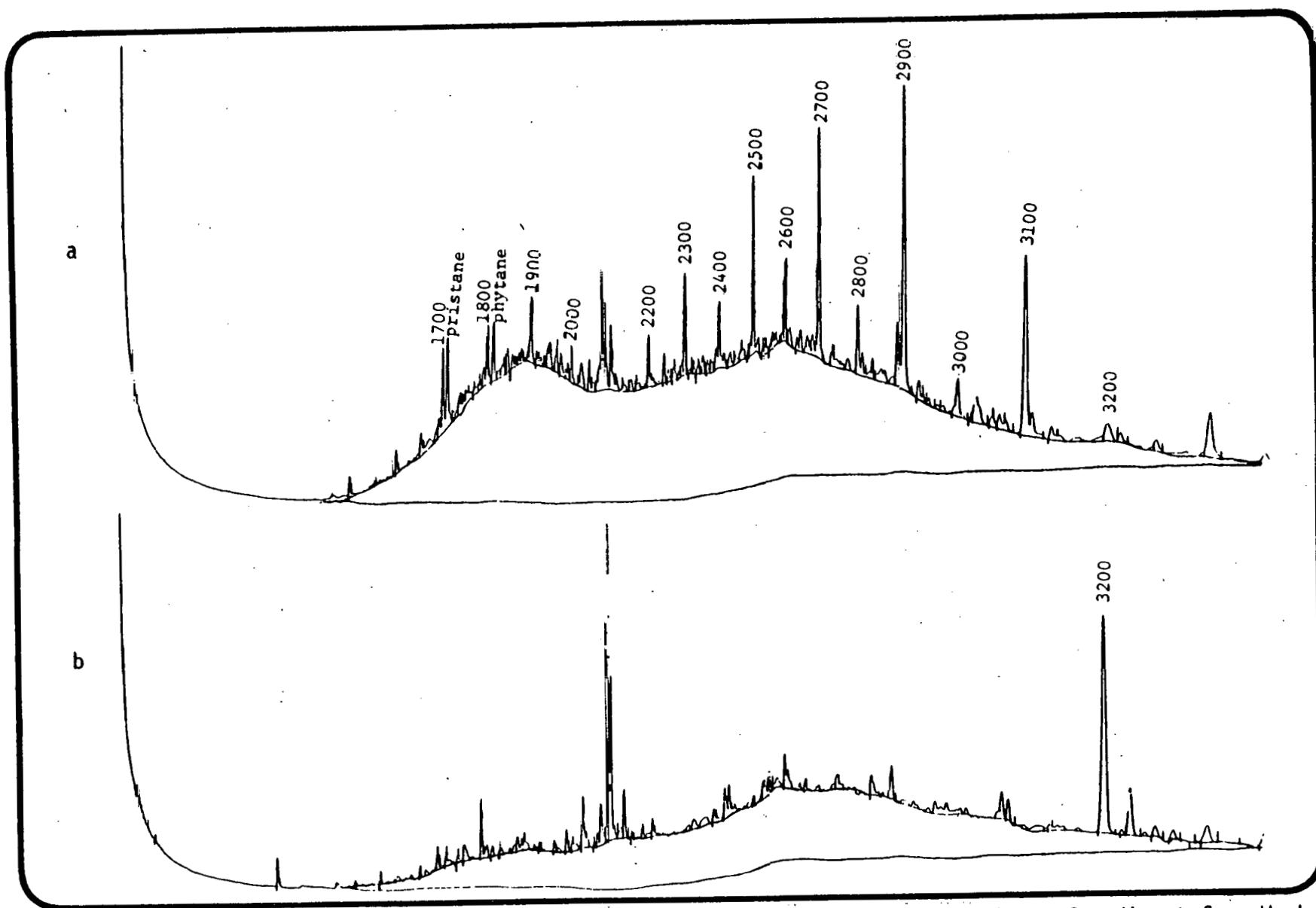
FIGURE 2-53   Gas chromatographic traces of the (a) hexane and (b) benzene fractions of sediment from Weeks Island Site A, station W-5.
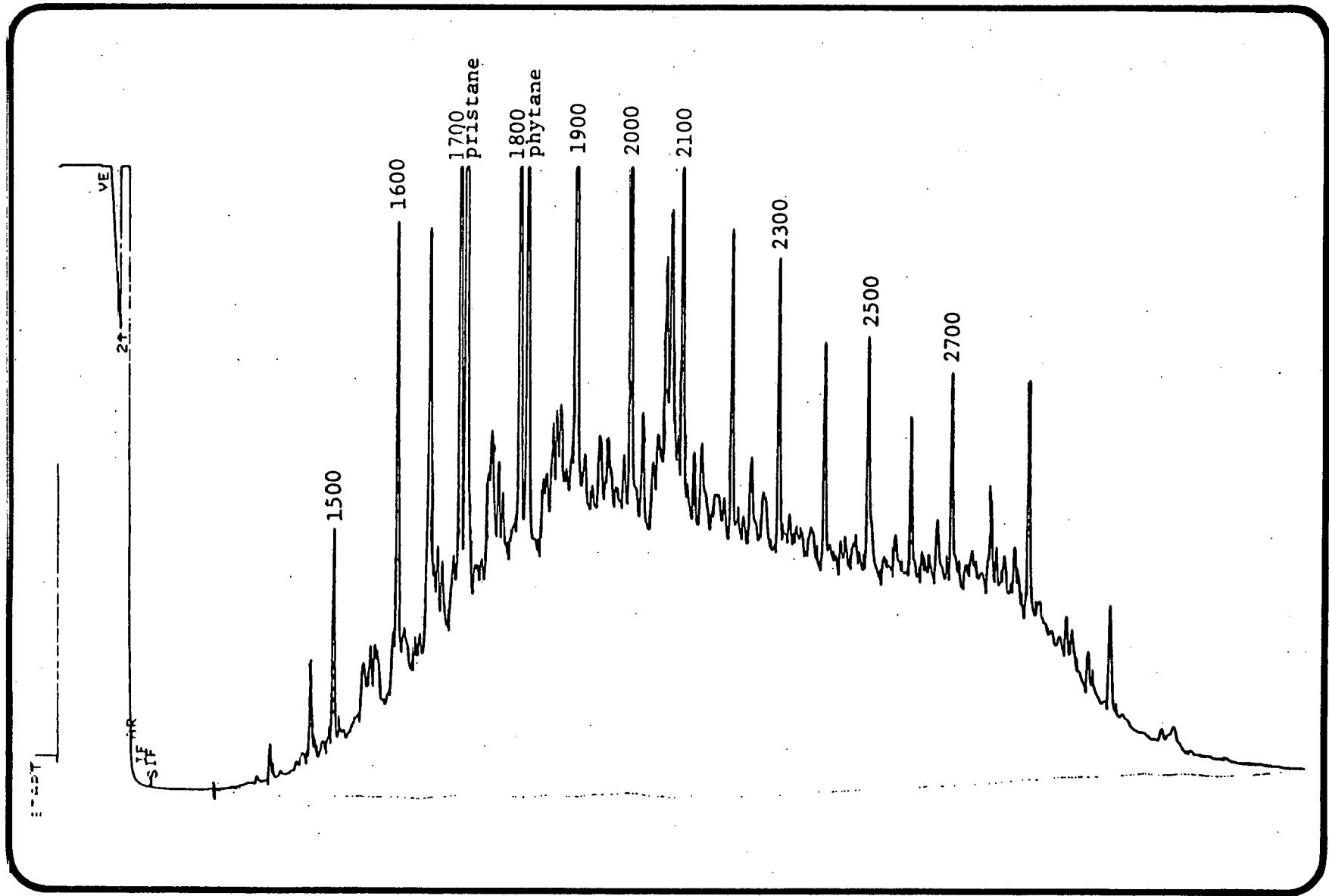
FIGURE 2-54   Gas chromatographic trace of the hexane fraction of sediment from Weeks Island Site B, station W-11.
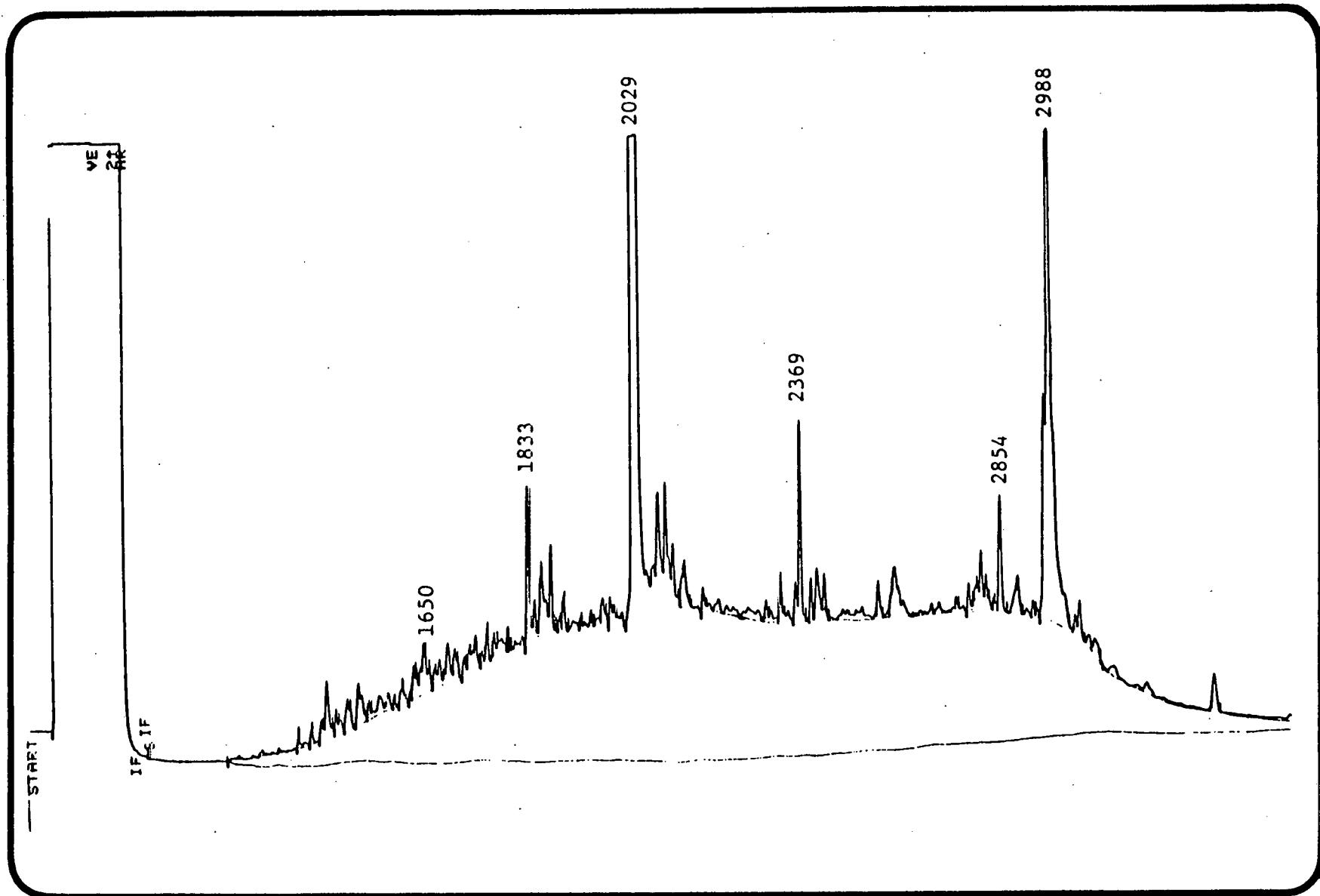
FIGURE 2-55   Gas chromatographic trace of the benzene fraction of sediment from Weeks Island Site B, station W-11.
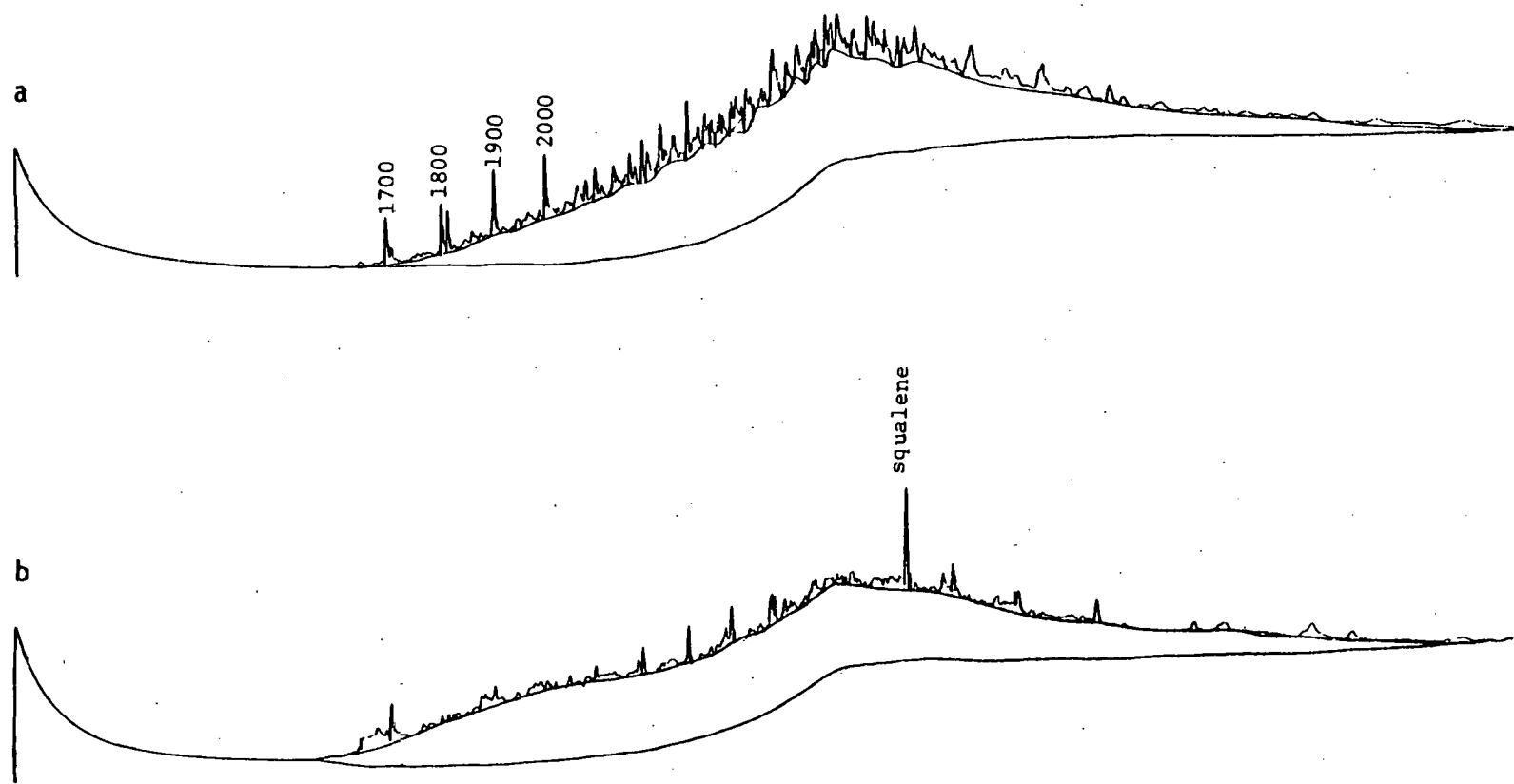
FIGURE 2-56   Gas chromatographic traces of the (a) hexane and (b) benzene fractions of water collected at mid-depth from Weeks Island Site A, station WR-3.

2-114
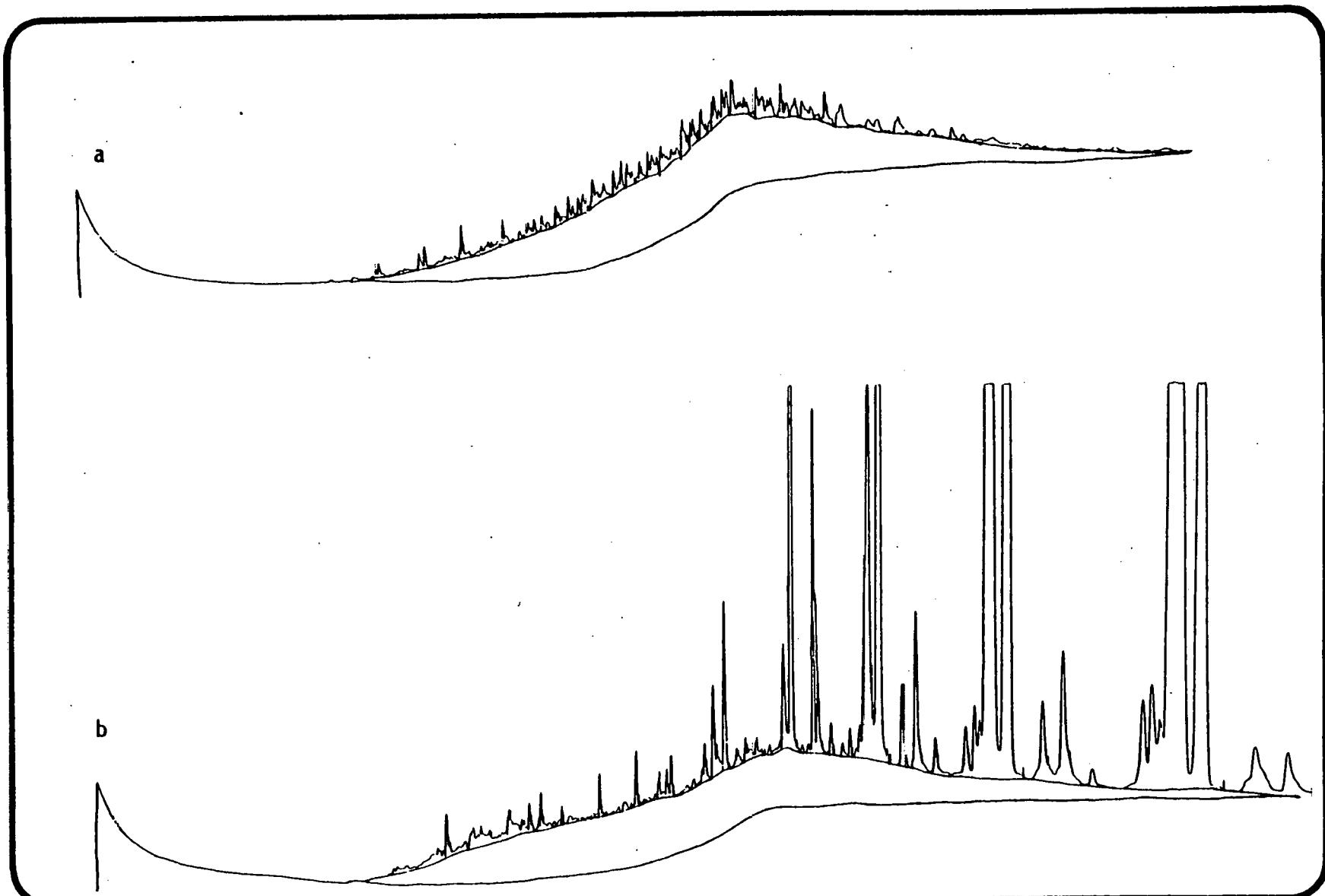
FIGURE 2-57   Gas chromatographic traces of the (a) hexane and (b) benzene fractions of surface water from Weeks Island Site A, station W-2.
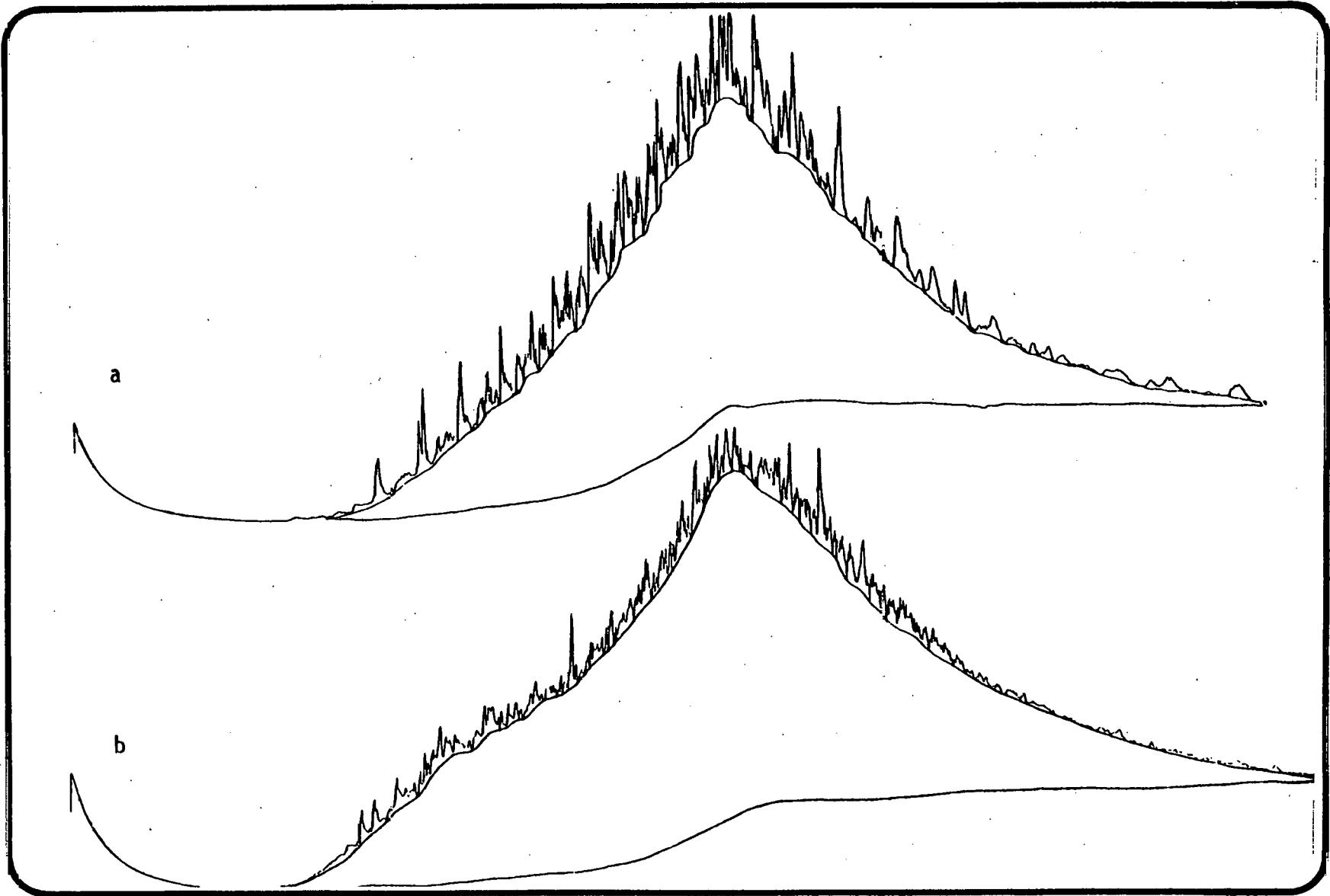
FIGURE 2-58   Gas chromatographic traces of the (a) hexane and (b) benzene fractions of surface water from Weeks Island Site A, station W-5.
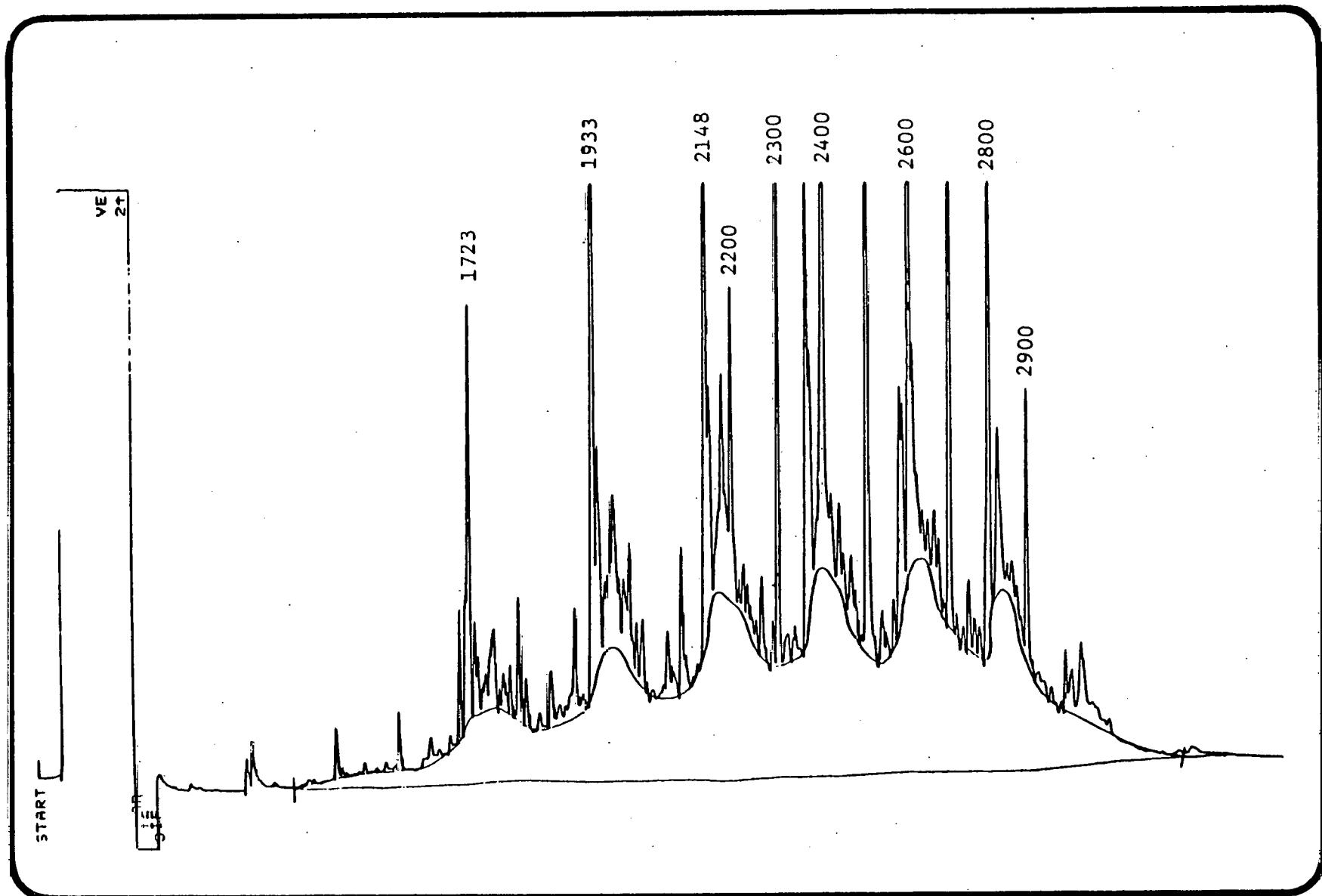
FIGURE 2-59   Gas chromatographic trace of the hexane fraction of the surface water filtrate from Weeks Island Site B, station WR-1.
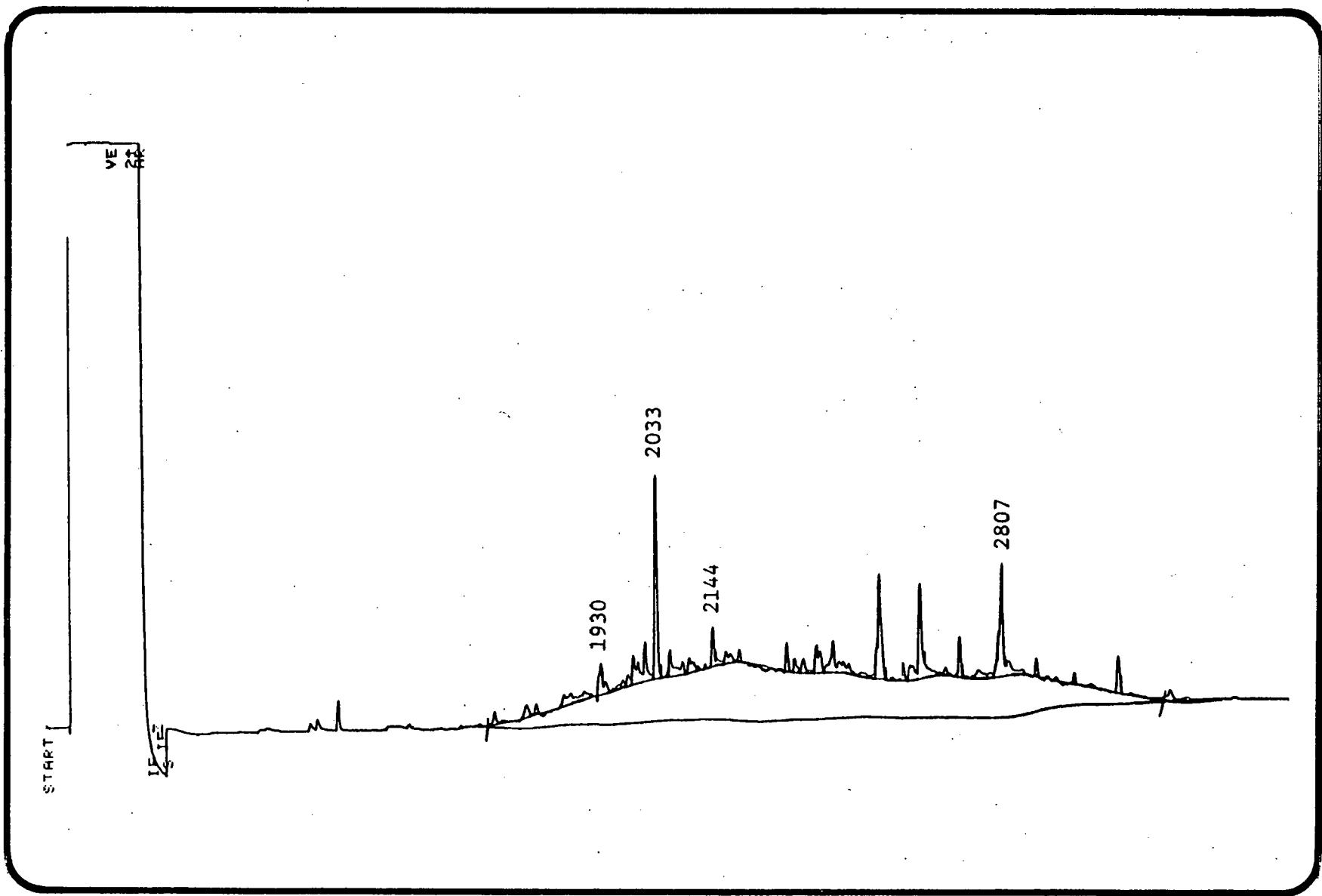
FIGURE 2-60   Gas chromatographic trace of the benzene fraction of the surface water filtrate from Weeks Island Site B, station WR-1.
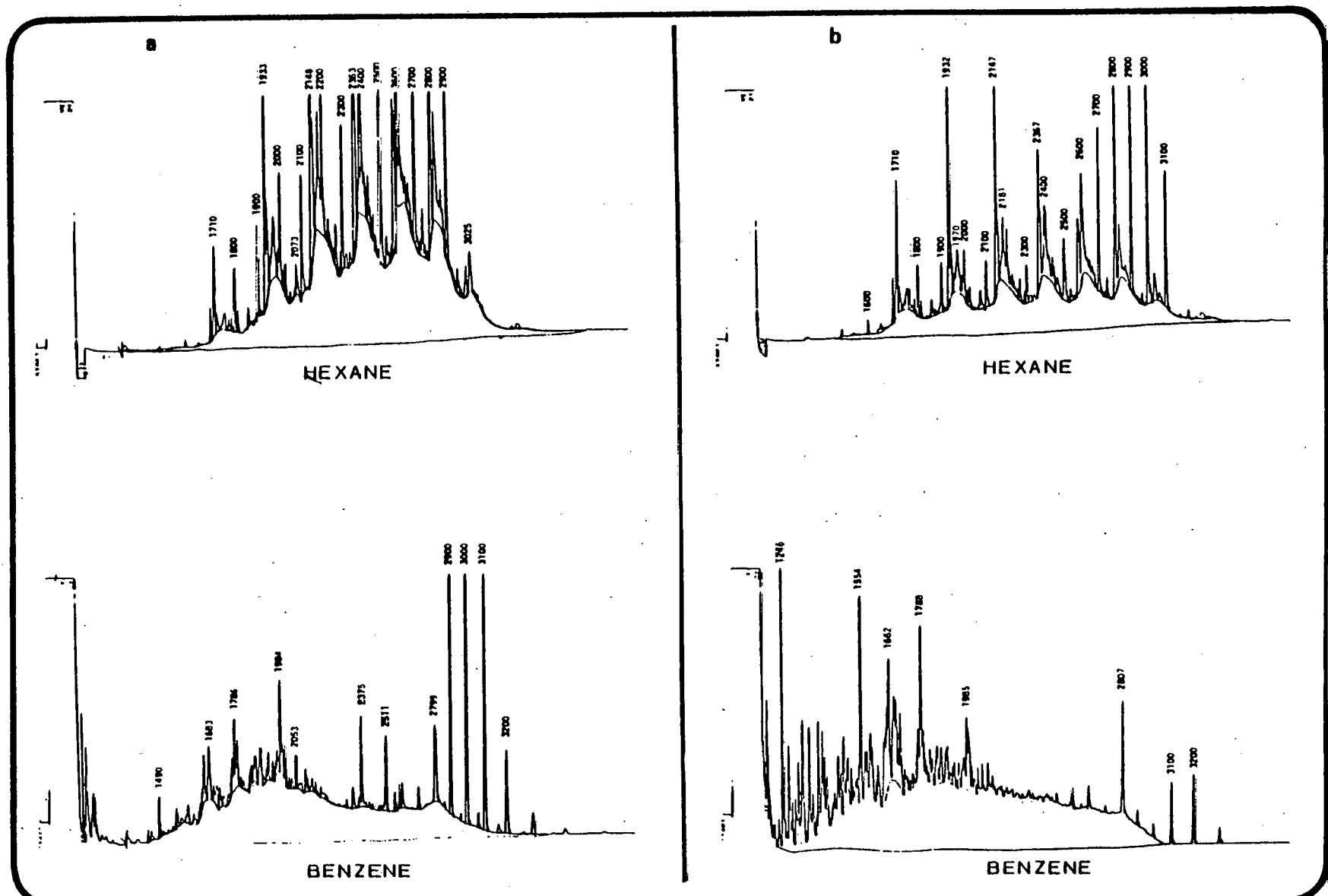
FIGURE 2-61 Gas chromatographic traces of the hexane and benzene fractions of the (a) surface water and (b) bottom water filtrates from Weeks Island Site B, station W-5.
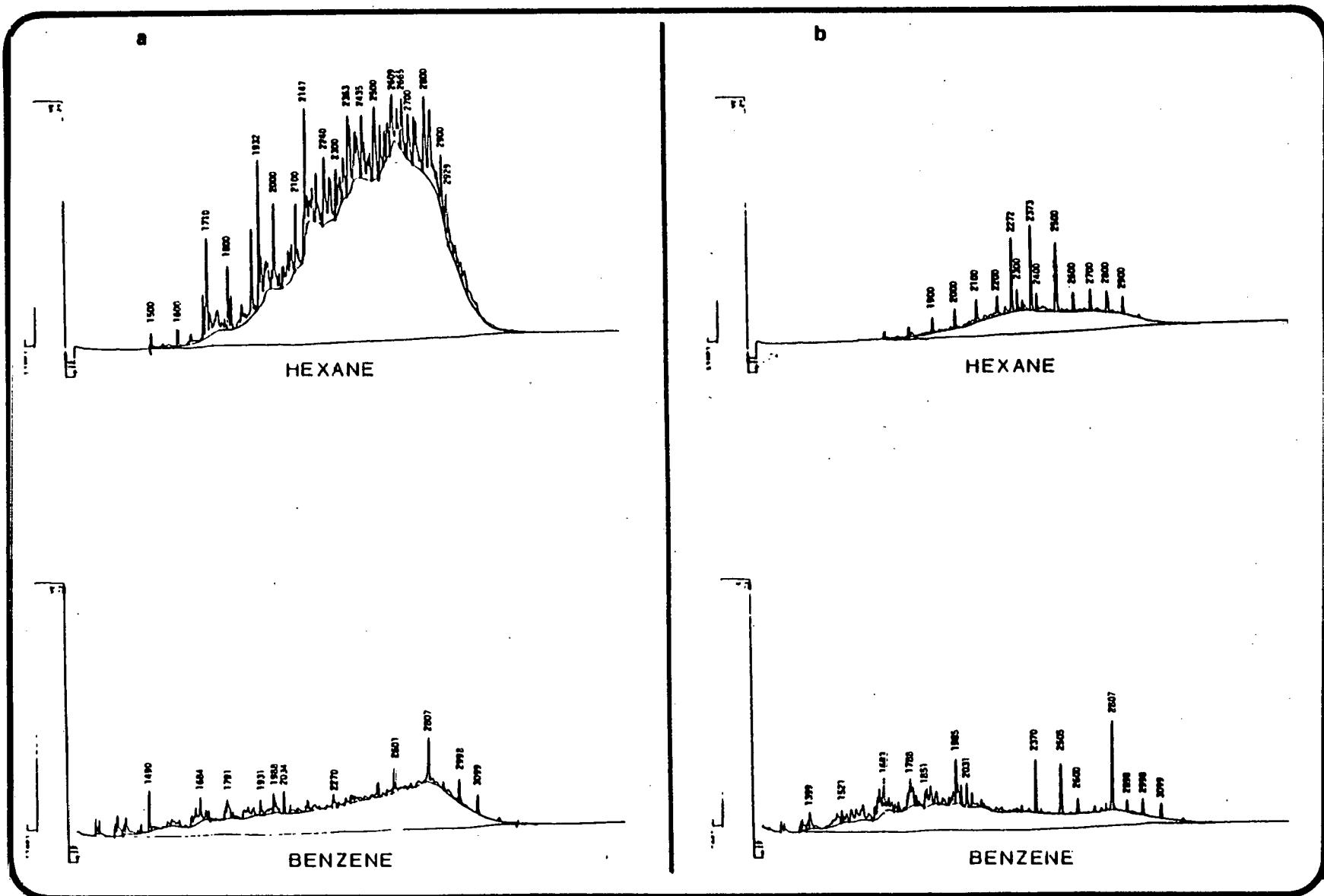
FIGURE 2-62   Gas chromatographic traces of the hexane and benzene fractions of the (a) surface water and (b) bottom water filtrates from Weeks Island Site B, station W-14.

TABLE 2-26   Hydrocarbon concentrations (ppm) in organisms collected from Weeks Island Sites A and B.

| | Hexane Fraction | | Benzene Fraction | | |
	Resolved	Unresolved	Resolved	Unresolved	Total
Site A (September 1977)					
Shrimp tails	0.023	0.649	0.105	0.407	1.184
Whole shrimp	0.276	12.628	0.245	2.832	15.981
Croaker w/o gut	0.509	8.16	Fatty acid methyl ester contamination		
Site B (February 1978)					
Whole anchovy[a]					
Mean	47.59	37.038	8.832	21.035	114.5
Range	38.634 - 57.384	31.594 - 45.022	5.235 - 11.745	13.456 - 32.186	101.42 - 139.73
Whole white shrimp[b]					
Mean	2.027	8.862	0.914	2.678	14.46
Range	1.555 - 2.429	6.492 - 10.824	0.326 - 1.796	1.312 - 5.085	12.07 - 16.77

[a]Mean of six pools of five to eight fish each.
[b]Mean of five pools of five to eight shrimp each.
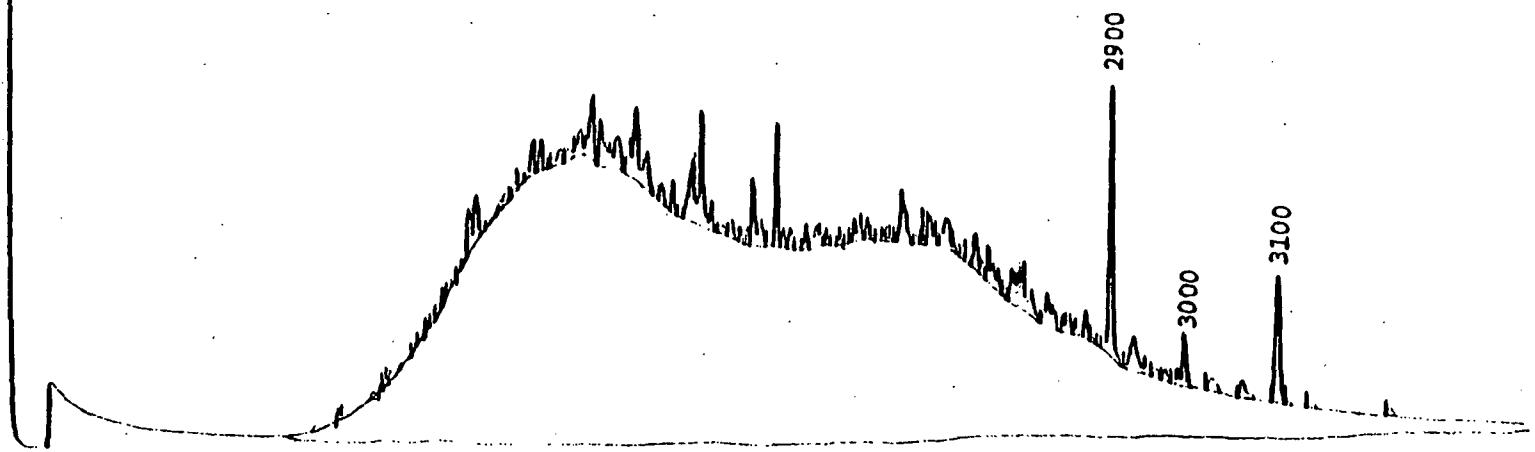
FIGURE 2-63   Gas chromatographic trace of the hexane fraction of croaker from Weeks Island Site A.
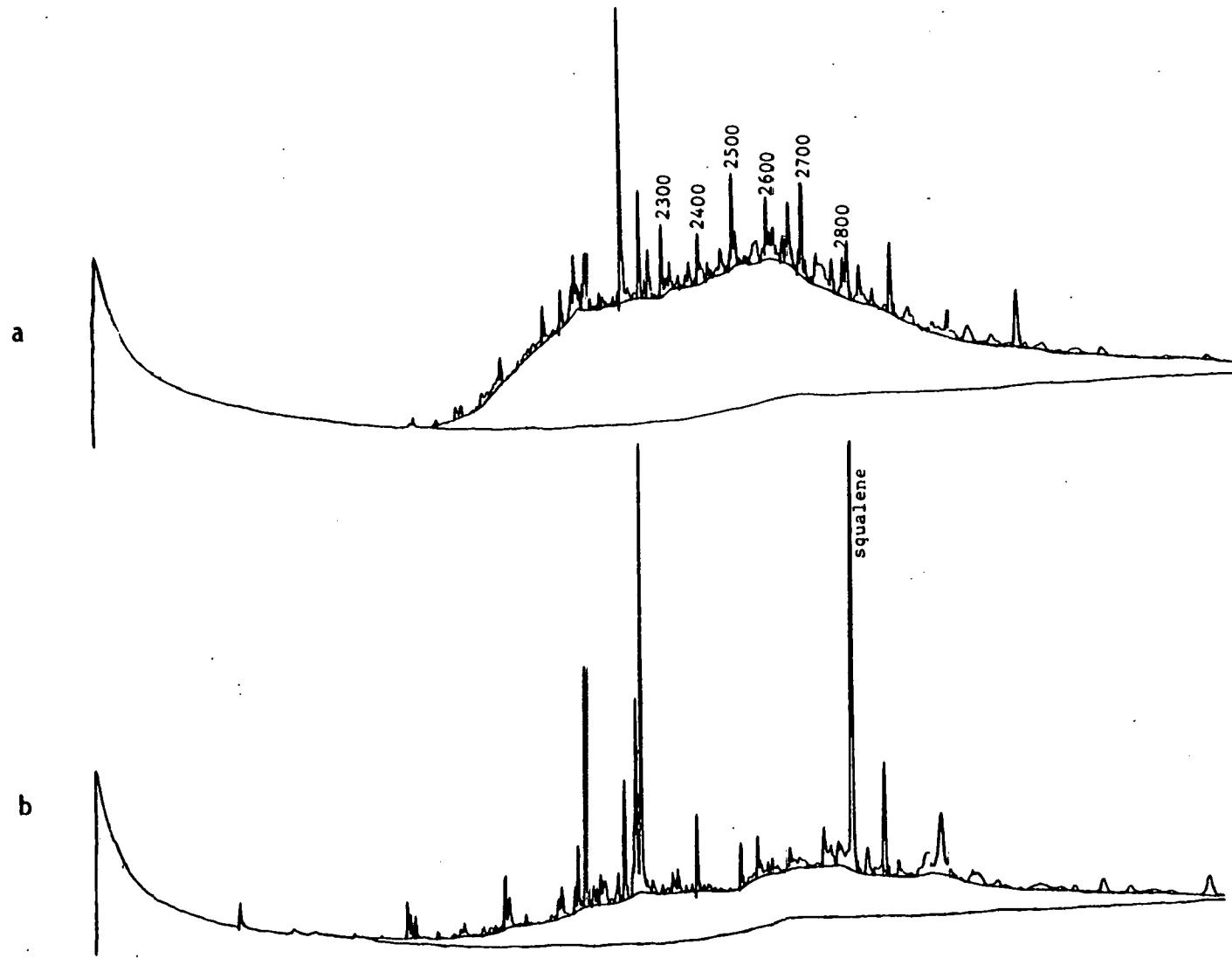
FIGURE 2-64   Gas chromatographic traces of the (a) hexane and (b) benzene fractions of whole white shrimp from Weeks Island Site A.
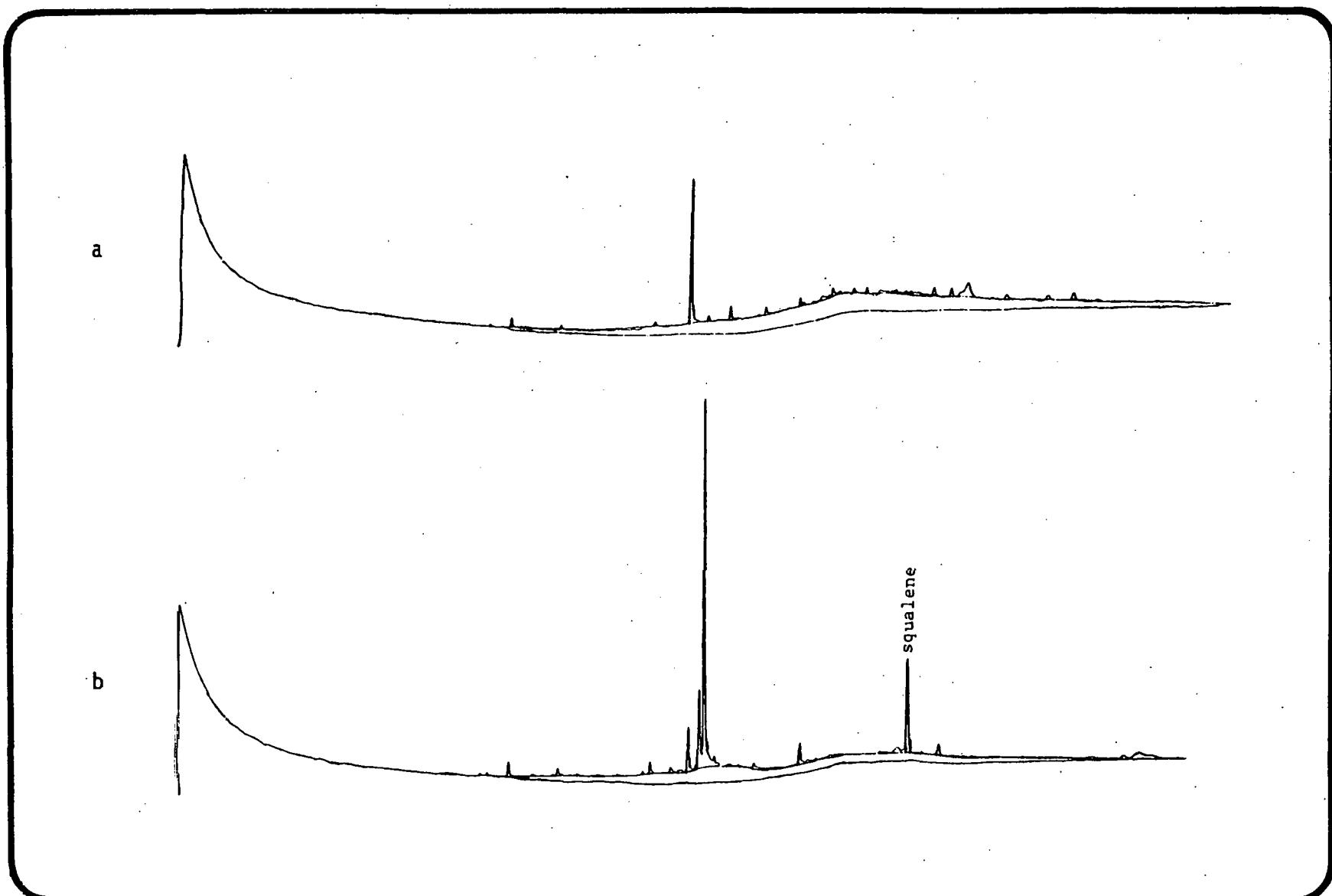
FIGURE 2-65   Gas chromatographic traces of the (a) hexane and (b) benzene fractions of the tail portions of white shrimp from Weeks Island Site A.
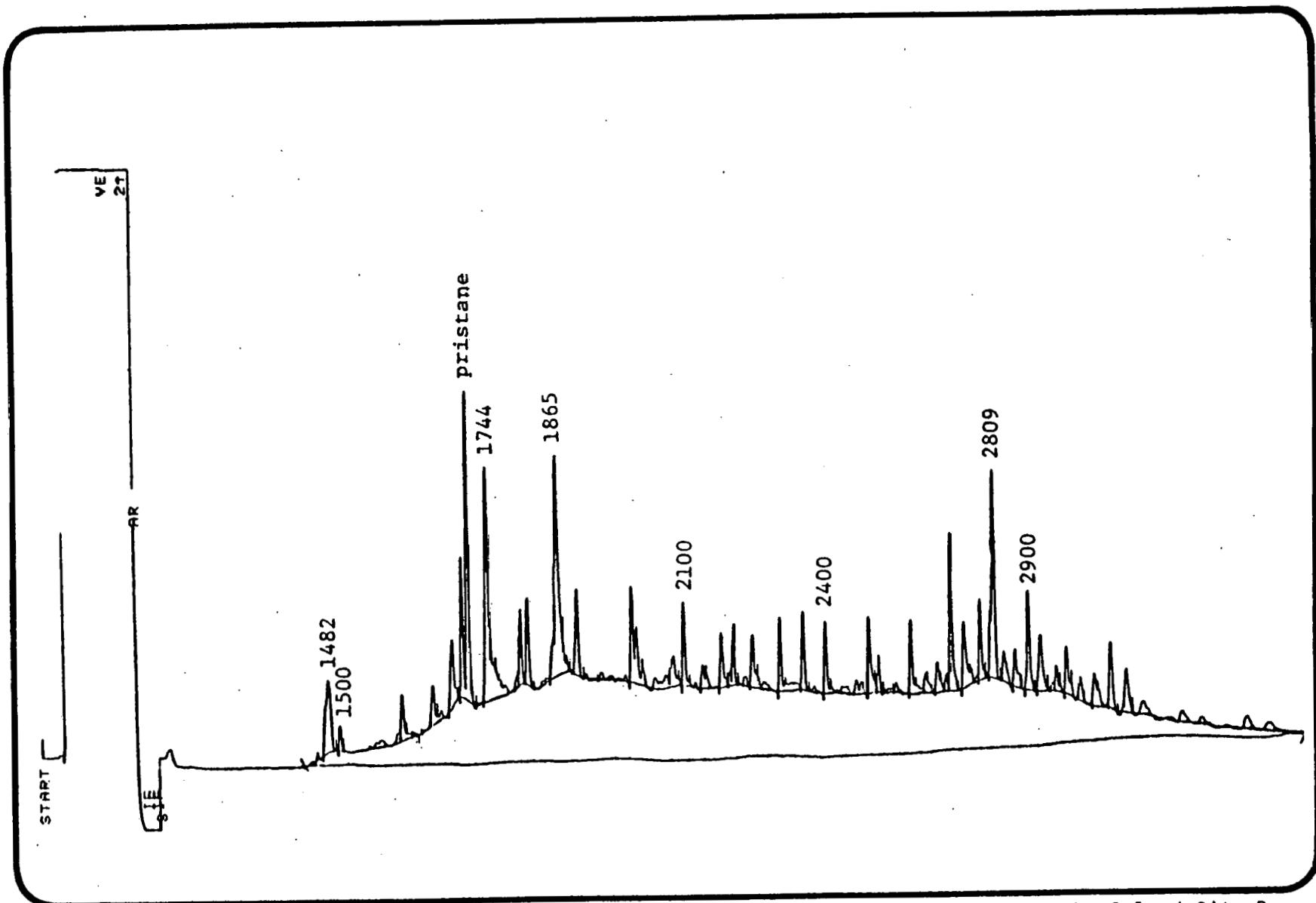
FIGURE 2-66   Gas chromatographic trace of the hexane fraction of white shrimp from Weeks Island Site B, WT-1 transect.
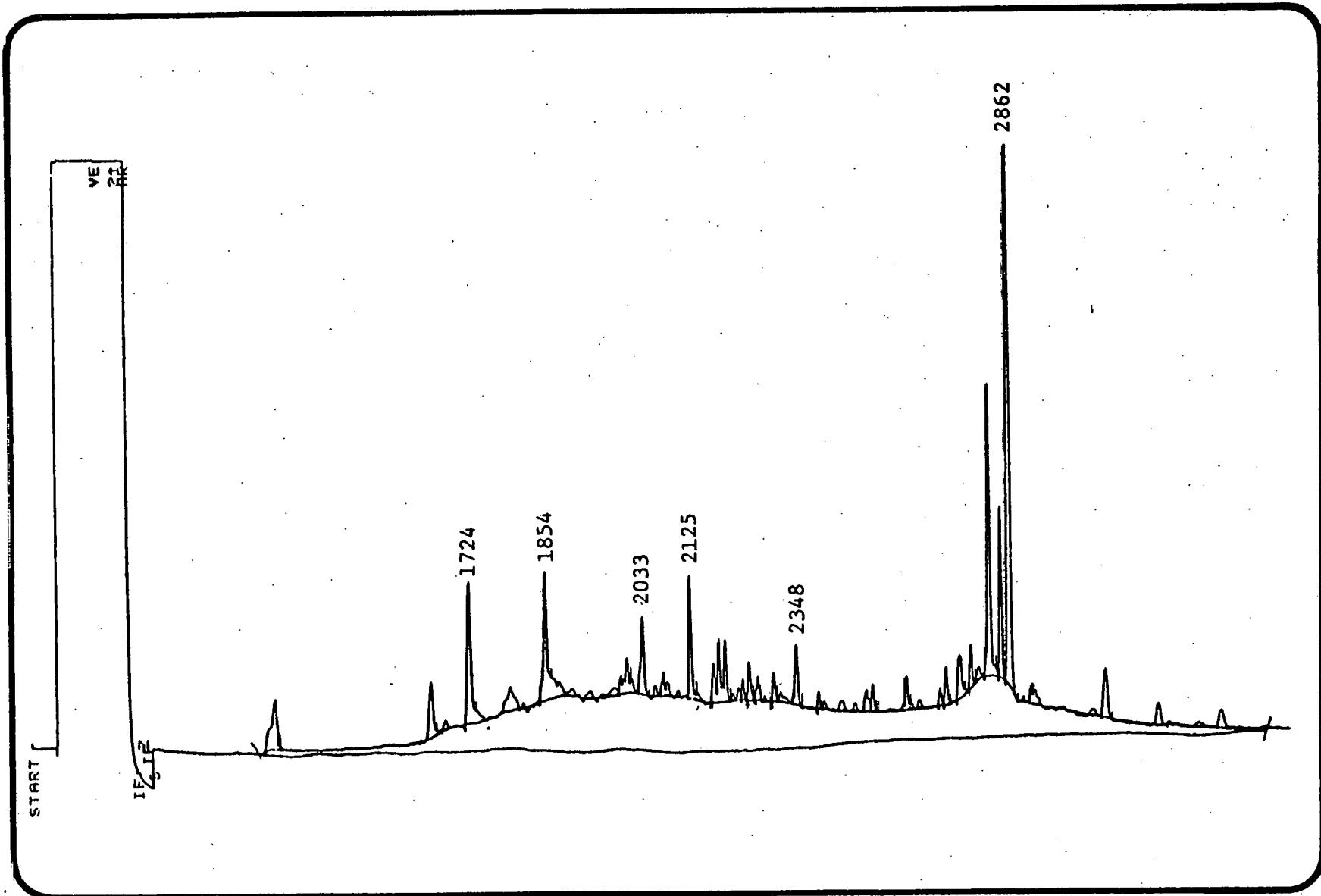
FIGURE 2-67   Gas chromatographic trace of the benzene fraction of white shrimp from Weeks Island Site B, WT-1 transect.

2.3.5 Suspended Matter

The turbidity of the water at Sites A and B is caused mainly by the presence of suspended matter in the water column. Turbidity has a large influence on light penetration (transparency) through the water column and affects the rate of photosynthesis and productivity of the area. The greatest turbidity occurs in shallow, inshore, low-salinity waters because of the influence of runoff from the Atchafalaya and Mississippi Rivers. These effects have been detected 15 to 18 miles offshore. Secchi disc measurements ranged from 1.5 to 21 feet (0.5 to 6.5 meters), (Flowers et al., 1975). Low transparency usually occurs in February, May, and June; high transparency occurs in September and March. Secchi disck readings off the Atchafalaya ranged from 0.7 to 2 feet (0.2 to 0.6 meters), with the greatest turbidity occurring in June and the least occurring in August and November (Juneau, 1975; Barrett, 1971).

The influence of the Atchafalaya River on suspended matter at the brine diffuser sites is evidenced by the greater total suspended matter at the more inshore Site A (Table 2-27)--particularly since Site A was sampled during a period of normally low turbidity. Analysis of the suspended material shows that particulate organic carbon makes up only a small proportion of the suspended matter at Site A, perhaps as a result of masking by the large quantity of terrigenous material found here.

TABLE 2-27.   Particulate material in the water column at Weeks Island Sites A and B.

		Total Suspended Matter (mg/l)	Particulate Organic Carbon (mg C/l)	POC/TSM (%)
Site A (September 1977)				
Surface	Mean	24.0	0.72	3
	Range	3.0 - 51.7	0.44 - 1.54	
Bottom	Mean	63.5	0.72	1.13
	Range	18.5 - 165.4	0.51 - 1.19	

Site B
(February 1978)

Surface	Mean	7.1	0.55	14.1
	Range	1.07 - 14.3	0.31 - 0.94	6.6 - 29.0
Bottom	Mean	10.7	0.64	8.3
	Range	3.55 - 24.7	0.37 - 1.15	4.7 - 10.4

2.4 Biological Oceanography

2.4.1 Habitats

North of the Weeks Island sites the Louisiana coastline is gener-
ally irregular and is characterized by a series of estuaries, bays, and
rivers. These highly productive areas support valuable sport and com-
mercial fisheries which include shrimp, crabs, oysters, and menhaden.
These species constitute almost 98 percent of Louisiana's commercial
fishery production. In addition, coastal areas serve as important
spawning and nursery grounds for many marine species.

The salinity of the waters at Sites A and B fluctuates seasonally
due to the large variations in freshwater runoff, precipitation, and
evaporation. The most influential factors regulating salinity at the
sites are the Gulf of Mexico and freshwater from the Mississippi and
Atchafalaya Rivers (Louisiana Wildlife and Fisheries Commission, 1971).
Surface salinity in this region varies from a few parts per thousand
in the estuaries to 36.5 ppt in the open Gulf waters.

Water temperatures varied seasonally from a low of about $43^{O}F$
($6^{O}C$) in December to a high of $96^{O}F$ ($35.6^{O}C$) in July. Currents in
the area show that the net long-term drift ranges from 0.25 to 0.75
knots (15 to 49 cm/sec) to the west and parallel to the coast.

Turbidity is highest in the estuaries and coastal regions and
decreases seaward. Dissolved oxygen attains maximum values (11.2 ppm)
during the winter months (December and January) and lowest values (below
5 ppm) during the mid-summer (July and August). Nutrient (nitrogen,
phosphorus) levels vary along the coast. Highest nutrient levels are
normally found where salinity values are lowest, indicating that the
major source of nutrients is from freshwater discharge into the coastal
waters. Nutrient concentrations decrease with distance from the coast.

The offshore bottom topography has a gentle slope and parallels
the coast. Within 20 nautical miles of the coast, the water depth
varies from less than 3 feet (1 meter) to more than 60 feet (18 meters),
a slope of about 0.05 percent. The sediments in the area are predomi-
nantly composed of highly organic silts and clays with some fine- to
medium-grained sands and shell fragments (LOOP, 1975).

2.4.2 Plankton

Because of the effect of the Atchafalaya River on the Gulf of Mexico, the plankton community is both diverse and productive. The indigenous plankton populations tolerate wide fluctuations in temperature and salinity. Due to this mixing of freshwater with Gulf waters, marine, estuarine, and freshwater plankton species may sometimes be found in the vicinity of the Weeks Island sites.

2.4.2.1 Phytoplankton

Phytoplankton are unicellular algae that rely on water currents for movement. These plankton convert water and nutrients into organic compounds by photosynthesis and are considered "the grasses of the sea." It is through the process of photosynthesis that phytoplankton act as an abundant source of energy for the higher trophic levels in the aquatic food web. The majority of the primary production at Sites A and B is due to phytoplankton rather than seaweeds or grasses.

Depending on the season, diatoms and dinoflagellates dominate the phytoplankton community. As listed in Table 2-28, 35 species and 26 genera of phytoplankton have been identified in the area (LOOP, 1975). During the late spring-summer, the dominant genera include Ceratium, Exuviaella, Goniaulax, Gymnodinium, Asterionella, Biddulphia, Coscinodiscus, Cyclotella, Lithodismium, Navicula, Skeletonema, and Thalassiasira. From September through December, Biddulphia, Navicula, Nitzschia, and Rhizosolenia are predominant; dinoflagellates are absent. During winter, the diatoms Asterionella, Fragillaria, Guinardia, Porosiria, Rhizosolenia, Skeletonema, and Thalassiosira dominate.

Phytoplankton biomass and productivity undergo large spatial and temporal fluctuations in the Louisiana coastal waters. Total phytoplankton density has been reported to range from 0 to 305,000 cells/liter (LOOP, 1975). Because of the high turbidities in the area, plankton biomass attains maximum values in the near-surface waters. Biomass reaches a maximum from June through August and a minimum from October to March. Cell densities are highest in the coastal bays and neritic zone and decrease seaward. In the neritic zone, phytoplankton diversity is greater than in either open Gulf waters or inland waters due to the presence of both freshwater and marine species. Values for primary

TABLE 2-28   Listing of phytoplankton taxa observed from May 1973 to
             March 1974.

Cyanophyta

    Oscillatoria sp.

Chlorophyta

    Chlorella sp.

Bacillariophyta

    Asterionella japonica

    Bacillaria sp.

    Biddulphia alternans

    Chaetoceros compressum

    C. peruvianum

    C. pelagicum

    Coscinodiscus excentricus

    Coscinodiscus sp.

    Cyclotella sp.

    Fragillaria sp.

    Guinardia flaccida

    Hemidiscus sp.

    Lithodesmium undulatum

    Navicula distans

    Navicula sp.

    Nitzschia sp.

    Pleurosigma sp.

    Porosira stelliger

    Rhizosolenia acuminata

    R. alata

    R. fragilissima

    R. imbricata

    Skeletonema costatum

    Stauroneis membranacea

    Thalassiosira aestivalis

Pyrrophyta

    Ceratium furca

    C. hircus

    Ceratium sp.

    Exuviaella sp.

    Goniaulax sp.

    G. monilata

    Gymnodinium splendens

    Peridinium sp.

SOURCE: LOOP, 1975.

production in the inshore surface and integrated euphotic zone (0.55 mg $C/m^3/hr$ and 7.04 mg $C/m^2/hr$, respectively) are higher than those for offshore waters (0.21 mg $C/m^3/hr$ and 5.45 mg C/m^2 hr, respectively), (El Sayed, 1972, as cited in U.S. Dept. of Interior, 1976).

The phytoplankton community at the Weeks Island brine diffuser sites conforms to the plankton community characteristic of the coastal waters of Louisiana. As listed in Tables 2-29 and 2-30, 115 species and 60 genera were identified in these waters between September 1977 and April 1978. The classes and number of species identified in each class are as follows: Bacillariophyceae (83), Dinophyceae (20), Chlorophyceae (7), Cyanophyceae (4), and Chrysophyceae (1). The majority of the Chlorophyceae and Cyanophyceae and several of the Bacillariophyceae were freshwater species, having been introduced into these coastal waters by riverine discharge. These species included Chlorella sp., Scenedesmus spp., Ankistrodesmus sp., Fragillaria sp., Actinastrum sp., and Navicula spp., and were most abundant at Site A in the surface waters in the fall and mid-winter and were generally absent at Site B in the late winter and spring. Several diatom species observed in this area, including Biddulphia spp., Chaetoceros spp., Rhizosolenia spp., Thalassiosira spp., and Skeletonema sp., are neretic forms (Cupp, 1943). Other species found in these waters in smaller numbers are mainly oceanic in distribution. Dinoflagellates were predominantly cosmopolitan and neretic species; two estuarine-neretic species (Dinophysis sp. and Peridinium sp.) were noted infrequently in surface and bottom waters.

Cell densities (Table 2-29, Figure 2-68) for surface and bottom waters at Site A were consistently low during the fall sampling period (September to December 1977). In contrast, chlorophyll a concentrations (Table 2-31, Figure 2-69) attained a maximum value (240 mg chl a/m^3) in September but fell to less than 30 mg chl a/m^3 in October and December.

During the late winter and early spring, phytoplankton and chlorophyll a concentrations at Site B increased (Table 2-32, Figure 2-68). Cell densities peaked in late winter-early spring (Figure 2-68). A small peak (105 x $10^4/m^3$) occurred in mid-March and an additional increase (214 x $10^4/m^3$) was evident in April. Chlorophyll a concentrations peaked in March and declined in April.

TABLE 2-29   Phytoplankton species and number of cells per cubic meter $(X\ 10^4)$ collected in the vicinity of Weeks Island Site A.

	September		October		November		December	
	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
CHLOROPHYCEAE								
Actinastrum hantzschii							4.7	
Ankistrodesmus falcatus			7.3				1.2	
Chlorella sp.	56.7	40.7						
Chodatella quadriseta	8.3							
Chlorococcum sp.			3.7	2				
S. armatus				4.6				
S. bijuga							14.3	
S. quadricauda			4.2					
TOTAL	65	40.7	15.2	6.6			20.2	
CYANOPHYCEAE								
Agmenellum thermale	211		24.5					
Anacystis incerta				72.3				
Oscillatoria spp.		18.6				35.3	1,014.3	
Schizothrix calcicola	126							
Spirulina subsalsa		0.7						
TOTAL	337	19.3	24.5	72.3		35.3	1,014.3	
BACILLARIOPHYCEAE								
Actinoptychus undulatus							3.1	14.5
Bacteriastrum delicatulum	0.1	0.1						
B. hyalinum	0.1							

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TABLE 2-29   (cont'd).

	September		October		November		December	
	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
Biddulphia aurita					4.9	6.1		
B. mobiliensis	0.3	1.4	5.3	4.4				
B. sinensis	0.4	0.9						
B. obtusa				3.7				
C. pelagica							3.6	
Chaetoceros affinis	6.1	0.6	28.6					45.7
C. brevis	18.6	12.4		19.2	59.5	15.5	4.7	56.1
C. compressus	26	19.5						
C. costatus	6.9	1.1						
C. curvisetum	17.9	11.7	170.9	170.6	7.7			98.3
C. decipiens	2.9	0.3				8.8	13.1	95.7
C. didynum	0.1	0.1						15.4
C. lacinosum	0.9							
Corethron criophylum	0.1	0.1		0.6				
C. centralis			1.4					8.8
C. granii	0.1							13.2
C. lineatus							3.6	31.4
C. oculus-iridis		0.5				5.1	5.4	7.6
C. radiatus		0.6		3.8	12.2			14.1
Coscinodiscus sp.	0.4	0.2			12.1	11.2	9.1	3.1
Cyclotella cf. C. caspia	104.3	61						
C. meneghiniana	8.3	20.3	8.6	1.3				
Eucampia sp.								2.2

TABLE 2-29   (cont'd).

	September Surface	September Bottom	October Surface	October Bottom	November Surface	November Bottom	December Surface	December Bottom
Guinardia flaccida				5.1				9.4
Hemidiscus hardmaniana								2.8
Hemiaulus hauckii		0.1					3.6	4.4
Leptocylindrus danicus		0.2	4.6	3.5				
L. minimus				6.6		6.6	12.2	16.9
Lithodesmium undulatum	1.5	1.4		4	7.1			17.2
Melosira granulata						39	300.1	50.7
Rhizosolenia alata	0.1	0.1		2.9				
R. calcar-avis				1.4				
R. imbricata		0.2						
R. setigera	0.3	1.4		11.7				
R. stolterfothii	0.2	2.2	2.4	18.9				2.8
Skeletonema costatum	3,953.1	3,929.3	1,688.7	1,673.3	231.6	483	86	894.3
Stephanopyxis palmeriana		0.1						15.7
Streptotheca thamensis	0.9	0.9	2.5	19.4		24		
Thalassiosira aestivalis								8.8
T. eccentrica		20.3	13.7	780	11.9	37		
T. rotula								36.7
Thalassiosira sp.	59.4	101.3						39.2
TOTAL	4,209	4,188	1,893	2,760	351	636	445	1,505

TABLE 2-29 (cont'd).

	September		October		November		December	
	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
PENNALES								
Amphiprora alata		0.2						
Asterionella cf. A. formosa							142.9	
A. japonica	15.2	34.7	5.3	54.5		45.7		
Diploneis crabro		0.2						
Fragilaria cf. F. leptostauron	52.7							
Gyrosigma balticum	0.1	0.6						
N. muralis				0.6				
Nitzschia acicularis				9.3				
N. capitata				1.7				
N. closterium	0.1	0.3			2.4			4.4
N. pungens	0.8	3.7		8.7		8.8	39.7	165.7
N. sigma		1.6	2.1	11				2.8
Nitzschia spp.			6.1					
Synedra ulna	8.3							
Thalassionema nitzschioides	1.6	1.8		45		8.8	14.8	171.3
Thalassiothrix splendens		0.1						
Tropodoneis sp.		0.3						
TOTAL	78.8	43.5	13.5	130.8	2.4	63.3	197.4	344.2

TABLE 2-29 (cont'd).

	September		October		November		December	
	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
DINOPHYCEAE								
C. hircus		0.1						
Dinophysis caudata	0.1							
P. conicum	0.1							
P. divergens	0.1	0.1						
Peridinium sp.						4.8		
Prorocentrum compressum		0.2						
Pyrophacus sp.	0.1							
TOTAL	0.4	0.4				4.9		
CHRYSOPHYTA								
Dictyocha fibula		0.03						
TOTAL		0.03						
SAMPLE TOTAL	4,690	4,292	1,946	2,970	353	739	1,682	1,849

TABLE 2-30 Phytoplankton species and number of cells per cubic meter $(\times 10^4)$ collected in the vicinity of Weeks Island Site B.

	February		Mid-March		Late March		April	
	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
CHLOROPHYCEAE								
Scenedesmus abundans				7.1				
TOTAL				7.1				
BACILLARIOPHYCEAE								
Biddulphia aurita								3.4
B. mobiliensis	38.1	22	68.9					
B. sinensis			1.8	6.9				
Ceratulina bergonii	60.2	84.6	29.8	10.3	225.7	141.8	431.1	21
Chaetoceros affinis			196.4	187.7	19.5	83.6	127	185.1
C. brevis	129.2	249.1		37.2	9	6.5	533.5	4151.5
C. costatus	91.4	320	184	498.8	844.5	435.8	57,931	93,195
C. curvisetum	410	494.6		230.6	110	72	61,623.1	33,194.5
C. decipiens	73.5							
C. didynum	460.5	75.8						
C. danicus		157.6					9	308
C. gracilis			40.6	157.3				9.7
C. lacinosum	69.8		67.4	62.8	2.2	3.2	663	337.6
C. socialis							2,413	2,892
C. similis			122.5	176.1				
C. cf. C. subtilis			50.6	27.4				
Chaetoceros sp.	6.9	18.4		140.4	4		22.1	42.5

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TABLE 2-30 (cont'd).

	February		Mid-March		Late March		April	
	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
C. centralis			18.4	20.5			441.5	228.8
C. lineatus							6	10.5
C. oculus-iridis		6.7		13.5				
C. radiatus	35.9	6.3					48.8	8.5
Coscinodiscus sp.	32.5	3.3	16.9			1	538.4	452.8
C. striata				5.4				
Cyclotella sp.					2.7	3.5		
Ditylum brightwellii	117.1	75.3	226.2	230.5	15.2	8.6	38.1	18
Hemiaulus hauckii	405	523.2	183.7	201.6			17	13.3
H. membranaceus		74.8		13.1	18.2	11.1	434.3	280.8
H. sinensis	265	310.5	19.7	77.9			31.5	18
Leptocylindrus danicus	107.1	111	197.1	114.7	16.1	34.5	117.3	114.6
L. minimus	26	39.3	103.1	138.5	112.8	174.3	49	6.5
Lithodesmium undulatum	66.5							1.6
Rhizosolenia alata							16	10
R. calcar-avis							63.8	33.2
R. fragilissima	20.2		88.7	96.8	3.5		350.2	135.5
R. imbricata							32.3	0.6
R. setigera	13.6	31.1	49.8	13.5			146.2	400.4
R. styliformis		2,160		6.3				
Skeletonema costatum	1,156.3	1,533.6	14,072.5	15,995.4	281	2,007.4	3,922.5	49,045.6
Stephanopyxis palmeriana	33.1	152.1		31.4				
Streptotheca thamensis		3.4						

TABLE 2-30   (cont'd).

	February		Mid-March		Late March		April	
	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
T. decipiens	248.9	7.6					32	28.3
T. eccentrica							15.3	3.6
T. rotula	350.7	160.8	33.7	5.1	1.1		17	
T. subtilis							13.5	16
Thalassiosira sp.	24.9	62.4				17.8	262.8	458.9
T. frauenfeldii		86						
TOTAL	4,244	6,769	15,772	18,499	1,666	3,001	130,346	185,665

PENNALES

	February		Mid-March		Late March		April	
	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
A. japonica			95,439	86,838.6	1.8	4.8	2,197.9	1,286.4
Gyrosigma balticum								4.9
N. closterium							60.9	60.4
N. cf. N. frustulum				1.8				
N. pungens							36,881.9	27,136.5
N. sigma					18.9	126.9		
Thalassionema nitzschioides							142.6	122.1
Tropodoneis lepidoptera				6.9				0.8
TOTAL			95,439	86,847	20.7	131.7	39,283	28,611

DINOPHYCEAE

	February		Mid-March		Late March		April	
	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
Ceratium furca								3.4
C. fusus						2.2		9.5
C. hircus					109.5	182.3	448.5	315.4

TABLE 2-30 (cont'd).

	February Surface	February Bottom	Mid-March Surface	Mid-March Bottom	Late March Surface	Late March Bottom	April Surface	April Bottom
C. tripos				9.6	3.5	7.2	16.3	
Cladopyxis sp.					5.3	7.6	4.3	
Dinophysis caudata					0.9			
Dinophysis sp.					0.8	5.5	1.8	
Noctiluca miliaris					92.7	65.1	71.9	37.9
Exuviaella baltica			335	243.9	427.4	584.7		
Goniaulax polygramma							4.8	1.3
Peridinium aciculiferum			3.6	5.1				
P. divergens					7.3	10.3	16.2	64
Peridinium sp.				38.6	21.9	5.4		
P. micans					1.1	8.9	30.1	9.2
P. maximum					1	1.1	16.7	40.8
P. scutellum			1.8		9.8	17.5	448.1	366.9
P. volzii			5			2.5		
Pyrophacus sp.								1.3
TOTAL			365	297	1	900	1,058	50
SAMPLE TOTAL	4,244	6,769	111,211	105,650	2,368	4,033	170,687	215,126

TABLE 2-31   Chlorophyll $\underline{a}$ concentration (mg/m^3) at Weeks Island Site A.

Station	September Surface	October Surface[a]	November Surface	December Surface	December Bottom
WR-1	0	23.5	36.3		
WR-2	0	33.44	0	13.2	19.7
WR-3	308	16.27	41.7	55.1	47.5
WR-4	0	20.46	25.1	16.9	34.8
W-1	0	0	0	29.1	40.4
W-2	178.5	0	29.8	17.9	38.6
W-3	0	20.46	40.9	0	0
W-5	263.2	21.85	28.2	25.4	56.4
W-6	0	0	0	22.6	36.7
W-7	0	21.39	53.9	0	0
W-8	0	0	43.7	50.5	16.9
W-10	263.2	0	25.1	0	0
W-11	0	14.66	26	7.5	20.7
W-14	0	22.32	25.1	13.2	33.8
W-15	206.8	0	27.9	0	0
AVERAGE	244.1	21.59	33.64	25.14	34.55

[a]Average of two surface replicates.

TABLE 2-32   Chlorophyll a concentration (mg/m^3) at Weeks Island Site B.

Station	February Surface	February Bottom	Mid-March Surface	Mid-March Bottom	Late March Surface	Late March Bottom	April Surface	April Bottom
WR-2	40	35.8	84.6	94	23.95	17.4	46.2	26.8
WR-3	65.1	75.3	159.8	112.8	17.4	46.1	41.7	28.3
WR-4	84.6	79.1	300.8	159.8	21.15	39.05	46.2	55.1
W-1	46.5	50.2	216.2	112.8	54.05	94	116.25	69.75
W-3	55.8	55.8	75.2	112.8	28.2	164.5	41.7	10.5
W-5	37.2	40.9	131.6	178.6	94	183.3	62.6	14.9
W-6	50.2	42.8	159.8	169.2	33.35	33.35	56.65	15.8
W-8	55.8	55.8	131.6	141	71.45	310.2	121.7	58.1
W-11	40	62.3	141	141	122.2	76.15	134.1	95.66
W-14	-	-	122	159.8	66.75	112.8	123.6	84.9
AVERAGE	32	55	152	138	53	109	79	46
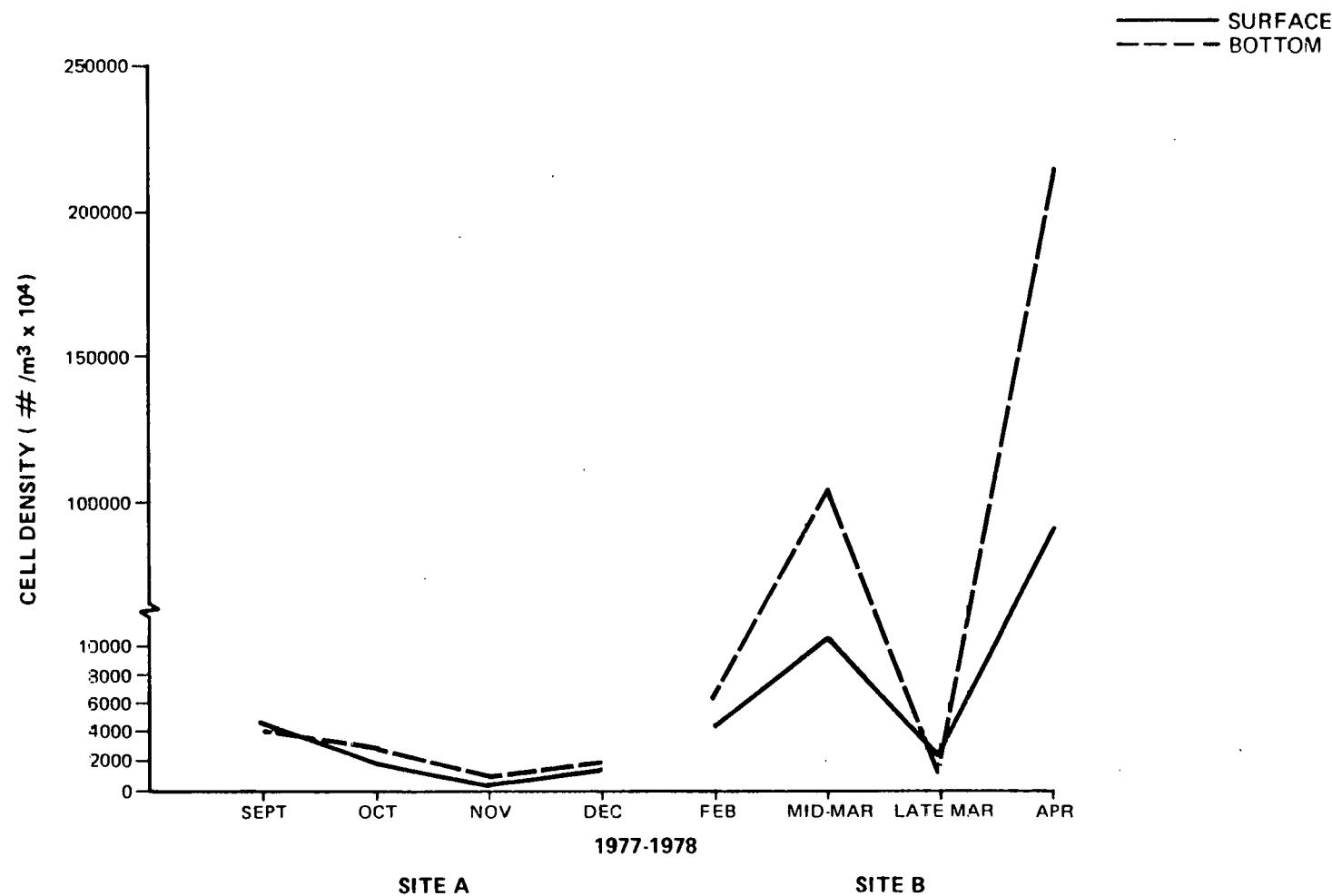
FIGURE 2-68   Average phytoplankton density at Weeks Island Sites A and B.
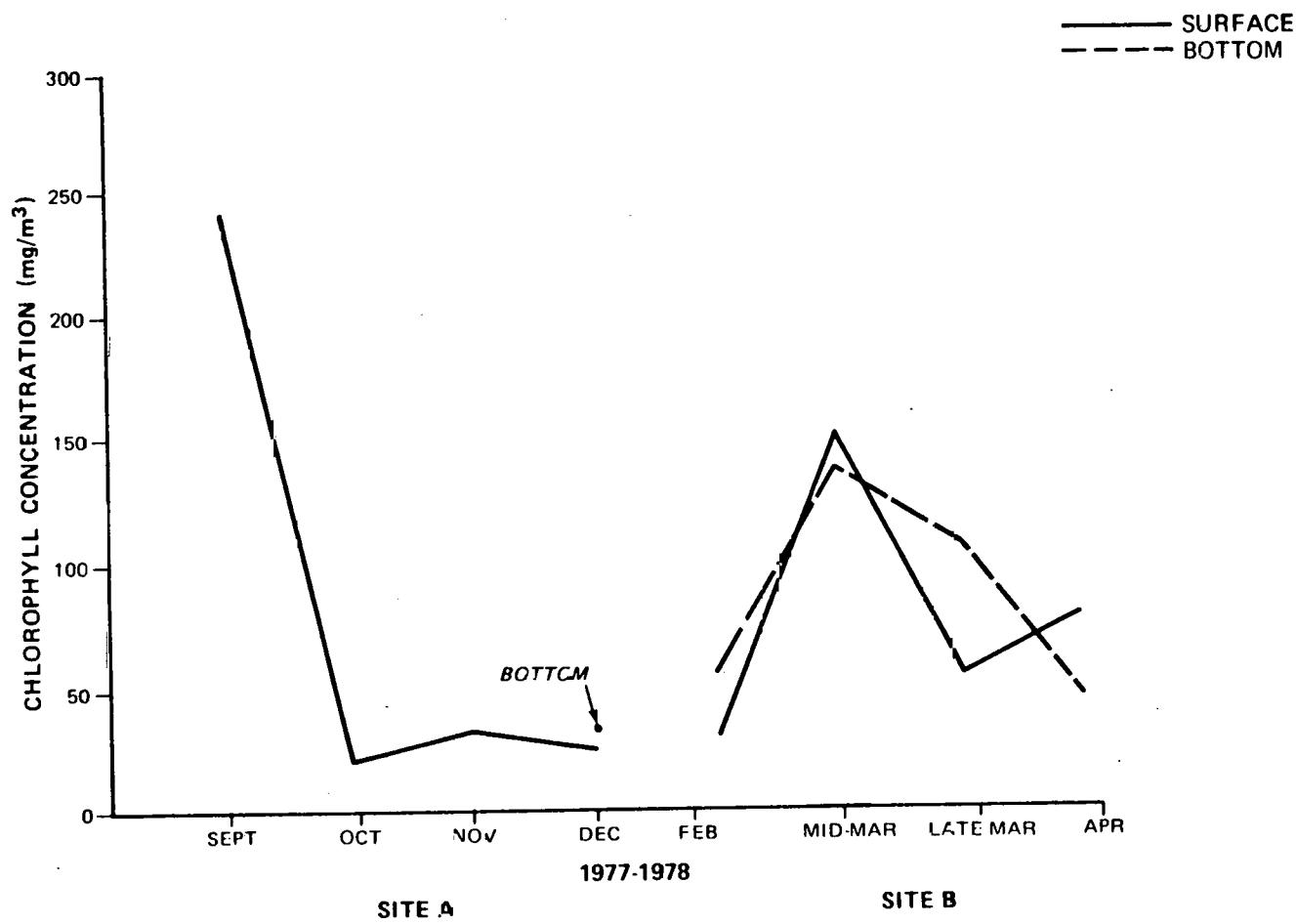
FIGURE 2-69   Chlorophyll concentrations at Weeks Island Sites A and B.

Diatoms were the major contributor to these plankton pulses throughout the 8-month sampling period (Tables 2-33 and 2-34, Figure 2-70). In general, the diatoms made up more than 71 percent of the plankton, with two exceptions--in December, when the percentage of Cyanophyceae in surface waters was high (Table 2-33, Figure 2-71), and in March and April, when the percentage of dinoflagellates in bottom waters was high (Table 2-34, Figure 2-72). The percentage contribution of each of the phytoplankton groups is summarized in Tables 2-33 and 2-34 and Figures 2-70 through 2-73.

Nutrients (silicate, phosphate, and inorganic nitrogen) were consistently higher at Site A than at Site D (Table 2-17). At Site A, surface nutrient concentrations were generally higher in the surface waters than in bottom layers; at Site B, nutrient concentrations in the surface and bottom waters were similar. There was little correlation between nutrient levels (Table 2-17) and phytoplankton densities (Figure 2-68).

2.4.2.2 Zooplankton

Zooplankton as a group have a limited ability for horizontal movement yet can undergo large vertical migrations within the water column. Herbivorous zooplankton transfer energy from the primary producers to higher levels of the food web. Zooplankters are also composed of eggs or larvae of fish, shrimp, crabs, oysters, and other organisms which spend a portion of their life cycles as plankton (meroplankton). Many other species are planktonic for their entire life cycle (holoplankton). Zooplankton tend to be omnivores though most species show a preference as herbivores or carnivores, and consume the alternate food source or detritus when their major food is scarce. The copepods Acartia, Paracalanus, and Oithona, the dominant zooplankton species at the diffuser site, are mainly herbivores and thus their seasonal population cycles follow those of the phytoplankton. These organisms are known to feed to a much lesser degree on detritus and other animals.

Zooplankton types collected east of the Mississippi Delta (LOOP, 1975) are listed in Table 2-35. Copepods dominated during all sampling months, composing 52 to 97 percent of the monthly total and averaging 79 percent over all months. Acartia sp., the predominant copepod genus, constituted 53 percent of the total. In the coastal waters of Louisiana,

TABLE 2-33   Composition (# cells x $10^4/m^3$) of major classes of phytoplankton, Weeks Island Site A.

	September		October		November		December	
	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
CHLOROPHYCEAE	65	41	15	7			20	
CYANOPHYCEAE	337	19	24	72		35	1,014	
BACILLARIOPHYCEAE								
Centrales	4,206	4,187	1,890	2,741	351	988	444	1,505
Pennales	79	43	14	140	2	63	197	344
Total	4,285	4,230	1,904	2,881	353	1,051	641	1,849
DINOPHYCEAE	0.4	0.4				5		
CHRYSOPHYCEAE		0.03						
TOTAL	4,687	4,290	1,943	2,960	353	1,091	1,675	1,849
CHLOROPHYCEAE (%)[a]	1.3	0.93	0.77	0.22		0.43	1.20	
CYANOPHYCEAE (%)	7.1	0.44	1.2	2.44		3.23	60.5	
BACILLARIOPHYCEAE (%)	91.4	98.57	97.19	97.33	100	96.32	38.24	100
DINOPHYCEAE (%)	0.008	0.009						

[a] These numbers represent the percentages of each of the four classes of phytoplankton in the surface and bottom samples.

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TABLE 2-34   Composition (# cells x $10^4/m^3$) of major classes of phytoplankton, Weeks Island Site B.

	February		Mid-March		Late March		April	
	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
CHLOROPHYCEAE				7				
CYANOPHYCEAE								
BACILLARIOPHYCEAE								
Centrales	4,244	6,769	15,772	18,500	1,656	747	78,197	185,662
Pennales			954	86,847	21	132	6,090	28,611
Total	4,244	6,769	16,726	105,347	1,677	879	84,287	214,273
DINOPHYCEAE			365	297	680	900	655	850
CHRYSOPHYCEAE								
TOTAL	4,244	6,769	17,091	105,651	2,357	1,779	84,942	215,123
CHLOROPHYCEAE (%)[a]								
CYANOPHYCEAE (%)								
BACILLARIOPHYCEAE (%)	100	100	97.86	99.61	71.0E	49.38	99.22	99.6
DINOPHYCEAE (%)			2.13	0.28	28.84	50.61	0.77	0.39

[a]These numbers represent the percentages of each of the four classes of phytoplankton in the surface and bottom samples.
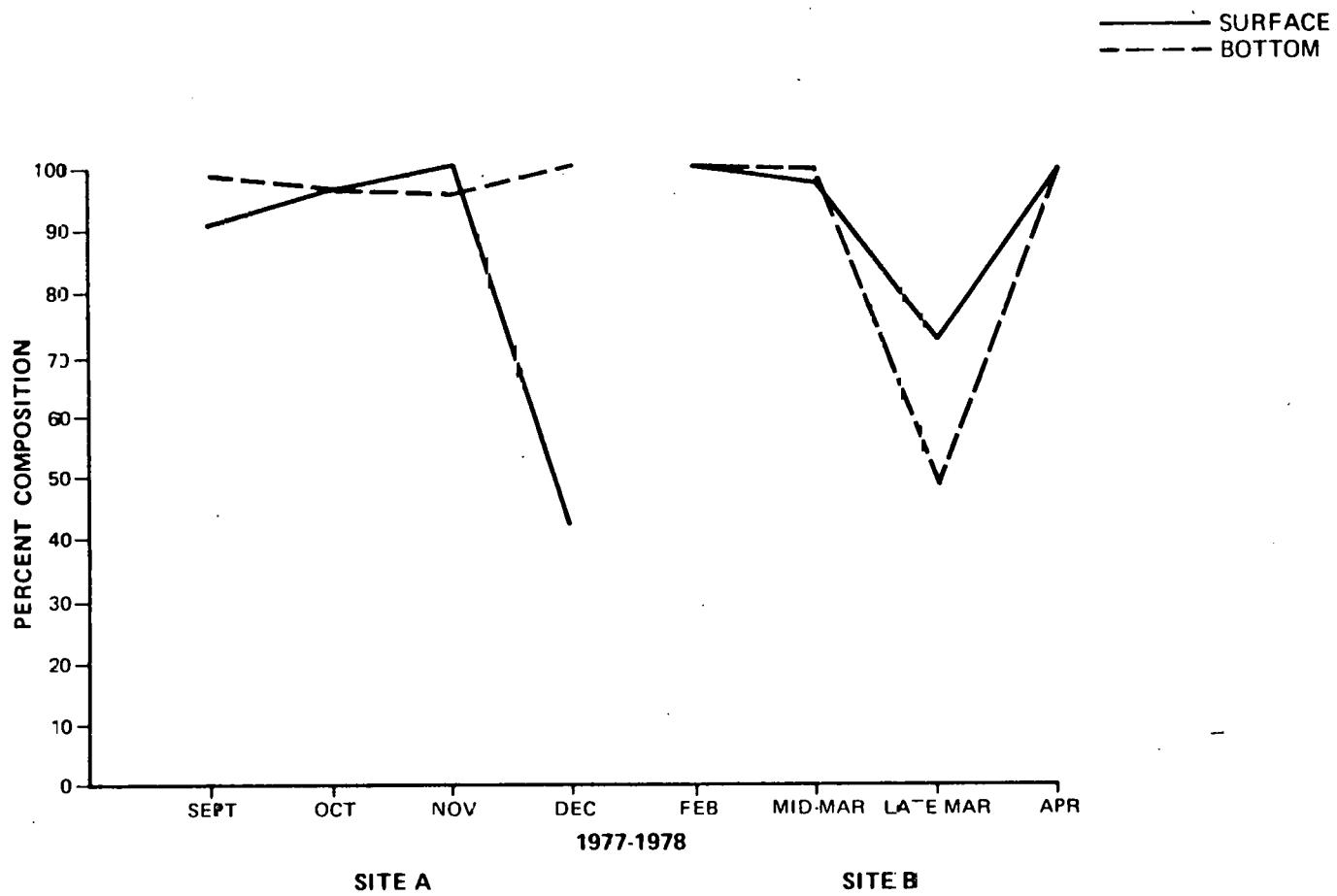
FIGURE 2-70   Percent composition of Bacillariophyceae in the total plankton count at Weeks Island Sites A and B.
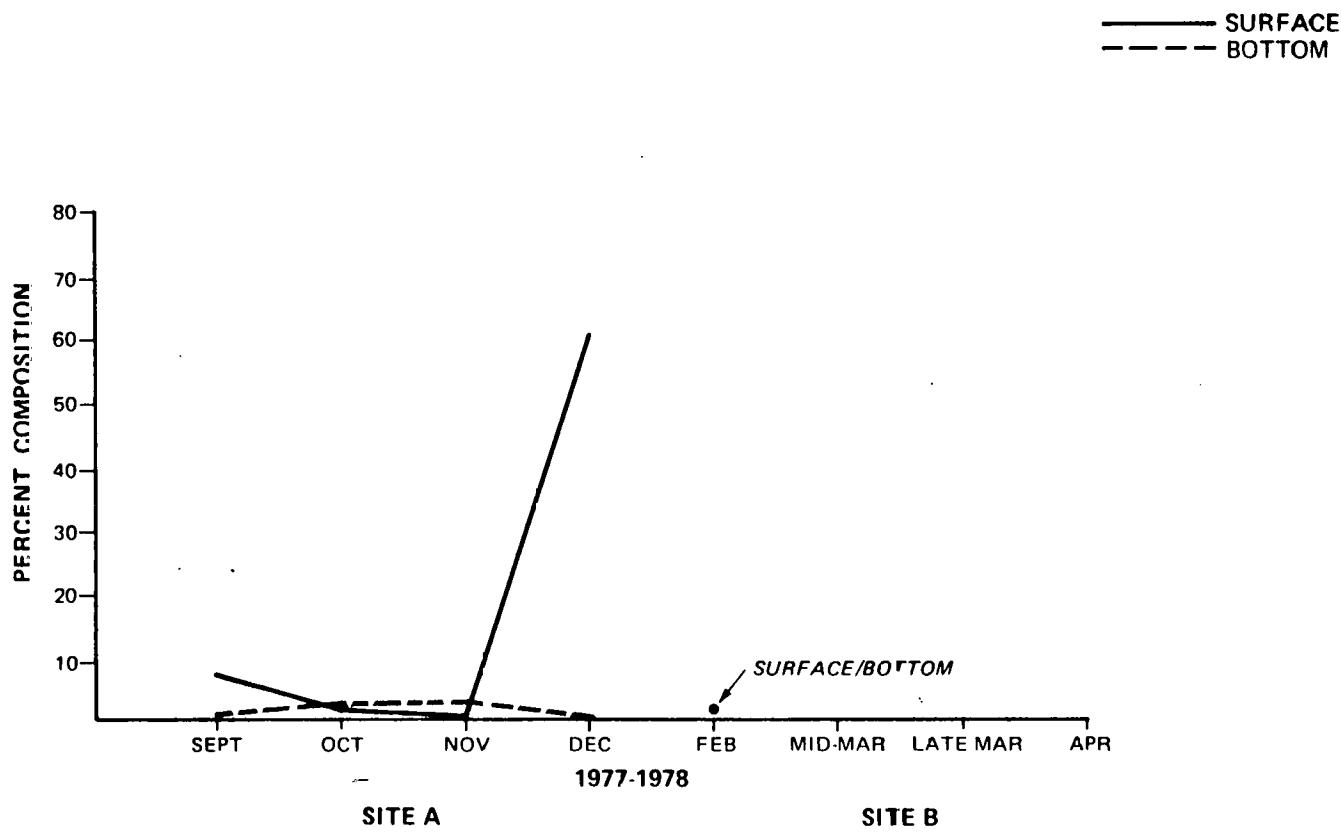
FIGURE 2-71   Percent composition of Cyanophyceae in the total plankton count at Weeks Island Sites A and B.
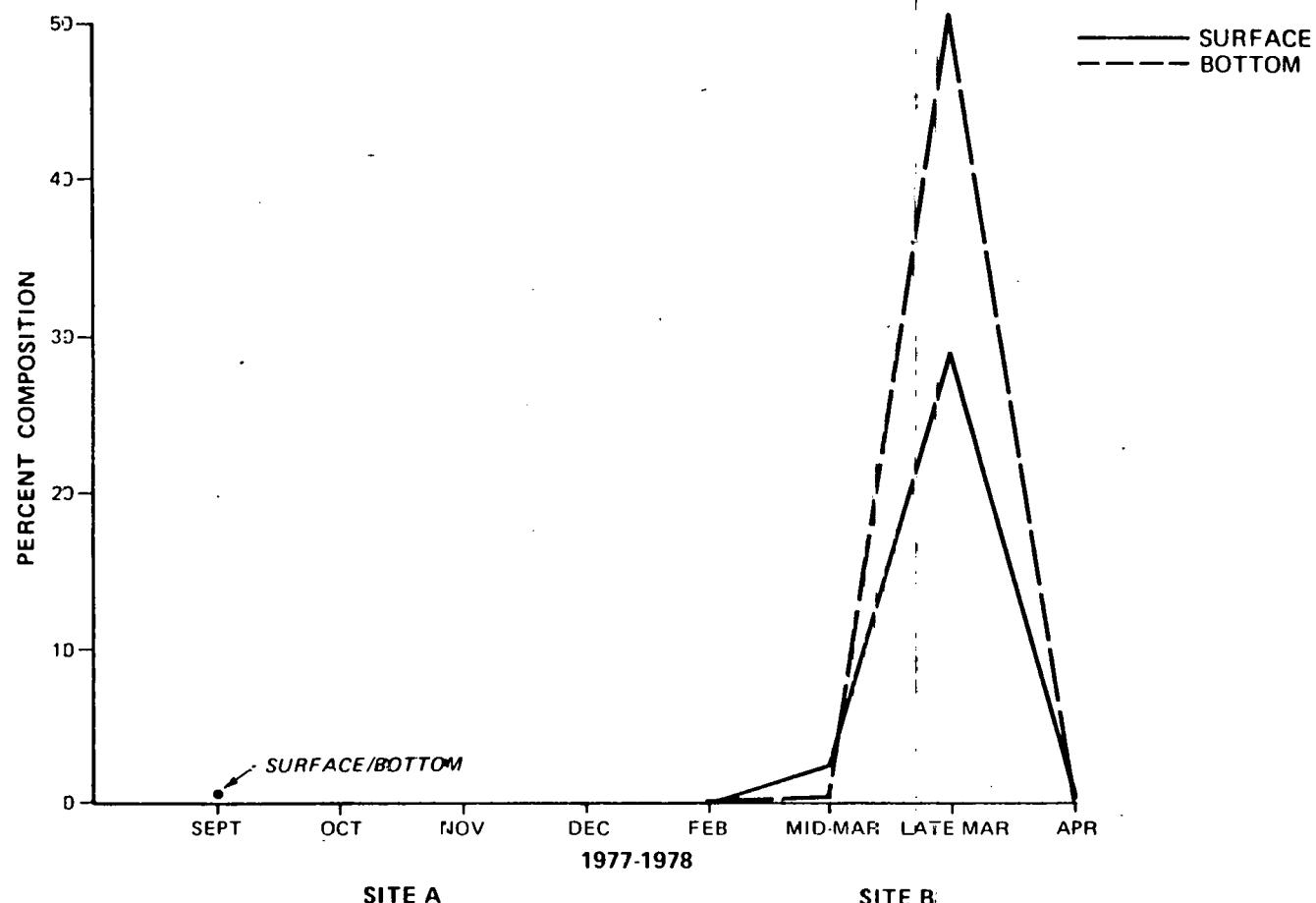
FIGURE 2-72 Percent composition of dinoflagellates in the total plankton count at Weeks Island Sites A and B.
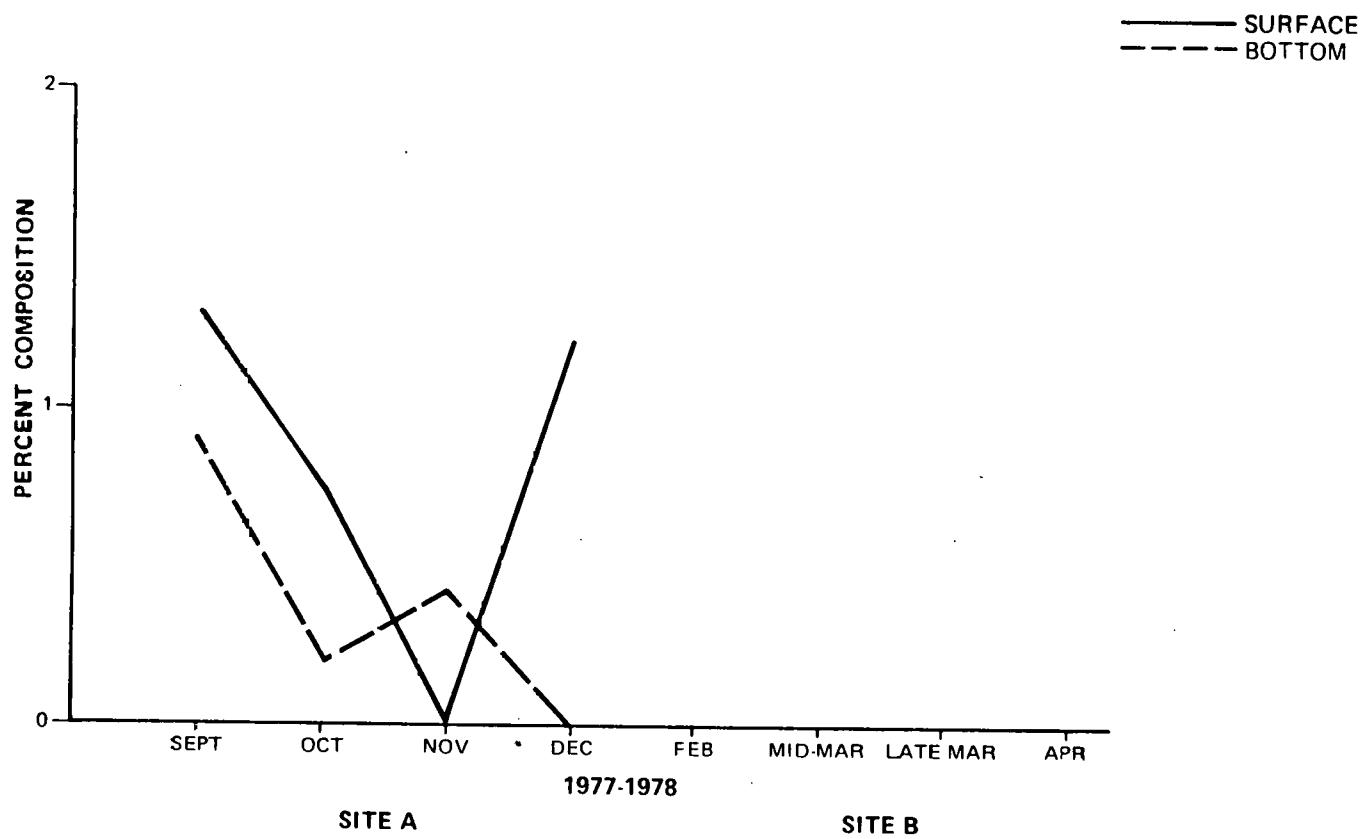
FIGURE 2-73   Percent composition of Chlorophyceae in the total plankton count at Weeks Island Sites A and B.

TABLE 2-35   Listing of zooplankton collected during the LOOP (1975)
              study.

Phylum PROTOZOA:

    Class Sarcodina

Phylum COELENTERATA

    Class Hydrozoa: medusae

    Class Scyphozoa: medusae

Phylum CTENOPHORA

    Class Tentaculata

Phylum ASCHELMINTHES

    Class Rotifera

    Class Nematoda

Phylum MOLLUSCA

    Class Pelecypoda: Lamellibranch larvae

    Class Pteropoda: Larvae

    Class Cephalopoda: Squid larvae

Phylum ARTHROPODA

    Class Crustacea

        Nauplei

        Zoea

        Megalops

        Ostracoda

        Cladocera

        Copepoda

            Acartia sp.

            Centropages sp.

            Eucalanus sp.

            Labidocera sp.

            Paracalanus sp.

            Pontella sp.

            Oithona sp.

            Herpacticoids

            Misc. copepods

TABLE 2-35 (cont'd).

        Amphipods

        Isopods

        Mysidacea

        Cumacea

        Stomatopoda larvae

        Decapoda

            Lucifer _faxoni_

            Acetes _americanus_

            Penaeid postlarvae

            Caridean postlarvae

            Unidentified decapod post larvae

Phylum CHAETOGNATHA

    Sagitta sp.

Phylum CHORDATA

    Subphylum Tunicata

        Class Larvacea

            Oikopleura sp.

        Class Thaliacea

            Doliolids

    Subphylum Verterata

        Fish eggs

        Fish larvae

SOURCE: Ragan, 1975.

Gillespie (1971) reported that Acartia sp. made up an average of 60 percent of the total plankton density, with maximum densities in May and October. During the LOOP study, Paracalanus sp. was the second most abundant genera, composing 28 percent of the copepods. Gillespie reported that this species occurred only in coastal waters east of Timbalier Bay, Louisiana, in the early spring and was absent during the summer months. Other copepods periodically present in quantity were Centropages sp., Oithona sp., Eucalanus sp., Labidocera sp., and Temora sp.

A successional pattern in zooplankton species occurs throughout the year (Gillespie, 1971); for example, pteropods are abundant from July to November, with a maximum abundance in October. In July, August, and February, pelecypod larvae are the abundant species. Cirripedia nauplii are present throughout the year but have maxima in April and October. Decopod larvae are found from April to November, with their maximum in August. From April through November many fish larvae are present; their densities peak in June.

Zooplankton peaks (1441 organisms/m^3) generally occur in May, with a low (740 organisms/m^3) in March and from June through September. During the LOOP study, mean zooplankton densities ranged from 2000 to 120,000 organisms/m^3. Densities at mid-depth were generally higher than those at the surface. During the LOOP study, zooplankton maxima were recorded in May through June and in September and November. Minima have been noted from December through March and from June through September (LOOP, 1975; Gillespie, 1971). The periods of zooplankton minima and maxima correlate closely with environmental parameters such as water temperature and salinity, local currents, winds, phytoplankton density, and predation, especially by ctenophores.

At the Weeks Island sites, eight zooplankton phyla were identified (Tables 2-36 and 2-37). Copepods dominated all of the samples, but were generally most abundant at Site A (September to December). This difference between sites is probably due to the seasonal plankton minima which occurs in the Gulf waters from December to March. The copepod population at both sites made up 95 to 99 percent of the total zooplankton community. Acartia tonsa, while generally more abundant at Site A,

TABLE 2-36   Average number of zooplankton per cubic meter collected at Weeks Island Site A.

	September	October	November	December
HYDROZOA	< 1			< 1
Hydromedusae				
TOTAL	< 1			< 1
CTENOPHORA				
Beroe sp.	< 1	< 1		
TOTAL	< 1	< 1		
ANNELIDA				
Polychaeta	< 1			
TOTAL	< 1			
ARTHROPODA				
Crustacea				
Cirripedia	< 1			< 1
Nauplii		5	21	
TOTAL	< 1	5	21	< 1
Copepoda				
Nauplii	143	16	182	3
Acartia tonsa	241	37	348	33
Caligus sp.	< 1	< 1		
Labidocera sp.	2			32
Longipedia sp.	< 1			
Oithona brevicornis		6	44	22
Oithona colcarva	57			
Paracalanus crassirostris	56	16	86	42

Table 2-36 (cont'd).

	September	October	November	December
Pseudodiatomus coronatus	< 1			
Temora tubinata	< 1	< 1		< 1
TOTAL	501	75	660	132
Isopoda				
Aegatha oculata	< 1	< 1		
TOTAL	< 1	< 1		
Mysidacea				
Mysidopsis sp.	< 1			
TOTAL	< 1			
DECAPODA				
Callinectus sapidus	< 1			
Clibinarus vittatus	< 1			
Lucifer faxoni	< 1			
Ocypodidae	< 1			
Palaemonetes sp.	< 1			
Penaeopsis sp.	< 1			< 1
Penaeus setiferus	< 1			
Petrolisthes armatus	< 1			
Pinnixia sp. zoea	< 1	< 1	< 1	
Rithropanopeus harrissii	1			
Xanthid metalops	< 1			
TOTAL	2	< 1	< 1	< 1

Table 2-36 (cont'd).

	September	October	November	December
BRYOZOA				
Larvae	17			
TOTAL	17			
CHORDATA				
Larvacea		< 1	< 1	
Anchoa mitchelli			< 1	< 1
Gobidae Larvae		< 1		
TOTAL		< 1	< 1	< 1
CHAETOGNATHA				
Sagitta enflata	2	< 1	2	< 1
TOTAL	2	< 1	2	< 1
SAMPLE TOTAL	524	81	662	133
Copepod/TOTAL (%)	96	95	97	99
Acartia tonsa/TOTAL (%)	46	46	53	24

TABLE 2-37   Average number of zooplankton per cubic meter collected at Weeks Island Site B.

	February	Mid-March	Late March	April
HYDROZOA				
Hydromedusae	< 1			
TOTAL	< 1			
CTENOPHORA				
Beroe sp.		< 1	< 1	
TOTAL		< 1	< 1	
ANNELIDA				
Polychaeta				
Larvae	< 1	< 1		
TOTAL	< 1	< 1		
ARTHROPODA				
Crustacea				
Nauplii	< 1		< 1	
Cypris larvae		< 1	< 1	
TOTAL	< 1	< 1	< 1	
Copepoda				
Nauplii	< 1		< 1	1
Acartia tonsa	< 1	1	50	4
Centropages sp.	< 1	< 1	< 1	< 1
Corycaeus sublatus	< 1			< 1
Labidocera sp.	< 1	< 1	< 1	< 1
Oithona brevicornis				< 1
Oithona colcarva	< 1		< 1	< 1

Table 2-37 (cont'd).

	February	Mid-March	Late March	April
Oncaea sp.	< 1			< 1
Paracalanus crassirostris	< 1		< 1	< 1
Sapharella sp.	< 1			
Temora tubinata	< 1			< 1
TOTAL	< 1	1	52	6
Mysidacea				
Mysidopsis sp.				
Mysid sp.	< 1			
TOTAL	< 1			
DECAPODA				
Acetes americanus	< 1			
Callinectus sapidus	< 1	< 1		
Clibinarus vittatus		< 1		
Lucifer faxoni				< 1
Pinnixia sp. zoea	< 1	< 1	< 1	< 1
Penaeus sp. larvae	< 1	< 1	< 1	
TOTAL	< 1	< 1	< 1	< 1
CHORDATA				
Larvacea			< 1	< 1
Brevortia sp.	< 1	< 1		
Syngnathus louisianae				< 1
Unidentified larvae	< 1			
TOTAL	< 1	< 1	< 1	< 1

Table 2-37 (cont'd).

	February	Mid-March	Late March	April
CHAETOGNATHA				
Sagitta enflata	< 1	< 1	< 1	< 1
TOTAL	< 1	< 1	< 1	< 1
SAMPLE TOTAL	< 1	2	52	6
Copepod/TOTAL (%)	99	98	99	97
Acartia tonsa/TOTAL (%)	58	92	95	71

contributed only 25 to 51 percent of the total zooplankton biomass.
At Site B, _A_. _tonsa_ contributed 69 to 95 percent of the total (Table
2-38). Copepod nauplii were codominant at Site A from September through
November and were considerably less abundant from February through
April at Site B. _Paracalanus_ _crassostrea_ was more abundant at Site
A. Two species abundant at Site A but absent at Site B were _Labidocera_
sp. and _Oithona_ _brevicornis_ (Table 2-38).

At Site A, average zooplankton densities ranged from a minimum
of 81 organisms/m^3 in October to almost 661 organisms/m^3 in November
(Figure 2-74). In contrast, a distinct series of minimum counts were
found at Site B from February to April. The fall maximum and spring
minimum correspond closely with plankton densities sampled west of
the Delta (LOOP, 1975; Gillespie, 1971).

Trace metal analyses performed on selected biological samples
collected at the diffuser site are presented in Appendix B. Zooplankton
contained higher concentrations of all metals (except copper) than
did fish or shrimp. This difference is due, in part, to the concentrat-
ing ability of these secondary producers (mostly chaetognaths) and
also to the difference of the extremely high surface area-to-mass ratio
of the zooplankton relative to the other macrofauna. Compared to two
other zooplankton samples taken from the northwest Gulf of Mexico (Appendix
B), manganese (Mn), zinc (Zn), and nickel (Ni) contents were higher
in the Weeks Island samples, while lead (Pb) content was considerably
less. Concentrations of iron (Fe), copper (Cu), cadmium (Cd), and
aluminum (Al), were within the range of values measured in northwest
Gulf samples.

TABLE 2-38   Percentage composition of the four most abundant zooplankton species collected during each sampling period.

	Site A					Site B		
	September	October	November	December	February	Mid-March	Late March	April
Acartia tonsa	46.2	45.7	50.9	25.7	69.1	92.1	95.5	71.4
Copepod nauplii	27.4	19.9	26.6		8.6		0.8	17.5
Centropages sp.						5.8		
Labidocera sp.				2.5				
Oithona brevicornis		7.1	6.5	35.5				
Oithona colcarva	10.7				14.5		1.4	
Paracalanus crassostrea	10.8	19.9	12.6	33.4	5.7		1.3	5.7
Sagitta enflata						0.4		
Cypris larvae						1.3		
Larvaceae								3.1
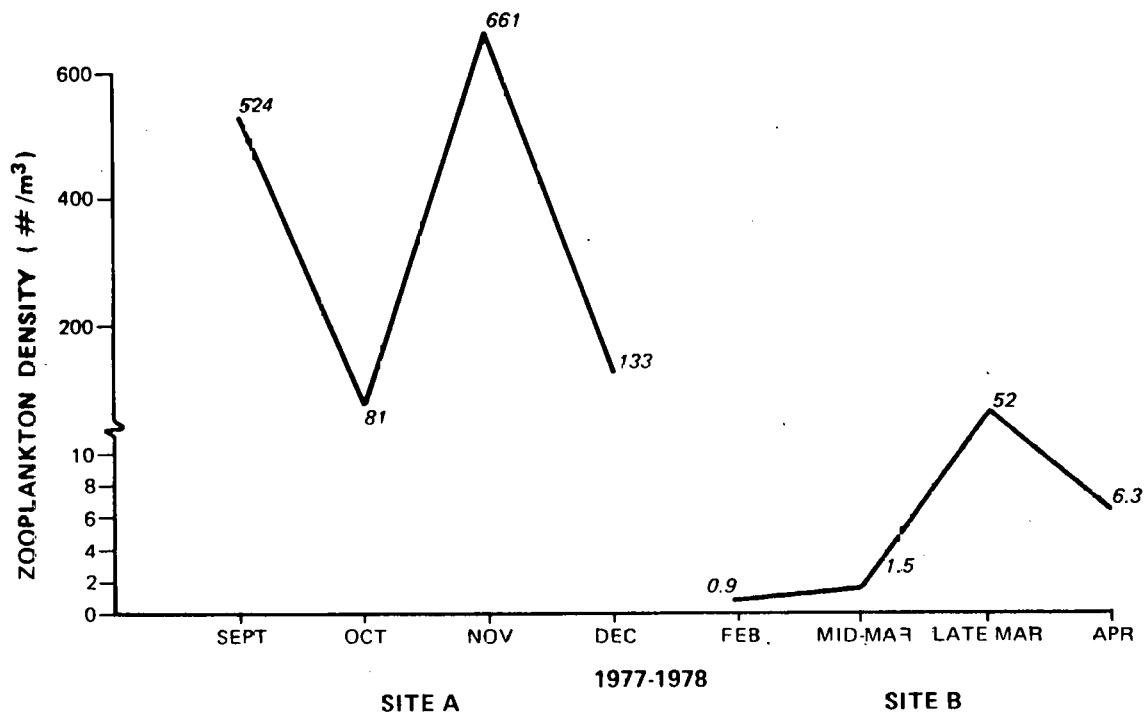
FIGURE 2-74   Average zooplankton density ($\#/m^3$) at Weeks Island Sites A and B.

2.4.3 Benthic Invertebrates

Benthic invertebrates representing many phyla and trophic levels are found at the Weeks Island sites and are important contributors to the trophic structure. Some benthic organisms feed on detritus and phytoplankton and convert this energy into a form not otherwise available to higher trophic organisms. Other benthic forms are carnivores or are preyed upon by higher carnivores; some of the top benthic carnivores are commercially important species such as shrimp, blue crab, croaker, and red drum.

In this study, shrimp, crabs, and fish that spend at least part of the time on the bottom were considered as nekton since they are highly motile and are most often caught with bottom trawls. The American oyster (Crassostrea virginica), a benthic organism of significant commercial importance in the region, does not inhabit the project area though some relic oyster reefs are located off Point Au Fer Island (Figure 1-2).

Benthic invertebrate distribution and abundance is greatly affected by environmental factors such as sediment type, water depth, DO, salinity, and temperature. The sediments in the area consist mainly of silt and fine sand which are deposited from the Mississippi and Atchafalaya Rivers. The DO in bottom water is often low during summer months. In waters west of the Mississippi River, there is a significant positive correlation between DO and total number of invertebrates and polychaetes. However, a statistically significant negative correlation is found between salinity and total polychaetes, total invertebrates, and phoronids. It is reported that between the 25- and 140-foot (8- and 43-meter) depth contours, there is a general decrease in the density of benthic macroinvertebrates; however, their densities are usually higher at stations in 49 to 62 feet (15 to 19 meters) of water than at those in 25 to 30 feet (8 to 9 meters), (Ragan, 1975).

Ragan (1975) reports the presence of 24 taxa of benthic macroinvertebrates (Table 2-39). Polychaetes are most abundant, averaging 69 percent of the total number of organisms. Phoronids and pelecypods are the second and third most abundant organisms, respectively. These three groups make up 94 percent of the samples. The mean density for total invertebrates is 860 organisms/m^2, with the range at individual stations from 180 to 2700

TABLE 2-39 Listing of benthic infauna collected by ponar grab sampler
           in Louisiana coastal waters during the LOOP study.

Scyphozoa: Medusae (jellyfish)

Anthozoa: Sea anemones

Nemertinea: Ribbon worms

Nematoda: Roundworms

Polychaeta: Sandworms

Gastropoda: Snails

     Cancellaria reticulata

     Oliva sayana

     Polinices duplicatus

     Other gastropods

Pelecypoda:

     Mulinia sp.

     Other Pelecypods

Isopoda: Isopods

Amphipoda: Amphipods

     Clibanarius vittatus: hermit crab

     Other hermit crabs

     Spider crabs

     Crangon sp.: Snapping shrimp

     Xiphopenaeus sp.: Sea bobs

     Unidentified shrimp

Phoronida

Chaetognatha: Arrow worms

     Sagitta sp.: Arrow worm

Echinodermata: Ophiuroidea - Brittle star

Chephlachordata: Lancelets

     Salpa sp.

Source: Ragan, 1975.

organisms/m^2. Seasonal density varies with depth; at shallow stations (25 to 62 feet (8 to 19 meters)) peaks occur in January and March, while at deeper stations (70 to 140 feet (21 to 43 meters)) the highest densities occur in September and December. Furthermore, these trends may depend on seasonal fluctuations in bottom salinity and DO rather than on light and temperature. Ragan (1975) concludes that the region's benthic invertebrates are not "exceptionally productive," though they are significantly more productive in onshore areas than in offshore areas.

In contrast to the LOOP study, 95 taxa of benthic invertebrates were collected at Weeks Island Site A from September through December 1977 and 183 taxa were collected at Site B from February through April 1978 (Table 2-40).

Species diversity, as measured by Shannon's density index, was calculated for each site during the sampling program. The index can be used to measure the quality of the environment and the effect of stress on the structure of a macrobenthic community. Communities with large numbers of species--none present in overwhelming abundance--have high diversity index values. Stress tends to reduce diversity by making the environment unsuitable to some species or by giving other species a competitive advantage. Thus, this index can be used to compare, on a relative basis, the healthiness of various organism assemblages. The calculated species diversities at Sites A and B are similar, but Site B had a greater range (Table 2-40). Individual station values range from 0.48 (WR-3, September) to 2.5 (W-1, November) at Site A and from 0.73 (W-2, April) to 3.11 (WR-2, mid-March) at Site B. Low diversity values are a result of certain polychaete species which dominated many samples at both sites and the bivalve Mulinia which dominated the April sample at Site B.

The density of benthic organisms was much greater at Site B than at Site A (Tables 2-41 and 2-42); values at Site A remained fairly constant from September to December, ranging from 530 to 604 individuals/m^2. Station densities ranged from 165/m^2 (WR-3, December) to 1410 individuals/m^2 (WR-1, October). At Site B, density values increased from 958/m^2 in February to 12,478 individuals/m^2 in April. Station densities ranged from 70/m^2 (W-4, February) to 45,360 individuals/m^2 (W-5, April), (Tables 2-40, and C-1 to C-8). Densities at Site A were similar to those

TABLE 2-40   Summary comparison of benthic macroinvertebrate infauna collected at
Weeks Island Sites A and B.[a]

	Site A (Sept - Dec 1977)	Site B (Feb - Apr 1978)
Total number of taxa	95	183
Mean monthly density range (individuals/m^2)	530 - 604	958 - 12,478
Mean monthly diversity (H') range	1.72 - 1.78	1.56 - 1.88
Number of polychaete taxa	28	94
Number of crustacean taxa	24	44
Number of mollusk taxa	33	38
Number of miscellaneous taxa	10	7
Percentage of polychaetes (monthly range)	64 - 73	26.8 - 86.2
Percentage of crustaceans (monthly range)	0.5 - 16	1.6 - 11.9
Percentage of mollusks (monthly range)	7 - 9	6.8 - 71.5
Percentage of miscellaneous groups (monthly range)	12 - 22	<0.1 - 0.4

[a]Based on data in Appendix C.

TABLE 2-41 Summary of benthic macroinvertebrate collections at Weeks Island Site A.[a,b]

| | Collection Date | | | |
	Sept	Oct	Nov	Dec
ANTHOZOA	R	R		UC
RHYNCHOCELA	A	A	A	A
CHAETOGNATHA				
Sagitta sp.	C	UC	C	A
GASTROPODA				
Anachis obesa		UC	R	UC
Anachis sp.	R			
Nassarius acutus	UC	C	C	C
Tectonatica pussilla	R	UC		R
Polinices duplicatus	R	R		
Epitonium rubicola			R	
Epitonium sp.	R	R		
Prunum apicinum	R			
Prunum sp.		R		
Terebra protexa			R	
Terebra sp.				R
Neritina sp.	R			
Olivella dealbata		R		
Turbonilla sp.		UC		UC
Cantharus cancelarius			R	
SCAPHOPODA				
Dentalium texasianum	R			
PELECYPODA				
Mulinia lateralis	C	C	C	C
Nuculana concentrica	C	C	C	C
Anadara ovalis		R	R	
Chione sp.	R		R	

TABLE 2-41 (cont'd).

| | Collection Date | | | |
	Sept	Oct	Nov	Dec
Noetidae	R			
Semele proficua	.R	R	R	R
Semele bellastritta	R			
Pandora trilineata				R
Lucina multilineata	R			
Lucia amiantus				R
Tellina sp.		UC	R	R
Abra aequalis		UC	R	UC
Gemma sp.		R		
Mactra sp.		R		R
Solen viridis			R	
Macoma constricta			C	
Macoma sp.		UC		UC
POLYCHAETA				
Spiophanes bombyx	A	A	A	A
Streblospio benedicti	A	A	A	A
Cossura longocirrata	A	A	A	A
Sigambra sp.	C	C	C	C
Lumbrineris sp.	R	UC	UC	UC
Lepidasthenia varia	UC	R	R	
Pseudeurythoe ambigua	C		R	R
Malmgrenia cf. lunulata	R			R
Glycera sp.	R	R		
Lepidonotus sp.	R			
Gyptis brevipalpa	UC	UC	R	R
Clymenella torquata	C	R	R	R
Chaetopterus variopedatus	R			
Onuphis opalina	R			
Onuphis sp.			R	UC
Diopatra cuprea	UC	UC	UC	UC
Megelona rosea		R	UC	R

TABLE 2-41 (cont'd).

	Collection Date			
	Sept	Oct	Nov	Dec
Cirratulus sp.				R
Amphictes gunneri		UC		
Chone infundibuliformis			R	
Glycinde solitaria	C	R	UC	UC
Paraonis fulgens	R			
Neanthes succinea	UC	C	C	C
Aglaophamus verrilli	UC	UC	UC	UC
Syllidae	R	UC	R	R
Stenolepis sp.		R		
Scolupus cf. elongatus	R	R		
Ancistrosyllis spp.	R	R	R	UC
OLIGOCHAETA	C	C	A	A
CRUSTACEA				
Monoculodes intermedius		R		
Corophium sp.			R	
Ogyrides limicola	R	R		
Campylaspis rubicunda	R	R		
Oxyurostylis smithi	UC	R		
Edotea montosa	R	R		
Paracaprella pusilla	R		R	
Calidus sp.			R	
Mysidopsis bigelowi		UC		
Lucifer faxoni	R			R
Acetes americanus cardinea	R	UC	R	
Hargeria rapax			R	
Xiphipeneus kroyeri	R			
Penaeus setiferus		A		
Upobegia affinis	R		R	
Callianassa latispina	R	R	R	
Polyonyx gibbesi	R			

TABLE 2-41 (cont'd).

	Collection Date			
	Sept	Oct	Nov	Dec
Euceramus praelongus	R		R	
Pagurus bullisi	R	UC	UC	R
Hepatus pudibundus	R			
Panopeus turgidus	R			
Panopeus herbstii		R	R	
Portunus sayi	R			
Pinnixa chaetopterana	UC	C	R	UC
ECHINODERMATA				UC
Amphipholis sp.	UC	C	C	
HEMICHORDATA (ACORN WORMS)			UC	UC
Ptychodera bahamensis	C	C		
CEPHALOCHORDATA				UC
Branchistoma sp.	UC	R	UC	
Total Taxa	61	55	49	42
Density (/m^2)	540	604	533	530
Diversity (H')^c	1.76	1.78	1.72	1.76

[a] Data from Appendix C, Tables C-1 through C-4, based on 32 samples in September and October and 38 in November and December.

[b] A = abundant (100 or more collected); C = common (20 to 99 collected); UC = uncommon (5 to 19 collected); R = rare (less than 5 collected).

[c] Diversity calculated using Shannon's diversity index, $H' = -\Sigma\, n_i/N \ln n_i/N$.

TABLE 2-42   Summary of benthic macroinvertebrate collections at Weeks Island Site B.[a,b]

| | Collection Date | | | |
	Feb	Mid-Mar	Late Mar	Apr
CNIDARIA				
Anthozoa				
Actiniaria	UC	C		
Paranthus sp.		C	A	A
Anemones (unidentified)				
RYNCHOCOELA	C	C	R	UC
Nemerteans (unidentified)			UC	C
ECTOPROCTA				
Bryozoans (unidentified)		R		
PHORONIDA	UC	UC	C	
Phoronids (unidentified)			UC	R
MOLLUSCA				
Gastropoda	R			
Vitrinellidae				
Cyclostremiscus pentagonus		R		R
Vitrinella floridana	R	R	R	R
Epitoniidae				
Epitonium multistriatum	R	R	R	UC
Melanellidae				
Eulima (=Strombiformis) bilineatus	R			R
Naticidae				
Natica pusilla		R	R	
Natica canrena	UC	UC	UC	UC
Polinices duplicatus		UC	UC	C
Columbellidae				
Anachis obesa				
Buccinidae				
Cantharus cancellaria	R			
Nassariidae				
Nassarius acutus	UC	UC	R	UC

TABLE 2-42 (cont'd).

		Collection Date		
	Feb	Mid-Mar	Late Mar	Apr
Olividae				
Oliva sayana	R			R
Olivella minuta	UC	UC	R	R
Terebridae				
Terebra protexta	R	UC	R	R
Turridae				
Kurtziella cf. rubella	R	R		
Pyramidellidae				
Turbonilla portoricana	R		R	
Odostomia gibbosa				R
Odostomia seminuda	R			
Odostomia sp. (near teres)				R
Acteonidae				
Acteon (=Rictaxis) punctostriatus		R		
Atyidae				
Haminoea succinea				
Retusidae				
Volvulella texasiana		R		R
Aplysia				
Aplysiidae				
Aplysia sp.				
Pelecypoda				
Solenidae				
Solen viridis	R	UC	R	UC
Arcidae				
Anadara transversa				R
Lucinidae				
Linga (=Lucina) amiantus	UC	UC	R	R
Parvilucina (=Lucina) multilineata				R
Cardiidae				
Trachycardium muricatum				UC

TABLE 2-42 (cont'd).

	Collection Date			
	Feb	Mid-Mar	Late Mar	Apr
Tellinidae				
Tellina squamifera				R
Tellina iris	UC	R	C	UC
Tellina versicolor	C	C	C	
Tellina sp.			UC	UC
Mactridae	R			
Mulinia lateralis	UC	A	A	A
Semelidae				
Abra aequalis	R	C	R	C
Veneridae				
Dosinia elegans	R	R	R	R
Mercenaria campechiensis				
Corbulidae				
Corbula cf. contracta	R	R	R	
Periplomatidae				
Periploma margaritaceum	UC	R	UC	R
Pelecypoda sp. A	R	R		R
Pelecypoda sp. B		R		
Ventricolaria rugatina		R		
ANNELIDA				
Polychaeta				
Polynoidae				
Lepidasthenia maculata	R			
Lepidasthenia sp.		R	R	
Harmothoe sp.		R		
Gattyana nutti			R	
Eulepethidae				
Grubeulepis cf. mexicana	R	R	R	UC
Sigalionidae			R	
Sthenelais boa	UC	R		R
Sigalion arenicola	R		R	
Sigalionids (unidentified)				

TABLE 2-42 (cont'd).

| | Collection Date | | | |
	Feb	Mid-Mar	Late Mar	Apr
Amphinomidae				
Pseudeurythoe ambigua			R	R
Phyllodocidae			R	
Eteone lactea			R	R
Eteone heteropoda				
Eulalia bilineata				
Paranaitis polynoides		R		
Phyllodoce mucosa			R	UC
Phyllodoce fragilis				
Phyllodocidae (juvenile)				
Pilargiidae				
Sigambra tentaculata			R	UC
Litocorsa stremma	R	R		R
Ancistrosyllis jonesi	R		R	R
Ancistrosyllis groenlandica	R			
Hesionidae				
Gyptis vittata	R		R	R
Nereidae				R
Nereis succinea			R	R
Nereid sp. A	R	R		R
Nereid sp. B		R	R	
Nereids (juvenile)				
Nephtyidae		UC	UC	R
Nephtys picta		C	R	R
Aglaophamus verrilli	C	C	C	C
Nephtyids (juvenile)				
Glyceridae				
Glycera americana	UC	UC	UC	UC
Glycera dibranchiata	R			
Glycera sp. (juvenile)			R	R

TABLE 2-42 (cont'd).

| | Collection Date | | | |
	Feb	Mid-Mar	Late Mar	Apr
Goniadidae				
Goniada littorea	R			
Glycinde nordmanni		R		
Onuphidae			R	
Onuphis eremita	UC	UC	R	UC
Onuphis nebulosa				
Diopatra cuprea	R	R	R	UC
Onuphids (juvenile)				
Lumbrineridae				
Lumbrineris albidentata		R	R	R
Lumbrineris tenuis	R		R	
Lumbrineris parvapedata	C	UC	UC	UC
Ninoe nigripes	R	_R	UC	R
Dorvilleidae				
Schistomeringos rudolphi				
Spionidae	R	R	R	R
Polydora ligni	R	UC	UC	
Polydora sp. (near caulleryi)				
Minuspio cirrifera	R	UC	R	UC
Paraprionospio pinnata	C	C	A	A
Appoprionospio pygmaea	UC	C	UC	UC
Prionospio cristata	R	UC	R	UC
Spiophanes bombyx	A	A	A	A
Spiophanes wigleyi				
Scolelepis texana	UC	C	UC	
Dispio uncinata	R	R	R	R
Spionids (unidentified)				
Magelonidae		R		
Magelona papillicornis	R	C	A	C
Magelona phyllisae	A	C	C	A
Magelona rosea			R	R
Magelona sp. (unidentified)				

TABLE 2-42 (cont'd).

| | Collection Date | | | |
	Feb	Mid-Mar	Late Mar	Apr
Poecilochaetidae				
Poecilochaetus johnsoni	R			
Chaetopteridae				
Spiochaetopterus costarum	R	R		R
Chaetopterids (unidentified)				
Cirratulidae				
Tharyx marioni		R	R	
Caulleriella sp.		R		R
Chaetozone sp. (near gayheadia)	R		R	R
Cirriformia grandis				
Cirratulid (unidentified)				
Cossuridae				
Cossura delta				R
Orbiniidae				
Haploscoloplos foliosus	R		R	R
Haploscoloplos fragilis	R	R		R
Haploscoloplos sp.		R	UC	R
Scoloplos capensis	C	C	C	A
Scoloplos rubra			UC	
Orbinia americana				
Paraonidae		R	R	R
Paraonis gracilis	R			
Paraonides lyra	R	R	UC	R
Aricidea cf. fragilis	R	R	UC	C
Aricidea sp. (near jeffreysii)	R	UC	UC	UC
Aedicira belgicae	R	R	R	UC
Paraonids (unidentified)				
Opheliidae				
Armandia agilis	UC	UC	UC	UC
Armandia maculata				

TABLE 2-42 (cont'd).

	Collection Date			
	Feb	Mid-Mar	Late Mar	Apr
Capitellidae				R
Mediomastus californiensis	A	A	A	A
Notomastus latericeus				
Notomastus cf. latericeus	R		R	
Notomastus lobatus			R	
Capitellids (unidentified)				
Maldanidae	UC	R	UC	UC
Asychis elongata				
Asychis sp.				
Clymenella torquata	UC	R	UC	
Maldanids (unidentified)				
Oweniidae				
Owenia fusiformis	UC	C	C	A
Galathowenia sp.	UC	UC	UC	UC
Flabelligeridae				
Piromis sp.		R		
Pectinariidae				R
Pectinaria gouldii				C
Ampharetidae		R	UC	C
Ampharete americana		R	R	R
Ampharetids (unidentified)				
Terebellidae				
Loimia medusa	R			
Amaeana trilobata	R			
Pista palmata				
Sabellidae				R
Chone americana	R	R	R	
Sabellid (unidentified)				
SIPUNCULA	UC	UC	R	C
Phascolion sp.				R
Golfingia sp.				

TABLE 2-42 (cont'd).

	Collection Date			
	Feb	Mid-Mar	Late Mar	Apr
ARTHROPODA				
Crustacea				
Ostracoda	C	UC		
Myodocopa				
Sarsiella gettlesoni			R	R
Sarsiella sp.	R			
Asteropteron oculitristis	R		R	R
Ostracods (unidentified)			C	C
Malacostraca				
Mysidacea				
Mysidopsis bigelowi				
Mysidopsis sp.			R	
Cumacea				
Cyclaspis varians		R	R	R
Cyclaspis sp.	R	R	UC	UC
Oxyurostylis sp.	R	UC	C	A
Isopoda				
Munnidae				
Munna sp.		R		
Sphaeromatidae				
Ancinus depressus	R	R		
Idoteidae				
Edotea montosa				
Amphipoda				
Ampeliscidae				
Ampelisca verrilli		R		R
Ampelisca agassizi				UC
Ampelisca sp. A		R	R	
Ampelisca sp. B				
Argissidae				
Argissa hamatipes			R	UC

TABLE 2-42 (cont'd).

	Collection Date			
	Feb	Mid-Mar	Late Mar	Apr
Oedicerotidae				
Synchelidium cf. americanum	C	C	C	C
Monoculodes nyei	UC	UC	UC	C
Corophiidae		R		
Erichthonius brasiliensis		R		
Corophium louisianum		C	UC	UC
Microprotopus raneyi		R	R	R
Microprotopus sp.				
Synopiidae				
Tiron tropakis				
Liljeborgiidae				
Listriella barnardi	R	UC	R	R
Phoxocephalidae				
Paraphoxus cf. epistomus	C	UC	C	UC
Haustoriidae				
Platyischnopus sp.	UC	UC	UC	UC
Acanthohaustorius sp.	UC	R	C	R
Protohaustorius bousfieldi	C	UC	UC	UC
Stenothoidae				
Parametopella texensis				
Bateidae				
Batea catharinensis				
Ischypoceridae				
Jassa falcata				
Decapoda				
Natantia				
Penaeidae				
Trachypenaeus similis		R		
Trachypenaeus constrictus				R
Xiphopenaeus kroyeri				
Sergestidae				
Acetes americana				R

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TABLE 2-42 (cont'd).

	Collection Date			
	Feb	Mid-Mar	Late Mar	Apr
Pasiphaeidae				
Leptochela serratorbita				
Alpheidae				
Automate rectifrons	R			
Hippolytidae				
Latreutes parvulus				
Ogyrididae				
Ogyrides limicola		R	R	R
Reptantia				
Callianassidae				
Callianassa acanthochirus			R	
Porcellanidae				
Euceramus praelongus		R		R
Diogenidae				
Isocheles wurdemanni				
Paguridae		R		R
Pagurus bonairensis	UC	UC	R	UC
Albuneidae				
Albunea paretti		UC	R	UC
Calappidae				
Hepatus epheliticus		R		
Leucosiidae				
Persephona mediterranea				
Majidae				
Majid (unidentified)				
Portunidae				
Ovalipes floridanus		R	R	
Callinectes similis				R
Callinectes sp. (juvenile)				
Portunid (juvenile)				
Xanthidae				
Hexapanopeus angustifrons				

TABLE 2-42   (cont'd).

| | Collection Date | | | |
	Feb	Mid-Mar	Late Mar	Apr
Goneplacidae				
Speocarcinus lobatus	R	R	R	R
Pinnotheridae				R
Pinnixa sayana	R		R	R
Pinnixa chacei				
Pinnixa sp. (juvenile)				
Pinnotherids (juvenile)				
ECHINODERMATA				
Asteroidea				
Luididae				
Luidia clathrata			R	
Ophiuroidea	R	R	R	R
Amphiuridae				
Micropholis atra		R		R
Ophiactidae				
Hemipholis elongata				R
Ophiuroids (juveniles)			R	
Holothuroidea				
Holothuroids (unidentified)	R			
CHORDATA				
Hemichordata			R	
Branchiostoma caribbaeum	R	R	R	R
Total Taxa	98	111	124	105
Density (/m^2)	958	2112	2070	12478
Diversity (H')^c	1.88	1.77	1.75	1.56

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[a]Data from Appendix C, Tables C-5 through C-8, based on 18 samples in February and mid-March and 19 in late March and April.

[b]A = abundant (100 or more collected); C = common (20 to 90 collected); UC = uncommon (5 to 19 collected); R = rare (less than 5 collected).

[c]Diversity calculated using Shannon's diversity index, $H' = -\Sigma\, n_i/N \ln n_i/N$.

reported by Ragan (1975) for coastal Louisiana, while those from Site B, as a whole, were slightly lower than values reported at similar depths off the Texas coast (1673 to 5008 individuals/m^2), (U.S. Dept. of Energy, 1978). These similarities in density may be due to the similar grain sizes of the respective groupings.

The benthic macroinvertebrate assemblages at both Sites A and B were dominated by polychaetes. This phylum made up 64 to 73 percent of the individuals collected from each cruise at Site A and 27 to 86 percent of the individuals collected from each cruise at Site B (Table 2-40). The polychaete Spiophanes was usually the most dominant benthic organism at both sites throughout the sampling period. Mollusks and crustaceans were abundant at both sites, particularly the bivalves Nuculana and Mulinia (Tables 2-41, 2-42, and C-1 to C-8).

Although phylum percentages were similar at the two sites, there were differences in density, as described earlier, and in distribution at the species level. The polychaetes Streblospio and Cossura were found mainly at Site A, while the polychaetes Mediomastus, Paraprionospio, Magelona, and Owenia were predominant at Site B. Mulinia and anenomes were in abundance at Site B; nemerteans and oligochaetes were found in greater densities at Site A.

These differences in distribution may have resulted from seasonal life cylces, feeding preference, grain size preference, or water quality parameters. Although sediment was silty at Site A and sandy at Site B, water quality at the two sites was similar. Species distribution may have varied between the sites because they were sampled at different seasons. For example, Mulinia was most abundant at Site A during the September sampling period but density decreased in subsequent months. At Site B, few Mulinia were collected in February, but the number increased in March and reached extremely high levels in April. This trend seems to indicate a distribution based on the organism's seasonal life style rather than sediment grain size. Anenomes and the polychaetes Paraprionospio, Magelona, and Owenia were found in greater numbers at Site B and their abundance increased with the onset of spring--perhaps due to both seasonal and sediment size factors.

A seasonal trend which has been reported along the Texas Gulf coast
(SEADOCK, 1975) is evident when combining data from the two sites.
Recruitment of the young begins during the winter, with peak populations
occurring from February through April. The benthic population is at a
reduced level in the autumn, after summer predation and mortality.

The SEADOCK (1975) study, conducted off the central Texas coast,
found similar species dominating the nearshore coastal areas--particularly
Spiophanes, Mediomastus, and Streblospio, and to a lesser extent, Cossura
and Mulinia. Magelona and Owenia were found farther offshore. As with
this study of the Weeks Island area, greater abundances were associated
with sandier grain size. Organism composition was similar to that of the
LOOP study site except that phoronids were the second most dominant group
in the LOOP study, but were rare in the Weeks Island area.

2.4.4 Nekton

2.4.4.1 Regional and Site Specific Characterization

Coastal Louisiana provides an extremely suitable habitat for one of
the major fisheries areas in the United States. Its high level of produc-
tivity is largely due to the interaction of the Mississippi River Delta
system with the Gulf of Mexico. Some of the major fisheries include
shrimp, menhaden, oysters, and blue crabs. Average annual harvests in the
area, from 1963 to 1967, are presented in Table 2-43. Many of these
species depend on the bays and estuaries for spawning, feeding, and growth,
and as a nursery area (Table 2-44).

Commercial landings in coastal and inland Louisiana during 1976 were
1.2 billion pounds, valued at $138 million. Menhaden was the leading
species in weight (1.1 billion pounds) and was second in value ($37
million). Shrimp was second in weight (82 million pounds) but first in
value ($80 million). The blue crab ranked third in weight (15.2 million
pounds) and fourth in value ($3.1 million). Oysters were third in value
($9 million). Louisiana led all states in volume and was third in value
(U.S. Dept. of Commerce, 1977b).

Sportfishing in the Louisiana coastal area is extremely popular and
provides for a large industry. The bays and nearshore regions yield
Atlantic croaker, spot, red drum, seatrout, black drum, southern flounder,

TABLE 2-43 Average annual harvest of major commercial fish and shellfish in Louisiana (1963-1967).

Species	Weight (millions of pounds)	Value (millions of dollars)
Menhaden	713.06	10.12
Shrimp	73.51	26.68
Croaker	23.71	0.42
Oyster	9.97	4.39
Blue crab	8.27	0.73
Spot	4.62	0.08
Catfish and bullheads	4.59	0.78
Seatrout	4.11	0.19
Red drum	0.53	0.09
TOTAL	842.37	43.48

SOURCE: U.S. Army Corps of Engineers, 1973.

TABLE 2-44 Migratory behavior of coastal organisms.[a]

Month	Movement into Estuaries (or nearshore zone)	Movement Out of Estuaries
Jan	Southern hake, Red drum (peak)	Menhaden, Spadefish
Feb	Stringray, Brown shrimp post-larvae, Menhaden, Spadefish	
Mar	Gulf killifish, Spot, Cutlassfish, Hogchoker, Butterfish, Rough silverside, Flounder, Tonguefish	Blue catfish, Sheepshead minnow, Longnose killifish
Apr	Gafftopsail catfish, Sea catfish, Bluefish, Bumper, Sand seatrout, Southern kingfish, Shipjack herring (in and out same month), Adult croaker, Back drum (peak), Pinfish, Atlantic threadfin, Toadfish, Midshipman	Bighead searobin
May	Striped anchovy, Lizardfish, Sardine, Spanish mackerel, White shrimp postlarvae	Menhaden, Southern hake
June	Needlefish, Pompano, Crevalle jack, Leatherjacket, Atlantic moonfish	Butterfish
July	Ladyfish, Lookdown	
Aug		Ladyfish, Atlantic threadfin
Sept		Adult croaker, Rough silverside
Oct	Menhaden, Sheepshead minnow, Bighead searobin	Sardine, Bluefish, Leatherjacket, Atlantic moonfish, Sand seatrout, Cutlassfish, Spanish mackerel

TABLE 2-44 (cont'd).

Month	Movement into Estuaries (or nearshore zone)	Movement from Estuaries
Nov	Blue catfish, Juvenile croaker	Striped anchovy, Gafftopsail, Sea catfish, Needlefish, Pompano, Crevalle jack, Bumper, Lookdown, Pinfish, Tonguefish, Toadfish, Midshipman, White shrimp juveniles
Dec	Longnose killifish	Stringray, Lizardfish, Gulf killifish, Spot, Southern kingfish, Flounder, Hogchoker

[a]From data contained in cooperative Gulf of Mexico Estuarine Inventory and Study, Louisiana, Phase IV, Biology. Perret, et al., 1971.

SOURCE: U.S. Dept. of Commerce, 1977a.

sheepshead, and spadefish. Oil rigs provide a reeflike environment with assemblages of cobia, crevalle jack, greater amberjack, sheepshead, great barracuda, king mackerel, blue runner, and Atlantic spadefish.

Recent studies of central coastal Louisiana (Perret, 1971; Ragan and Harris, 1975) characterize the region as having more than 42 species of invertebrates (Table C-9). Some of the more abundant invertebrates found in these studies are seabob, brief squid, white shrimp, brown shrimp, and blue crab.

Based on trawl data from Site A (September to December 1977), the dominant invertebrates collected were the white shrimp, seabob, blue crabs (including juveniles), and brief squid (Table 2-45). The dominant invertebrates collected in trawls at Site B (February to April 1978) were the seabob, brief squid, and white, sugar, and broken-neck shrimp (Table 2-46). At least 21 and 23 taxa of invertebrates were collected at Sites A and B, respectively. The number of invertebrates collected, their diversity, and the number of collections in which they were present were greater at Site A (Tables 2-45, 2-46, and C-10 to C-18). The sparseness of benthic organisms collected in the Site B trawl during April may have been due to low dissolved oxygen levels found at certain stations at that time. This anoxic layer became well developed at the sites during the summer (see Section 2.3.1) and was quite extensive in the northern Gulf of Mexico.

Brown shrimp were not very abundant in trawl collections at either site. This was expected since these shrimp are usually located farther offshore and have their peak abundances between June and late October. The commercially important invertebrates--including white and brown shrimp, seabob, and blue crab--were more abundant during autumn and early winter at Site A than during late winter and early spring at Site B. During the October survey, at least 23 trawlers were observed within a 5-mile radius of Site A.

Fish tended to dominate trawl samples, outnumbering invertebrates in both number of species and total individuals and weight. The regional ichthyofauna are comprised of at least 105 fish species (Table C-20), (Perret, 1971; Ragan and Harris, 1975; Dunham, 1972; Juneau, 1975). Many other fish which are scarce or elusive are also likely to inhabit the area, since more than 600 species of fish are known to occur in coastal Gulf water off Texas (U.S. Dept. of Energy, 1978).

TABLE 2-45   Summary of trawl catches of invertebrates and fish collected
             at Weeks Island Site A.[a,b]

Common Name	Scientific Name	Sept	Oct	Nov	Dec
Invertebrates					
Hydroid colony	Hydrozoa		P	P	
Sea nettle	Chrysaora quinquecirrha	UC			
Cabbagehead	Stomolophus meleagris	C			
Sea anemone	Calliactis tricolor	R			
Sea anemone (unidentified)	Anthozoa			UC	
Bryozoan	Bryozoa		P	P	
Moon snail	Polinices duplicatus	UC		R	
Arc shell (clam)	Arcidae	R	R		
Brief squid	Lolliguncula brevis	C	A	C	C
Mantis shrimp	Squilla empusa	C	UC	C	R
White shrimp	Penaeus setiferus	A	A	A	A
Brown shrimp	Penaeus aztecus	C	R	UC	
Penaeid shrimp	Penaeidae (juvenile)	C		A	
Rock shrimp	Sicyonia dorsalis	UC			
Seabob	Xiphopenaeus kroyeri	A		A	A
Striped hermit crab	Clibanarius vittatus		R		
Hermit crab	Pagurus pollicaris	R			
Purse crab	Persephona aquilonaris	R	R		
Spider crab	Libinia sp.			R	
Blue crab	Callinectes sapidus	C	R	A	UC
Swimming crab	Portunidae (juvenile)	A	UC	R	UC
Fish					
Shrimp eel	Ophichthus gomesi			R	
Gulf menhaden	Brevoortia patronus	R		R	
Bay anchovy	Anchoa mitchilli	A	A	A	A
Striped anchovy	Anchoa hepsetus	R	UC		
Sea catfish	Arius felis	A	C	A	R
Gafftopsail catfish	Bagre marinus	C			
Atlantic midshipman	Porichthys porosissimus	C	R		

TABLE 2-45   (cont'd).

Common Name	Scientific Name	Collection Date			
Fish		Sept	Oct	Nov	Dec
Skilletfish	Gobiesox strumosus				R
Crested cusk-eel	Ophidion welshi	UC		R	
Chain pipefish	Syngnathus louisianae	R		R	R
Atlantic moonfish	Vomer setapinnis		R		
Lookdown	Selene vomer		R		
Atlantic bumper	Chloroscombrus chrysurus	UC	C		
Bluntnose jack	Hemicaranx amblyrhynchus	UC			
Crevalle jack	Caranx hippos		R		
Southern kingfish	Menticirrhus americanus			R	
Atlantic croaker	Micropogon undulatus	A	C	UC	R
Sand seatrout	Cynoscion arenarius	A	A	A	A
Spot	Leiostomus xanthurus	R			UC
Star drum	Stellifer lanceolatus	A	A	A	A
Banded croaker	Larimus fasciatus			R	
Silver perch	Bairdiella chrysura				R
Spadefish	Chaetodipterus faber	R	UC	R	R
Atlantic threadfin	Polydactylus octonemus	UC			
Southern stargazer	Astroscopus y-graecum		R	R	
Fat sleeper	Dormitator maculatus	R			
Atlantic cutlassfish	Trichiurus lepturus	R	A		R
Gulf butterfish	Peprilus burti	UC	R		UC
Bighead sea robin	Prionotus tribulus			R	R
Blackfin sea robin	Prionotus rubio	R			
Fringed flounder	Etropus crossotus	R	R	R	
Bay whiff	Citharichthys spilopterus	UC	R	R	
Lined sole	Achirus lineatus		R	R	R
Hogchoker	Trinectes maculatus	R		UC	UC
Blackcheek tonguefish	Symphurus plagiusa	UC	UC	UC	UC
Least puffer	Sphoeroides parvus	A	UC	R	R

---

[a]Data from Appendix C, Tables C-10 through C-13.

[b]A = abundant (more than 50 collected); C = common (21 to 50 collected);
UC = uncommon (5 to 20 collected); R = rare (less than 5 collected);
P = present.

TABLE 2-46   Summary of trawl catches of invertebrates and fish collected at Weeks Island Site B.[a,b]

Common Name	Scientific Name	Feb	Mid-Mar	Late Mar	Early Apr	Apr
Invertebrates						
Anenome	Anthozoa			R		
Bryozoan	Bryozoa		P			
Gastropods (unidentified)	Gastropoda	UC	UC			
Razor clam	Ensis sp.		R			
Brief squid	Lolliguncula brevis	C	UC	A	A	UC
Mantis shrimp	Squilla sp.		R	R		
	Leptochelia serraturbita			R		
Parasitic isopod	Aegathoa oculata				UC	R
White shirmp	Penaeus setiferus	A				
Broken-neck shrimp	Trachypenaeus constrictus			A		
Sugar shrimp	Parapenaeus longirostris	R	A			
Rock shrimp	Sicyonia dorsalis		R			
Sergestid shrimp	Acetes americanus			R		
Seabob	Xiphopenaeus kroyeri	A				
	Ogyrides limicola			UC		
Hermit crab	Pagurus pollicaris		R			
Porcellin crab	Porcellana sayana		R			
	Albunea paretii			R		
Mole crab	Lepidopa websteri	R		R		
Lady crab	Ovalipes sp.	R	R	R	R	
Portunid crab	Portunus gibbesii		R			
Starfish	Astropectin sp.	UC	R			
Seastar	Luida clathrata			UC	UC	R
Fish						
American eel	Anguilla rostrata			UC		
Bay anchovy	Anchoa mitchilli	A	A			
Striped anchovy	Anchoa hepsetus			R	A	
Lizardfish	Synodus sp.			A		
Sea catfish	Arius felis	R	R	UC	R	
Gulf hake	Urophysis cirratus		R			

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TABLE 2-46 (cont'd).

Common Name	Scientific Name / Fish	Feb	Mid-Mar	Late Mar	Early Apr	Apr
				Collection Date		
Southern hake	Urophysis floridanus	UR		R		
Crested cusk eel	Ophidion welshi		R	R		
Chain pipefish	Syngnathus louisianae	UC				
Sheepshead	Archosargus probatocephalus	R				
King whiting	Menticirrhus saxatilis	UC				
Gulf kingfish	Menticirrhus littoralis		R			
Sand seatrout	Cynoscion arenarius	A	A	R	R	
Red drum	Sciaenops ocellata		R			
Spot	Leiostomus xanthurus	UC				
Star drum	Stellifer lanceolatus	UC				
Banded croaker	Larimus fasciatus	A				
Silver perch	Bairdiella chrysura	R				
Atlantic cutlassfish	Trichiurus lepturus	UC			UC	
Gulf butterfish	Peprilus burti	R		A		
Bighead searobin	Prionotus tribulus	R	R			
Blackfin searobin	Prionotus rubio			C		
Fringed flounder	Etropus crossotus			UC		
Bay whiff	Citharichthys spilopterus	R	R			
Blackcheek tonguefish	Symphurus plagiusa	UC	R			
Least puffer	Sphoeroides parvus	R	R			

[a]Data from Appendix C, Tables C-14 through C-18.

[b]A = abundant (more than 50 collected); C = common (21 to 50 collected); UC = uncommon (5 to 20 collected); R = rare (less than 5 collected); P = present.

Some of the more abundant fish of the region include the bay anchovy, Atlantic croaker, sea catfish, rock seabass, Gulf menhaden, Atlantic cutlassfish, fringed flounder, spot, sand seatrout, Gulf butterfish, Atlantic bumper, blue spotted sea robin, and Atlantic threadfin. Depth, distance offshore, and DO have been shown to have a highly positive correlation with nekton abundance in this nearshore coastal region. Seasonal differences may also affect species abundance (Ragan and Harris, 1975).

The bay anchovy, sand seatrout, and star drum were the most abundant fish collected from trawls at Site A, though the Atlantic croaker and sea catfish were also common (Tables 2-45, and C-10 to C-13). Striped anchovies were plentiful in September, and Atlantic croaker, banded croaker, and silver seatrout were abundant in December.

At Site B during February and mid-March, the bay anchovy and sand seatrout were most abundant; at the end of March, the Gulf butterfish and blackfin sea robin were dominant. Striped anchovies appeared at the end of March and became abundant within the next week (Tables 2-46, and C-14 to C-18). No fish were caught during April--perhaps because of the anoxic layer which was forming in the bottom waters at that time (Section 2.3.1).

In summary, 36 species of fish were collected at Site A (September to December 1977) and 26 species were collected at Site B (February to April 1978). The number of fish, their diversity, and the number of collections in which they were present were also much higher at Site A.

The low number of Gulf menhaden and the absence of stingrays, which are usually abundant in this part of the Gulf, were probably due to their movement offshore during the seasons sampled. Ladyfish, bluefish, Spanish mackerel, pompano, and crevalle jack, which are likely to be present in the vicinity of the sites, were not collected (except for one crevalle jack) during the trawl surveys due to their relatively high swimming speeds.

There was no evidence of commercial finfish operations in the vicinity of either site during the trawl surveys, though several commercial species were present, including croaker, sea catfish, menhaden, and flounder. Likewise, no sportfishing was observed, but this area may provide a more productive sportfishery at other times of the year. Sportfishing species found included the crevalle jack and sand seatrout.

There were no threatened or endangered species found during the site surveys (see Section 2.4.5).

2.4.4.2 Life Histories of Major Nektonic Species

2.4.4.2.1 Shrimp

The life histories of brown and white shrimp are fairly similar. Mating and spawning take place offshore. During mating, the male transfers a sperm capsule or spermatophore to the female. Upon spawning, the female releases 500,000 to 1,000,000 eggs, simultaneously fertilizing them with the stored sperm. The timing of this event with white shrimp seems to depend on water temperature and occurs in 26- to 102-foot (8- to 31-meter) depths from March to October, with peaks in June or July. Brown shrimp spawn throughout the year at depths of 151 feet (46 meters) or more and from spring to early winter in shallower water. Spawning activity of the brown shrimp does not occur in waters of less than 46-foot (14-meter) depth. The eggs of both species are pelagic and hatch within 24 hours (Gaidry and White, 1973; Christmas and Etzold, 1977; Lindner and Cook, 1970).

Larval shrimp go through five nauplii, three protozoeal, and three mysid stages. During this time (2 to 3 weeks), they are planktonic, drifting with the currents toward the bays and estuaries. Brown shrimp postlarvae enter the estuaries on flood tides in winter and spring; white shrimp postlarvae enter from June to September (Christmas and Etzold, 1977). These shrimp concentrate in the shallow, vegetated, fresh waters of the estuary. In warm waters, they grow rapidly, settling to the bottom and feeding omnivorously. As the shrimp grow to the juvenile stage in the estuary, they move to more saline water during ebb tides. White shrimp have a greater tolerance for lower salinities than do brown shrimp; during periods of rapid growth, the optimum salinity for the former is 0.5 to 10 ppt, and for the latter, 19 ppt. However, both species can withstand a wide range of salinites (Barrett and Gillespie, 1973; 1975).

After being in the estuaries for a few months, depending on environmental conditions, the young shrimp move offshore during ebb tides; white shrimp remain in the estuary longer and migrate at a larger size than do brown shrimp. White shrimp spawned late in the summer may overwinter in the estuaries and migrate the following spring.

As an annual crop, shrimp are capable of reaching maturity and spawning within a year. Brown shrimp are found from Cape Cod to Yucatan, but are absent on the west coast of Florida. White shrimp are distributed from Long Island to Yucatan, but are absent in western and southeastern Florida. Highest densities are in depths of 89 to 180 feet (27 to 55 meters) and up to 115 feet (35 meters), respectively (Christmas and Etzold, 1977).

The seabob is of minor importance in the commercial shrimp fishery and is exploited primarily in the fall and winter months when the brown and white shrimp have moved offshore. Approximately 90 percent of the Gulf seabob catch occurs in Louisiana. They are primarily caught in shallow water, of 6.5- to 13-foot (2- to 4-meter) depth, and tend to concentrate along the beach after a cold front. They are found from Cape Hatteras through the Gulf of Mexico and Caribbean Sea to Brazil. It appears that this shrimp completes its life cycle in a narrow zone of the coastline, out to the 43-foot (13-meter) depth contour, and rarely, if ever, enters bays or estuaries either in the juvenile or adult stages. The female is gravid during the spring, summer, and fall. Laboratory studies indicate that the seabob larvae go through five naupliar stages and one protozoeal stage. However, there are limited data on the presence of larval, postlarval, and juvenile stages (Christmas and Etzold, 1977; Juneau, 1977).

2.4.4.2.2 Blue Crab

The blue crab (Callinectes sapidus) ranges from Nova Scotia to Uruguay and is found mainly in estuaries and shallow oceanic waters. Females tend to be in more saline waters than males, but both can tolerate waters of from 0.7 to 88 ppt. Mating occurs from late winter to early fall while the female is in the soft-shell stage of molt; the male passes the spermatozoa into the female for storage of up to 1 year. The female then moves to more saline waters where spawning occurs. As the 700,000 to 2,000,000 eggs are released, they become fertilized by the stored sperm. The embryos become attached to the female's abdomen until hatching, a process of 9 to 15 days. Only one or two of these eggs will survive to adulthood (Jaworski, 1972).

The larval zoeal stage lasts from 30 to 39 days, with the organism undergoing from four to eight molts. Optimum salinities for survival and growth of the larvae are 15 to 45 ppt. The zoea then metamorphose into

megalops, a stage lasting 6 to 20 days. The megalops is crablike in appearance and is able to swim or walk on the bottom. Optimum salinities for this stage are greater than 15 ppt. The final metamorphosis leads to the juvenile crab, an active predator that migrates from one part of the estuary to another in search of food. As its grows, the exoskeleton is repeatedly shed in molting. Growth to maturity requires 12 to 18 months; the lifespan is 2 to 4 years, though many are caught upon reaching commercial size, 12 to 18 months after hatching (Jaworski, 1972).

The blue crab is omnivorous and, as such, plays an important role in the coastal ecosystem. Rangia clams, mussels, xanthid crabs, snails, fish, plants, and insect larvae have been reported in the diet of the blue crab, as well as scavenged material. In turn, the species, especially smaller members, are fed upon by spotted seatrout, red drum, Atlantic croaker, black drum, and sheepshead. Blue crab larvae and eggs are also found in the diet of many fish (Adkins, 1972).

2.4.4.2.3 Gulf Menhaden

The Gulf menhaden, found mainly in the Gulf of Mexico, make up a majority of the U.S. menhaden fishery. Adult menhaden overwinter from 40 to 62 miles (65 to 100 kilometers) offshore in waters of 295-foot (90-meter) depth. There they spawn from late fall through the winter. The larvae move into the estuarine nurseries from September through April. They remain in the low salinity waters, metamorphose into juveniles, and return to the open Gulf from October through February. Menhaden have a relatively short lifespan, returning to the spawning areas after 1 year. Most of the fisheries catch consists of 1- and 2-year old fish. In general, menhaden are found in a wide range of salinities, from 0 to 60 ppt (U.S. Dept. of Commerce, 1977a).

2.4.4.2.4 Anchovy

Two species, bay and striped, are abundant off the Louisiana coast. The striped anchovy prefers more saline, clearer water and is thus found farther offshore than the bay anchovy, which is generally restricted to bays and nearshore areas. Both species are found in schools and have similar life histories. Diet consists mainly of mysids and copepods (Hildebrand and Schroeder, 1972). Spawning occurs in the spring, summer and fall, and the pelagic eggs hatch within a day. Increasing numbers of

bay anchovy eggs and larvae enter the estuaries from January through June and in September and November. The larvae and young juveniles tend to reside in low salinity areas and move to higher salinity waters as they grow (Dunham, 1972).

2.4.4.2.5 Sciaenid Fishes

The Atlantic croaker is one of the most abundant fish in the Louisiana coastal area. Spawning occurs from October to May in the shallow, open sea. As with the other estuarine-dependent species, the larvae move into the estuary where they feed and grow. They remain in the estuary until the onset of cold weather and then move offshore. They are bottom feeders, consuming mainly annelids, mollusks, and ascidians. Atlantic croaker are distributed from Massachusetts to Texas and are found in salinities ranging from 0 to 75 ppt (Hildebrand and Schroeder, 1972; U.S. Dept of Commerce, 1977a).

Various types of seatrout, including the spotted seatrout and weakfish, are found in the Gulf of Mexico. The sand seatrout, the most abundant coastal species, is confined to the Gulf of Mexico and is found in waters of from 1.3 to 32.5 ppt. Spawning occurs in the spring and summer, near passes and inlets. The adults and larvae move into the bays during the summer, then offshore with the onset of cold weather (U.S. Dept. of Commerce, 1977a).

Red drum or redfish are found from Massachusetts to northern Mexico, commonly in the 5- to 30-ppt range, though they have been taken in waters of between 0 to 50 ppt. The adults under 3 years generally remain in the bays and, during the fall, spawn in the shallower waters of the Gulf near passes. Older adults make spawning runs along the coast in the late summer and winter (U.S. Dept of Commerce, 1977a). Juveniles tend to remain in the bays until fall when some migrate to the Gulf. Red drum are known to live at least 8 years.

2.4.5 Threatened or Endangered Species

Several threatened or endangered (U.S. Dept of Interior, 1977a) species of marine reptiles have been reported in the northern Gulf of Mexico (Table 2-47). The Atlantic Ridley turtle population has undergone severe reductions since the 1940's when they numbered almost 40,000. In 1976,

TABLE 2-47   Endangered reptiles and mammals reported in the northern Gulf of Mexico.

Common Name	Scientific Name	Distribution	Food Source
Reptiles			
Atlantic Ridley turtle	_Lepidochelys kempii_	Tropical and temperate seas	Portunid crabs
Hawksbill turtle	_Eretmochelys imbricata_	Tropical seas	
Leatherback turtle	_Dermochelys coriacea_	Tropical and temperate seas	Jellyfish
Mammals			
Sperm whale	_Physeter catodcn_	Rare in offshore Louisiana, Mississippi, and Alabama	Squid, shark, bonyfishes
Black right whale	_Eubalaena glacidis_	Extremely rare throughout Gulf of Mexico	Zooplankton, copepods
Humpback whale	_Megaptera novaeangliae_	Rare in Gulf of Mexico; one siting off Florida	
Sei whale	_Balaenoptera borealis_	Offshore Louisiana	Krill, schooling fish, copepods
Fin whale	_Balaenoptera physalus_	Offshore Texas and Louisiana	Krill, squid, small fish
Blue whale	_Balaenoptera musclus_	Offshore Texas	Euphausids

SOURCE: U.S. Dept. of the Interior, 1977a; 1977b.

there were only 400 to 500 nesting females. The Atlantic Ridley nests in abundance only in Tamaulipas, Mexico. Its primary foraging area is in the northern Gulf of Mexico coastal area, especially off Louisiana where it feeds heavily on portunid crabs (Callinectes sp.). Leatherback turtles have been caught by shrimp trawlers off the coast of Louisiana. This species nests in tropical waters, but ranges throughout the Gulf and Western North Atlantic to Nova Scotia. The Leatherback turtle has been associated with large concentrations of jellyfish on which it feeds (U.S. Dept. of Interior, 1977b). The Hawksbill turtle has been reported to range the warmer coastal waters of the Atlantic Ocean between New England and Brazil (Conant, 1958).

Six species of endangered (U.S. Dept. of Interior, 1977a) marine whales (Table 2-47) have been sighted in the northern Gulf of Mexico. Most were fortuitous sightings (U.S. Dept. of Interior, 1976) and do not indicate indigenous populations.

2.4.6 Unique or Important Habitats

In the continental shelf region where sand and silt bottoms prevail, shipwrecks often serve as artificial reefs for a variety of pelagic nekton and fouling communities. Shipwrecks provide a hard, stable substrate for the attachment of fouling organisms (e.g., bryozoans, barnacles, urchins, amphipods, green algae, and sponges) and a protective cover for small fish. Fish trophically associated with these reefs include the spadefish, sheepshead, greater amberjack, crested blenny, and high hat (Fotheringham, 1976). Bait fish use shipwrecks to avoid predators (Wickham et al., 1973).

Several shipwrecks are located in the vicinity of Weeks Island Sites A and B. One wreck is located about 7 miles to the west of Site A, and five are located in the shoal area to the north and northeast of Site B (Figure 2-75). These wrecks may provide a hard, stable substrate for the attachment of benthos and a protective cover for juvenile fish.
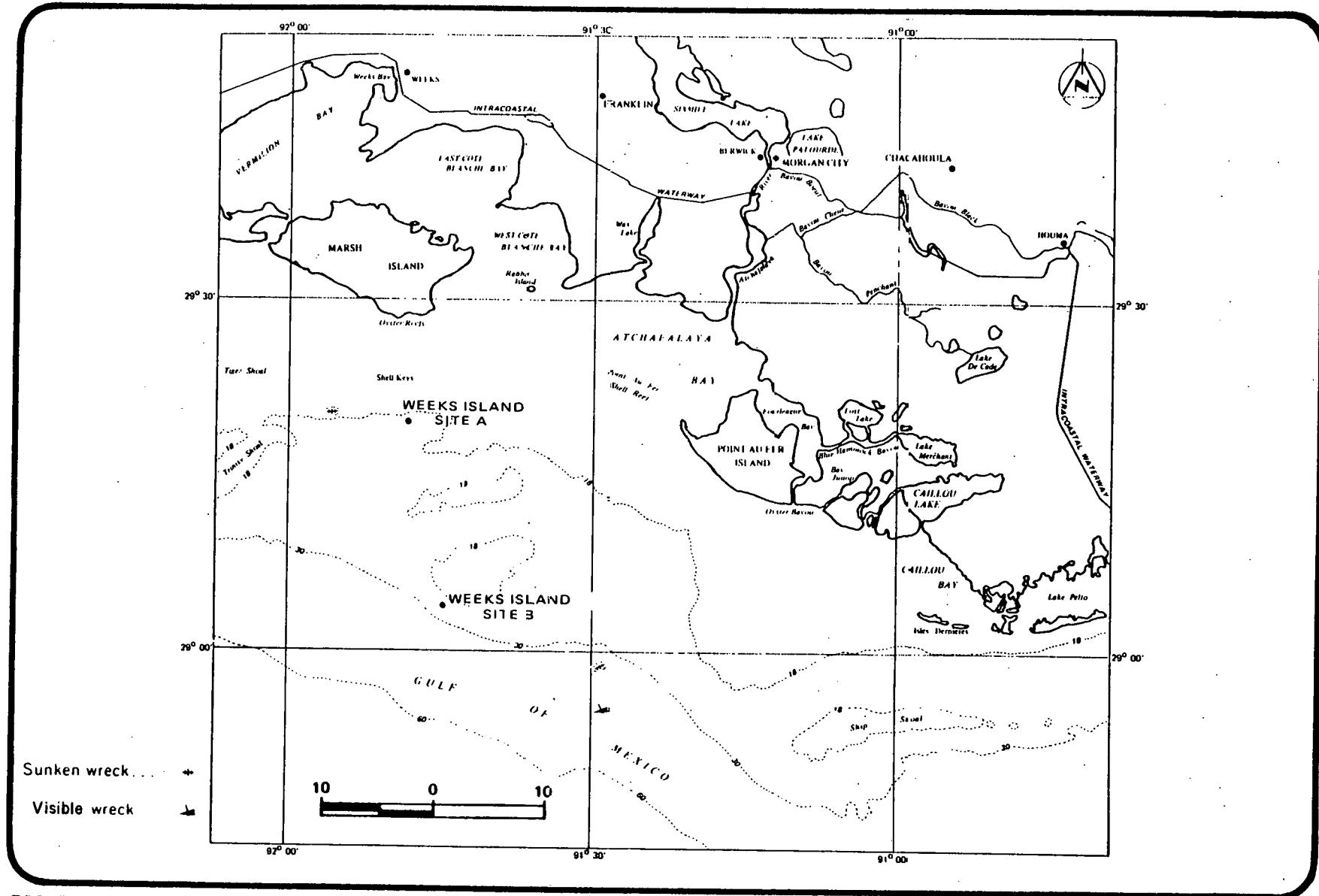
FIGURE 2-75   Shipwrecks in the vicinity of Weeks Island Sites A and B.

SECTION 3
IMPACTS OF BRINE DISPOSAL ON THE MARINE ENVIRONMENT

3.1 Impacts on the Physical Environment

3.1.1 Introduction

Offshore disposal of brine from the Capline Group in the Gulf of
Mexico would be a large-scale operation over the short term, but over the
life of the project it would occur only infrequently. Initially, expansion
of crude oil storage capacity by leaching new caverns would involve dis-
charge of brine over a period of 50 to 60 months. Subsequent filling of
new caverns would require disposal of additional brine over 24 months.
For study purposes, the larger disposal rate was selected to maximize
projected impacts.

A mathematical simulation model, developed by the Ralph Parsons
Laboratory at the Massachusetts Institute of Technology (MIT), was used to
determine the most efficient design and location for the diffuser system.
The model runs were used by the National Oceanic and Atmospheric Administra-
tion (NOAA) in a study undertaken at the request of DOE to determine
the effects of brine disposal connected with the SPR program (U.S.
Dept. of Commerce, 1977a). The MIT model is a time-dependent model
which simulates the transient plume conditions at the diffuser site
when wind-driven current speeds and direction are input to a computer
for analysis. The analysis uses results from diffuser performance
studies conducted by the U.S. Army Corps of Engineers Waterways Experiment
Station to determine the mathematical dilution factors in the near
and intermediate fields (up to 1000 feet (305 meters) from the diffuser).
Salinity concentrations in the far-field region were calculated using
the MIT transient plume model, which has been calibrated through thermal
discharge studies (see Section 1.3).

The regions of analysis for the MIT model are shown in Figure
3-1. In the near-field region, dilution is affected by turbulent jet
mixing and is a function of diffuser design, ambient current velocity,
and water depth (which in shallow water would limit plume rise). The
trajectory and the lateral spreading of each plume after it falls to
the bottom are strongly affected by the (negative) buoyancy flux of

NEAR FIELD
(SIDE VIEW)

~100 ft

V

INTERMEDIATE
FIELD
(TOP VIEW)

~1000 ft

V   L

BOUYANT SPREADING

FAR FIELD
(TOP VIEW)

Y

X

V   DIFFUSER
LOCATION

~10,000 ft
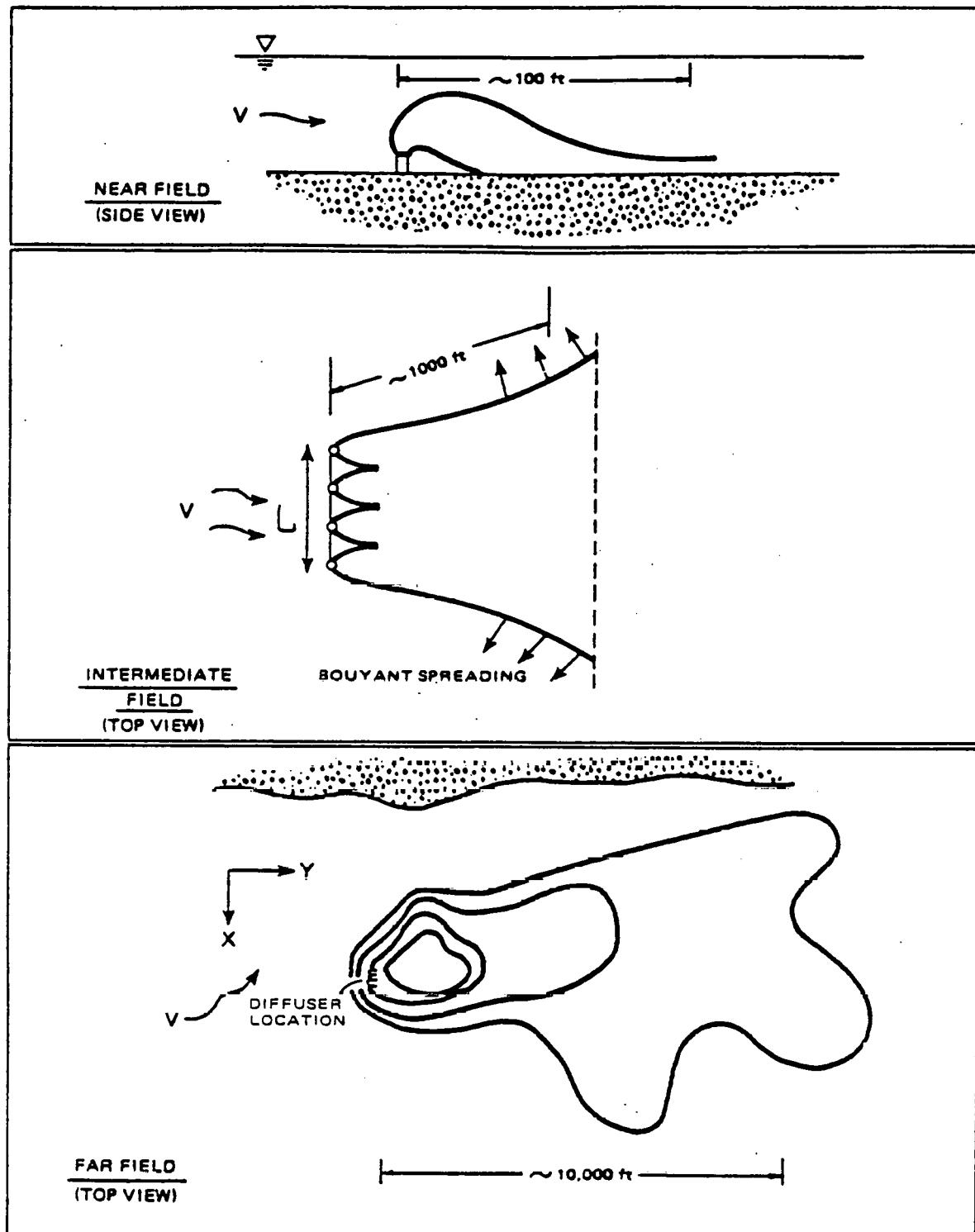
SOURCE: U.S. Dept. of Commerce, 1977 a.

FIGURE 3-1   Regions of analysis for the MIT model.

the discharge. The near-field region is assumed to extend downstream
until the plumes from adjacent nozzles merge to form a continuous plume,
a distance of about 100 feet (30.5 meters).

The intermediate field is characterized primarily by buoyant lateral
spreading and vertical collapse of the plume. Normal advective diffusion
causes further dilution of the plume. The intermediate field is assumed
to end (and the far field to begin) at about 1000 feet (305 meters),
corresponding to the point at which vertical collapse of the plume
due to buoyancy is comparable with vertical growth due to diffusion.

The far field is the largest of the three regions and is character-
ized by the ambient processes of advection and diffusion. These processes
are essentially independent of diffuser design and ultimately control
any accumulation of effluents.

3.1.2 Brine Plume Salinity Analysis

3.1.2.1 Estimated Baseline Conditions

Using historical current data, a plume analysis was initially
conducted (U.S. Dept. of Commerce, 1977a) to determine the excess salinity
values at the bottom, mid-depth, and surface for various combinations
of current speed, direction, and duration (including stagnant conditions).

Computations were made for five combinations of water depths,
estimated current sequences, and diffusion coefficients, as shown in
Table 3-1. The base case analysis (Run No. 5) assumes a 2000-foot
(610-meter) bottom diffuser length, a water depth of 20 feet (6 meters),
a flow rate of 650,000 BPD (42 ft^3/sec), and a 4-day wind-driven current
cycle. Additional analyses consider the effect of stagnant flow condi-
tions (Run No. 14) and reduced values of horizontal and vertical diffu-
sion coefficients (Run Nos. 15, 16, and 17).

Current sequences in the model were a combination of tidal components
and wind-driven components (for the alongshore component only) assumed
as:

$$u = u_T \qquad \text{(inshore component)}$$
$$v = v_T + v_W \qquad \text{(alongshore component)}.$$

TABLE 3-1 Summary of parameters used in brine discharge calculations
(for a bottom diffuser).

Run	Variables / Condition Tested	Discharge Parameters Q_0 (ft^3/sec)	Ac_0 (ppt)	Diffuser Parameters II (ft)	L (ft)	N	Current Parameters I (hr)	A (ft/sec)	B (ft/sec)	Diffusion Parameters K_z (ft^2/sec)	K_h (ft^2/sec)	Calculation Times T_n (hr)
18	Base case	71	230	30	3,420	58	96	0.5	-0.1	0.001	$0.003\sigma_h^{1.15}$	309,333 357,381
19	Stagnant flow	71	230	30	3,420	58	384	0.25	-0.75	0.001	$0.003\sigma_h^{1.15}$	477,573 669,765
20	Reduced vertical diffusivity	71	230	30	3,420	58	96	0.5	-1.0	0.0003 (10' ceiling)	$0.003\sigma_h^{1.15}$	309,333 357,381
21	Reduced horizontal diffusivity	71	230	30	3,420	58	96	0.5	-1.0	0.001	$0.001\sigma_h^{1.15}$	309,333 357,381
22	Reduced vertical & horizontal diffusivity	71	230	30	3,420	58	96	0.5	-1.0	0.0003 (10' ceiling)	$0.001\sigma_h^{1.15}$	309,333 357,381

Q_0: brine discharge rate (total)

Ac_0: brine concentration at port

H: water depth

II: diffuser length

N: number of diffuser ports

I: period

A: upcoast current

B: downcoast current

K_z: vertical diffusion coefficient

K_h: horizontal diffusion coefficient

T_n: calculated time interval

SOURCE: U.S. Dept. of Commerce, 1977a.

Rotary tidal components were specified in the form:

$$u_T = 0.3 \cos \left(\frac{2\pi}{24} t\right)$$

$$v_T = 0.6 \cos \left(\frac{2\pi}{24} (t + 6)\right)$$

where t is in hours and u_T and v_T are in feet per second. The wind-driven current was assumed to fit the schematic cycle described in Figure 3-2. Although idealized, this sequence reproduces the observed phenomena of wind reversals following the passage of a front, coupled with periods of stagnation. A 4-day wind-driven cycle was selected to simulate conditions of moderate wind and current. A 16-day wind-driven cycle was selected to simulate the buildup of salinity concentrations with time during an 8-day period of stagnation.

3.1.2.2 Results and Conclusions (Estimated Currents)

For each run, excess concentrations were calculated four times within the current sequence and at three depths (bottom, mid-depth, and surface). Isoconcentration plots for those depths and times (Table 3-1), at which predicted excess concentrations exceeded 0.1 ppt, are presented in "Analysis of Brine Disposal in the Gulf of Mexico, Capline Sector" (U.S. Dept. of Commerce, 1977a).

Conclusions drawn from the model outputs may be summarized as follows:

(1) The current sequence has only a moderate effect on the maximum predicted concentration (~2 to 5 ppt) in the far field, but it substantially influences the shape of the predicted plume. Periods of strong ambient currents produce long narrow plumes with salinity concentrations near the diffuser remaining relatively low. During periods of weak ambient currents, the plumes tend to remain close to the diffuser.

(2) Salinity concentrations in the vicinity of the diffuser are generally higher for cases of strong ambient currents within a current cycle. The time T_1 for each cycle represents a time when the current is instantaneously high, but the effects of prior stagnation or a reverse current duration can be seen.

FIGURE 3-2   Idealized nontidal current cycle.

The figure contains the following labels:

$V_{NT}(t)$

T

$\frac{T}{4}$ $\frac{T}{4}$ $\frac{T}{2}$

A

B

TIME (t)

1
2
3
4

T= PERIOD OF CYCLE
A= MAXIMUM UPCOAST CURRENT (EAST)
B= MAXIMUM DOWNCOAST CURRENT (WEST)
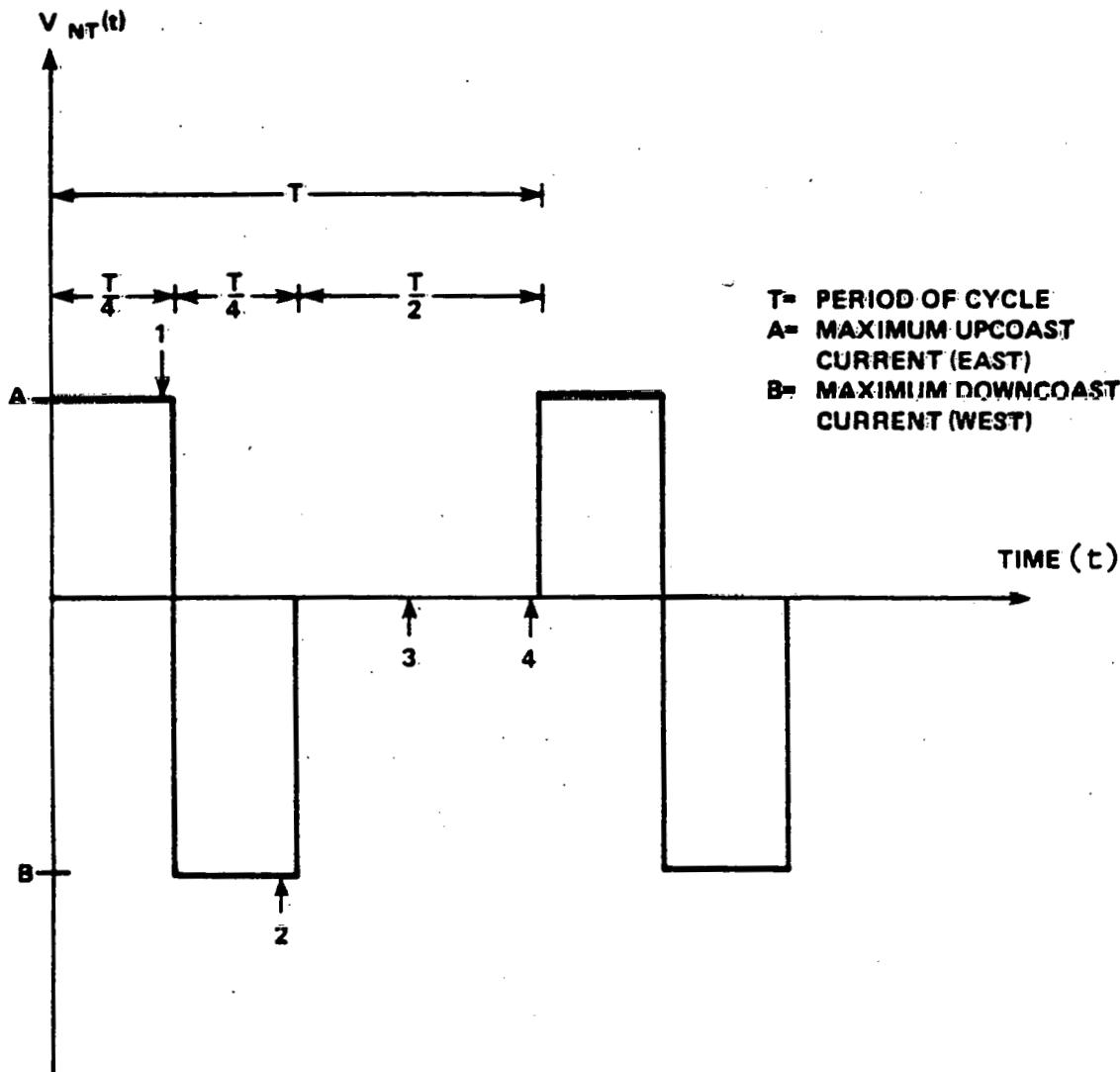
MODEL OUTPUT TIMES

1. END OF PERIOD OF UPCOAST CURRENT
2. END OF PERIOD OF DOWNCOAST CURRENT
3. MIDDLE OF SLACK PERIOD
4. END OF SLACK PERIOD

SOURCE: U.S. Dept. of Commerce, 1977a.

(3) Extended stagnation periods significantly increase background salinity concentrations. An 8-day stagnation period resulted in an increase of only 1 ppt compared to a 1- or 2-day stagnation period.

(4) Reduction of the horizontal and vertical turbulent diffusion coefficients has no significant effect on the maximum predicted salinity concentration in the far field. If the vertical diffusion coefficient is reduced (for example, by a factor of 3.3), bottom concentrations over the entire plume are increased only slightly (0.5 ppt). This effect is greatest closest to the diffuser. At increased distances from the diffuser, more mixing takes place, and the predicted concentrations approach those of the base case analysis. If the horizontal diffusion coefficient is reduced by a factor of 3, for example, the lateral spreading of the plume is reduced, which increases the predicted bottom concentrations along the centerline of the plume.

(5) Plots of affected bottom areas versus excess salinity for various runs are shown in Figures 3-3 through 3-5. The base case calculations indicate that an increase of less than 5 ppt above ambient may be expected within a boundary of 1 million square feet (23 acres (9.3 hectares)). Figure 3-5 illustrates four time periods for Run No. 14 with extended stagnation. An overall increase in background salinities of approximately 1 ppt occurs between the T_1 curve (after 4 days of upcoast current) and the T_4 curve (after 8 days of stagnation). A plot at the end of a slack water period (T_4), with reduced horizontal and vertical diffusion (Run No. 17), shows that salinity concentrations in the near field remain similar, and that the area within isoconcentration lines is increased by a factor of 4 or 5 over the base case condition.

The effect on bottom areas by reducing only the vertical diffusion (Run No. 15) is greater than by reducing only the horizontal diffusion (Run No. 16) because the former process moves excess salinity concentra-

WEEKS ISLAND
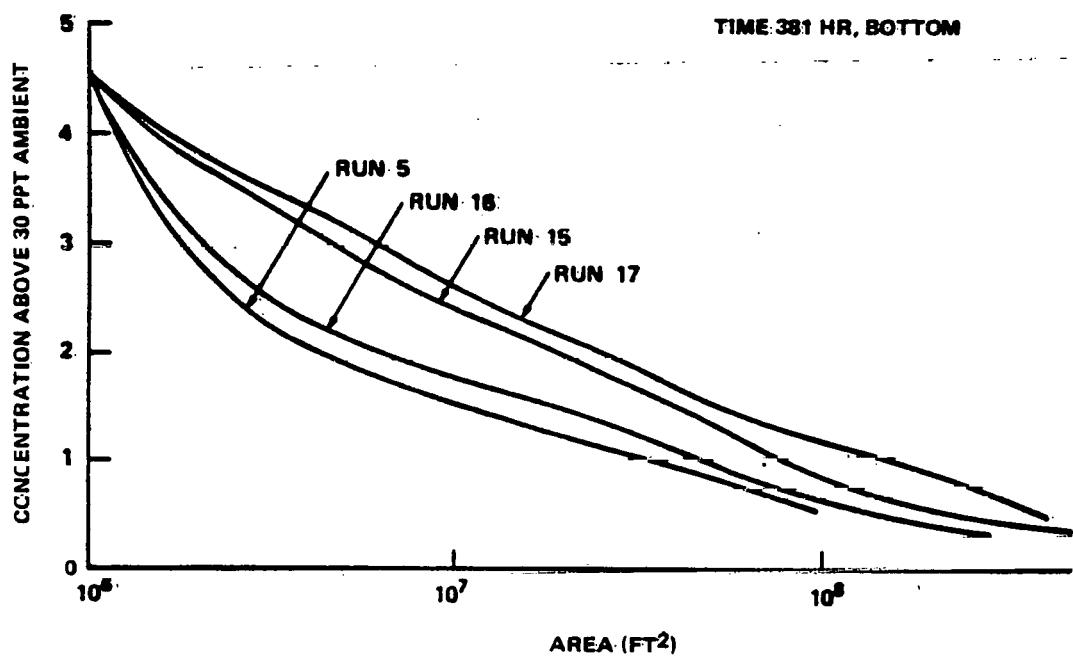
FIGURE 3-3   Excess salinity concentration versus bottom area for various runs, output time 4 (see Figure 3-2).

WEEKS ISLAND
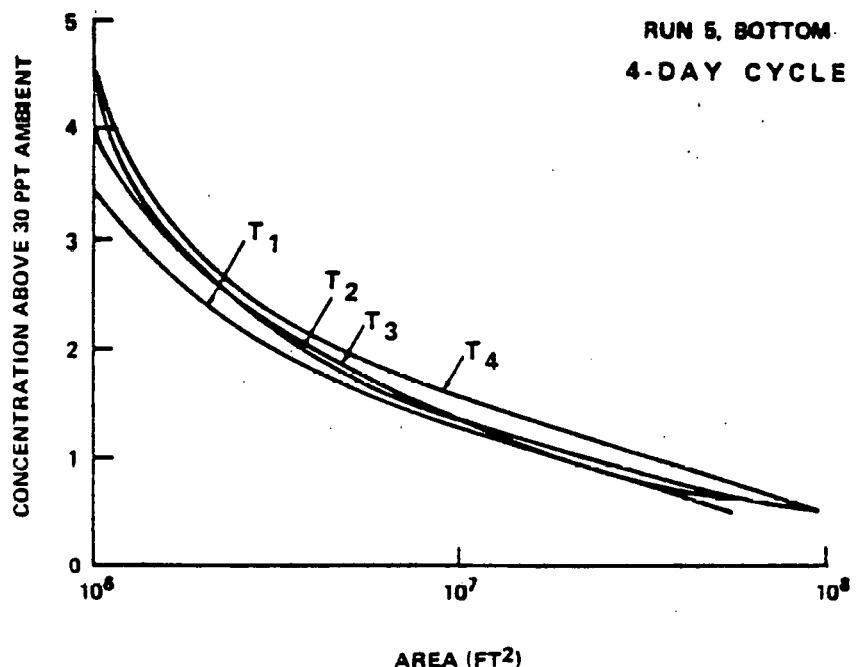
KEY:

T_1 = END OF 1-DAY UPCOAST CURRENT

T_2 = END OF 1-DAY DOWNCOAST CURRENT

T_3 = AFTER 1 DAY OF STAGNATION

T_4 = END OF 2-DAY STAGNATION

SOURCE: U.S. Dept. of Commerce, 1977a.

FIGURE 3-4   Excess salinity concentration versus bottom area for base case calculations with a 4-day cycle (run no. 5), output times 1, 2, 3, and 4 (see Figure 3-2).
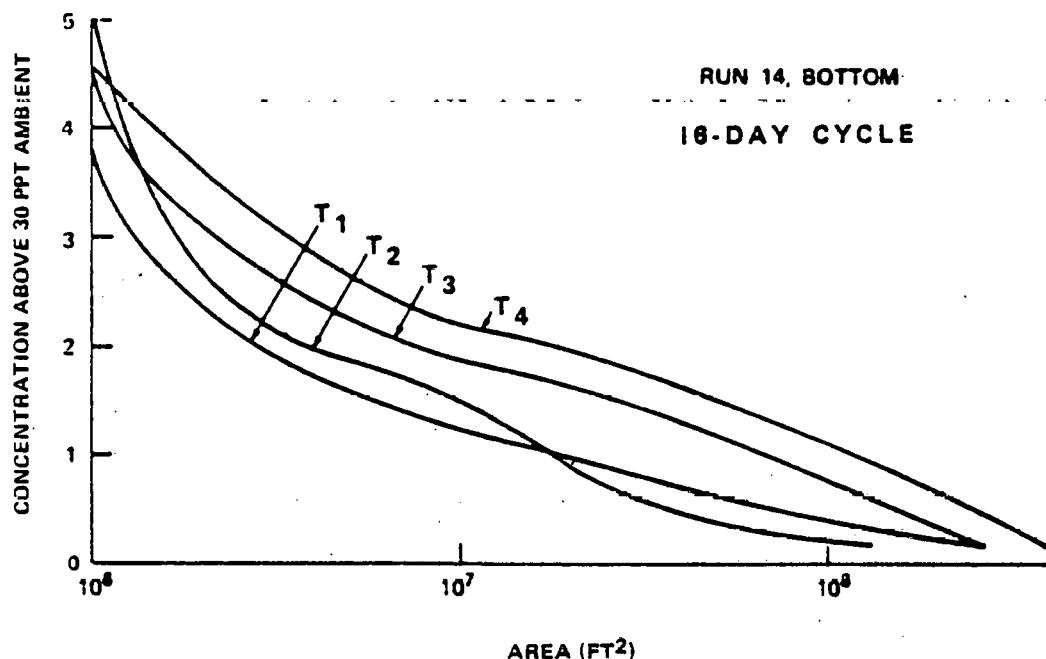
FIGURE 3-5   Excess salinity concentration versus bottom area for calculations
with a 16-day cycle (run no. 14), output times 1, 2, 3, and 4
(see Figure 3-2).

tions away from the bottom, while the latter merely redistributes the saline mass along the bottom.

3.1.2.3 Observed Baseline Conditions, Results and Conclusions

Additional plume analyses were conducted using in situ current data collected at Site A from October 1977 through January 1978 and at Site B from January through July 1978.

Outputs from the MIT transient plume model were selected to provide salinity contours of the far field under a variety of ambient current conditions. The outputs were reviewed to determine the best, worst, and base case conditions. Whenever applicable, a stagnated condition (low current velocity during tidal-dominated circulation) has also been presented.

The figures represent an instant time analysis of the plume as it would dynamically change in response to changes in the tidal and wind-driven currents found in the proposed diffuser area. In the cases where current data were collected at two water depths (11 and 14.5 feet (3.4 and 4.4 meters), 17 and 21.5 feet (5.2 and 6.6 meters)), the deeper current data were used for input to the model.

The isopleths of salinity in the figures are plotted where the predicted excess salinity contours exceed 0.1 ppt above an assumed ambient salinity of 30 ppt. Salinity concentrations near the diffuser head are relatively high due to the positive dependence of the near-field dilutions on current speed.

Salinity concentrations are calculated by the model on a 1500-foot-square (457-meter-square) grid. Areal calculations of the 5-, 4-, 3-, 2-, 1.5-, 1-, 0.5- and 0.1-ppt contours are determined, where applicable, by cumulatively counting the number of salinity nodal points and multiplying by 2.25×10^6 square feet (52 acres). One salinity value of 4.25 ppt, for example, would extend over an area of 2.25×10^6 square feet. Three additional nodal points with salinity values ranging from 3 to 3.99 ppt would then have an areal calculation of $4 \times 2.25 \times 10^6$ or 9×10^6 square feet (207 acres). This represents the minimum excess salinity value that would be expected within the calculated area--in this case, 3 ppt.

3.1.2.3.1 Site A, October 1977

Figure 3-6 illustrates the current velocity vectors at 11 and 14.5 feet (3.4 and 4.4 meters), measured on October 28. Figures 3-7 through 3-10 depict contours of the far-field salinity patterns emanating from the proposed diffuser at 3-hour intervals during a tidal cycle. About 13 days of data on observed currents were input to the model to obtain the salinity contours shown.

Currents at Site A on October 28 were generally flowing to the east at speeds less than 0.7 ft/sec (20 cm/sec). The plumes reflect an eastward drift with the highest excess salinity of 4 ppt occurring after a slack water period.

The October in situ current data indicate that the currents at the site are weaker than those previously estimated using historical current data (U.S. Dept. of Commerce, 1977a). The expected dilution effect of the currents would therefore be less, causing an increase in the observed excess salinity and temperature values.

3.1.2.3.2 Site A, December 1977 - January 1978

Figures 3-11 and 3-12 show contours of the far-field salinity patterns during best and worst case conditions, respectively. About 13 days of observed current data were input to the model. The current velocity vectors at 12 feet (3.7 meters) correspond to the time of the plume model outputs and are shown in Figure 3-13. The best case analysis occurs during a period of high-current velocity usually associated with a passing storm. The predicted plume indicates a corresponding minimum area affected by excess salinity values. From December 27 to 29, current velocities attained a maximum speed of 2.4 ft/sec (72 cm/sec); the direction of flow was consistently to the northwest. A plot of affected area versus excess salinity indicates that an increase of 3 ppt above ambient may be expected within a boundary of 2.25 x 10^6 square feet (52 acres), (Figure 3-14). The worst case analysis occurred during stagnated conditions with reduced current velocity and little net drift. Figure 3-14 indicates that an increase of 5 ppt above ambient may be expected within a boundary of 2.25 x 10^6 square feet.

ONSHORE (-)

ALONGSHORE (+)

OCTOBER 28, 1977
TIME = 0300

OCTOBER 28, 1977
TIME = 0900

OCTOBER 28, 1977
TIME = 1800

OCTOBER 28, 1977
TIME = 0000

14.5 FEET ——————————

.11 FEET — — — — — —

0   10

SCALE: cm/sec
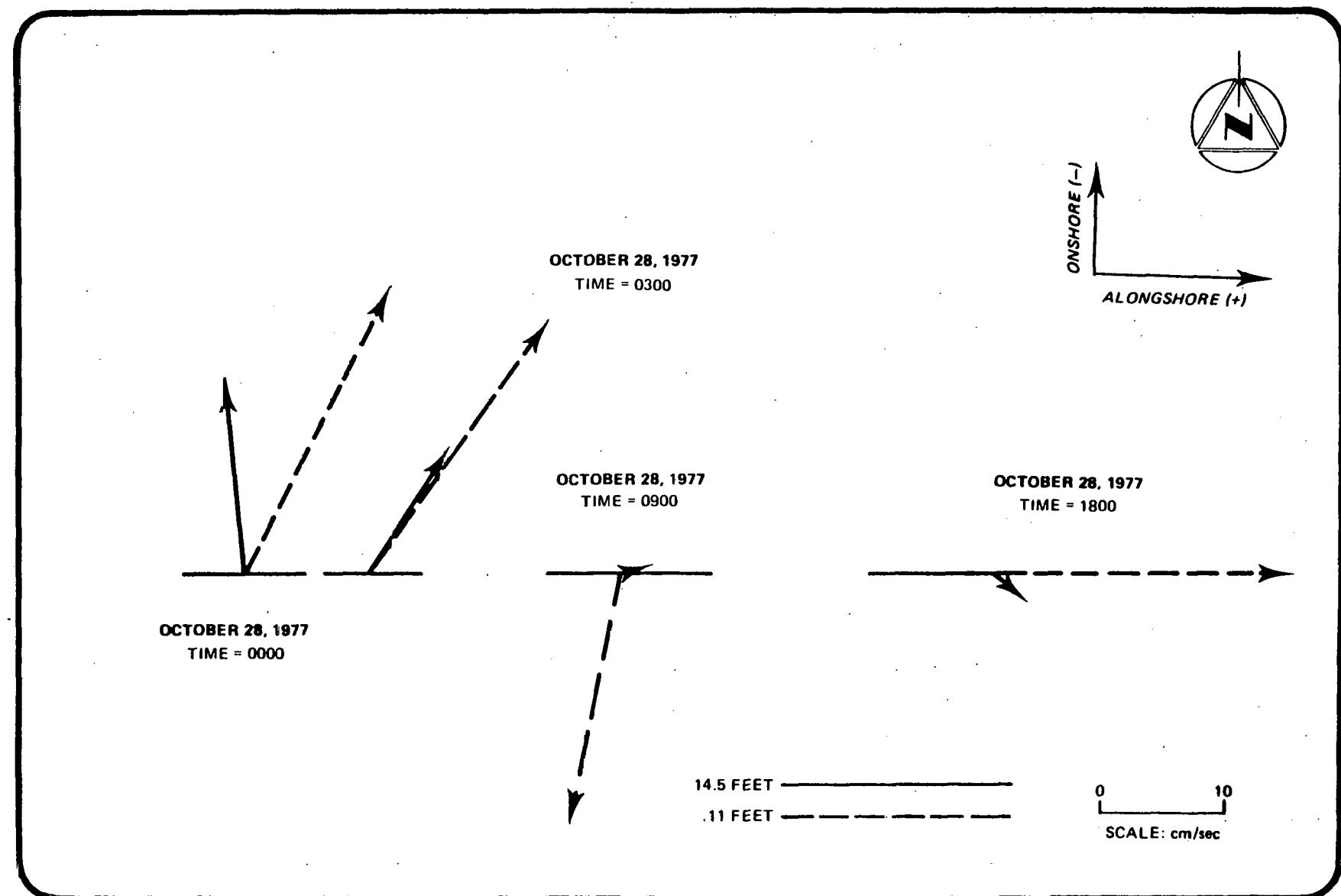
FIGURE 3-6   Weeks Island Site A current velocity vectors corresponding to the snapshot times for the plume
model output, October 28, 1977 (see Figures 3-7 through 3-10).
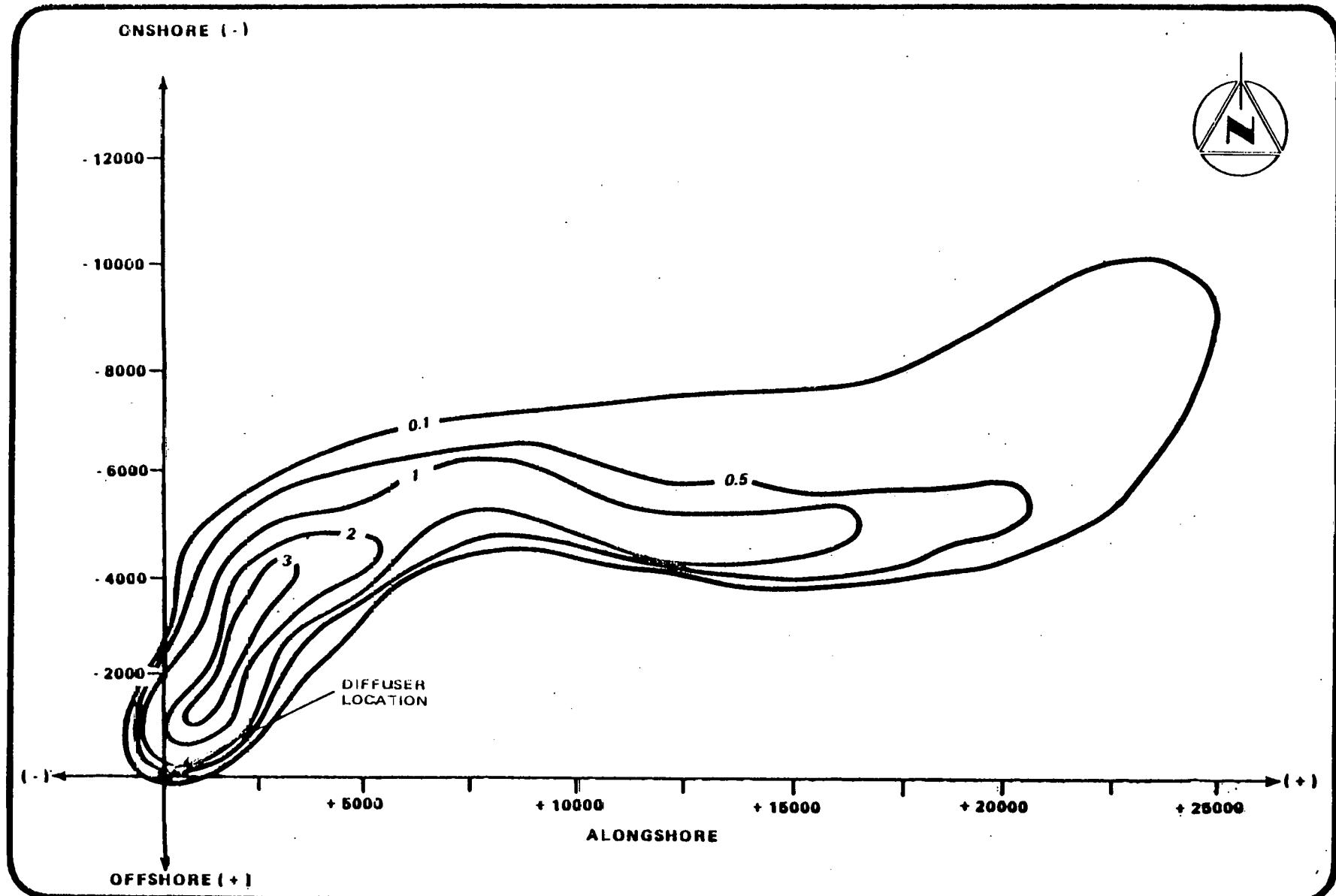
FIGURE 3-7   Contours of excess salinity concentration (ppt) at various distances (feet) from the proposed
diffuser for Weeks Island Site A (using observed currents at T = 0 hours on October 28, 1977).
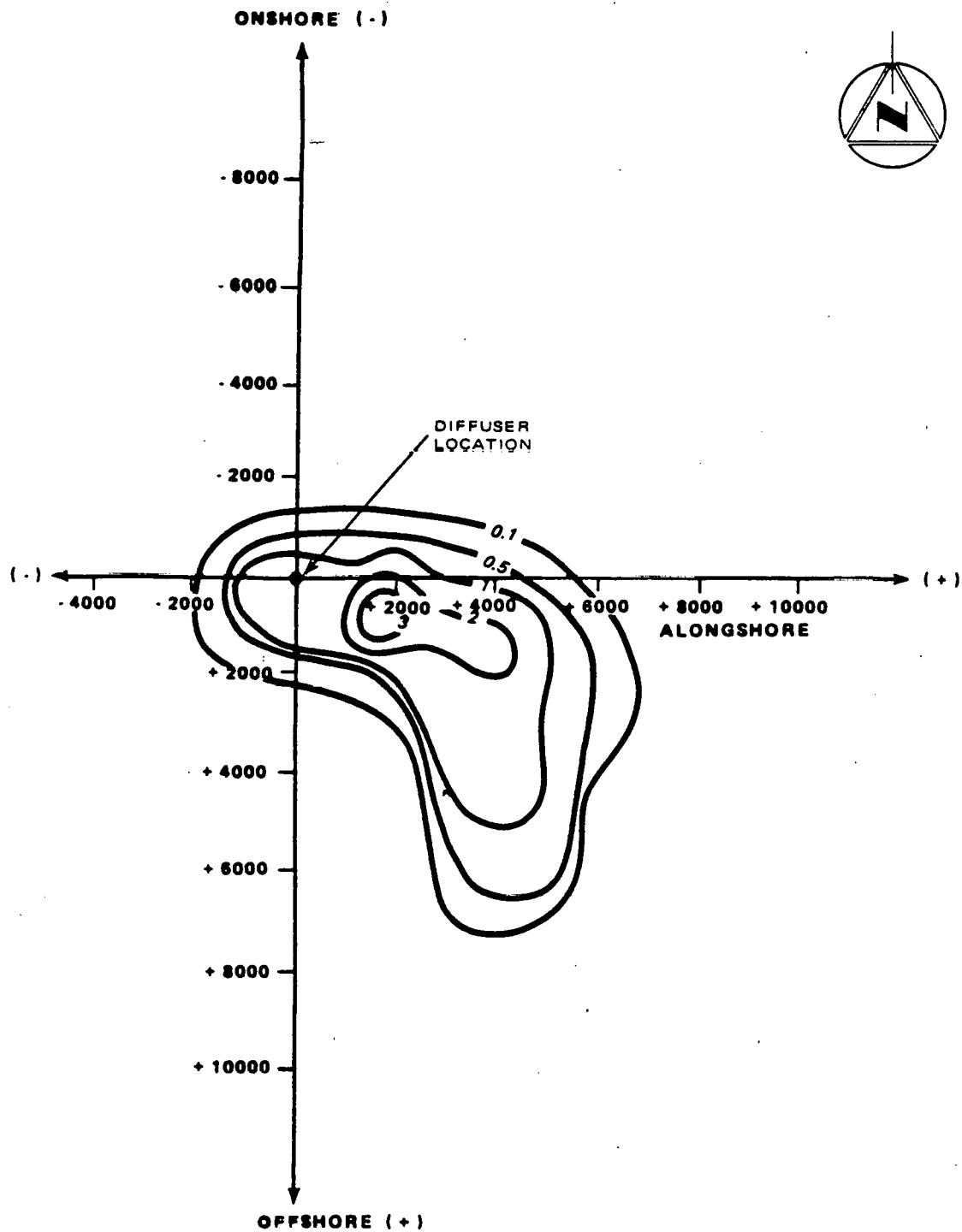
FIGURE 3-8   Contours of excess salinity concentration (ppt) at various
distances (feet) from the proposed diffuser for Weeks Island
Site A (using observed currents at T = 3 hours on October 28,
1977).
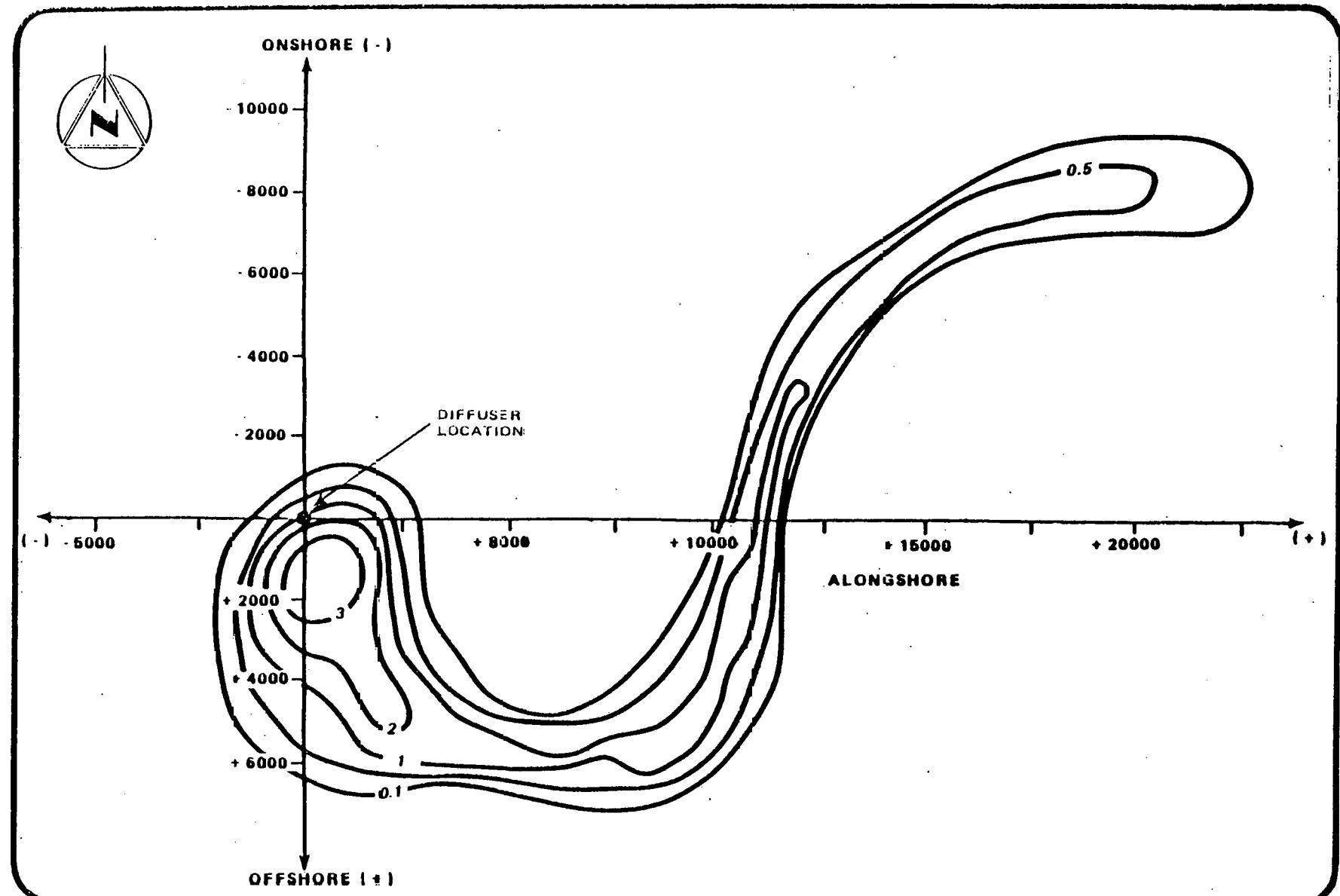
FIGURE 3-9   Contours of excess salinity concentration (ppt) at various distances (feet) from the proposed diffuser for Weeks Island Site A (using observed currents at T = 9 hours on October 28, 1977).
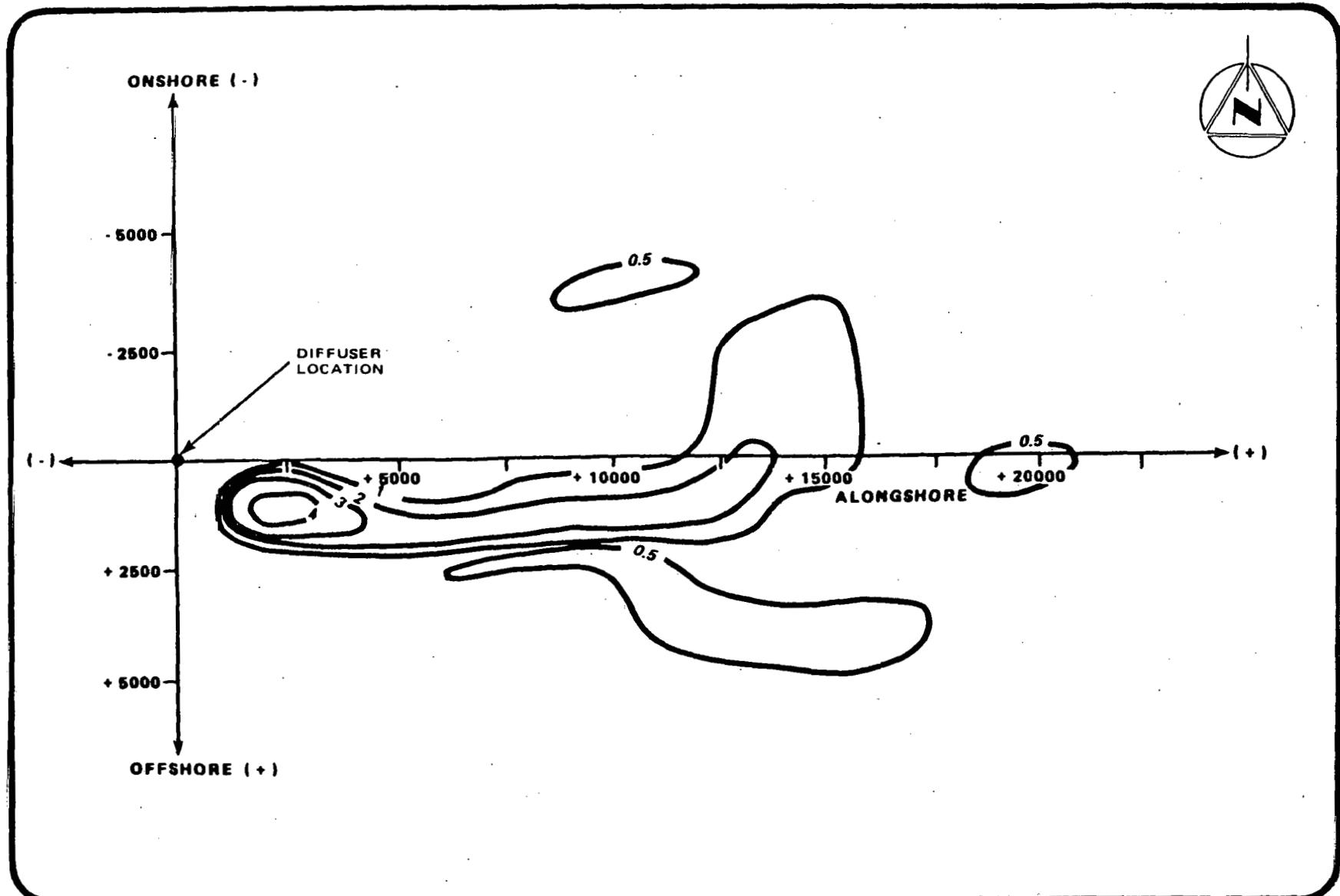
FIGURE 3-10   Contours of excess salinity concentration (ppt) at various distances (feet) from the proposed
diffuser for Weeks Island Site A (using observed currents at T = 18 hours on October 28, 1977).

ONSHORE (-)

ALONGSHORE (+)

DECEMBER 29, 1978

TIME = 0800

46.4 cm/sec

JANUARY 3, 1978

TIME = 0800

18.5 cm/sec

————————— 12 FEET

0   20

SCALE : cm/sec
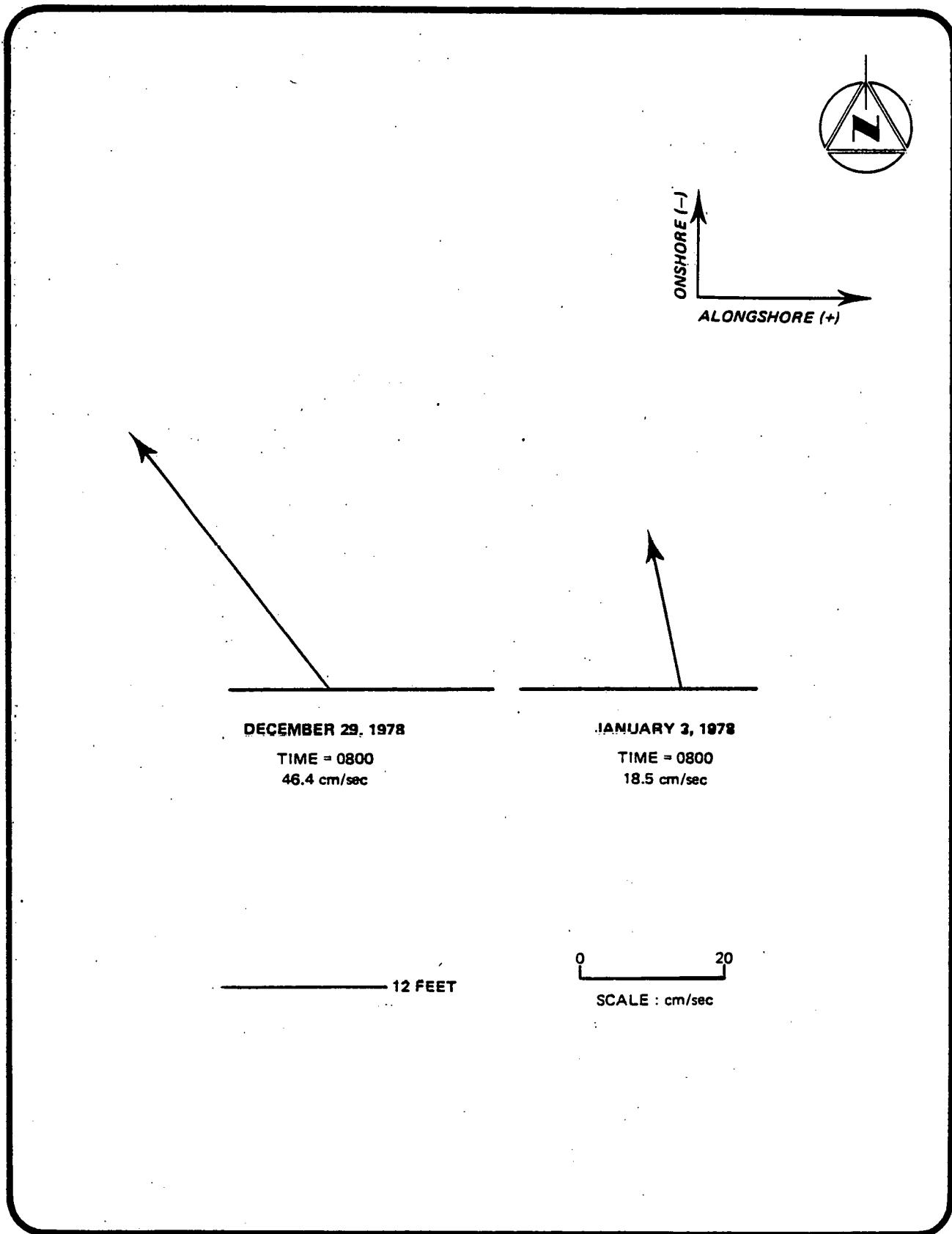
FIGURE 3-11   Weeks Island Site A current velocity vectors corresponding to the snapshot times for the plume model output, December 29, 1977 and January 3, 1978 (see Figures 3-12 and 3-13).
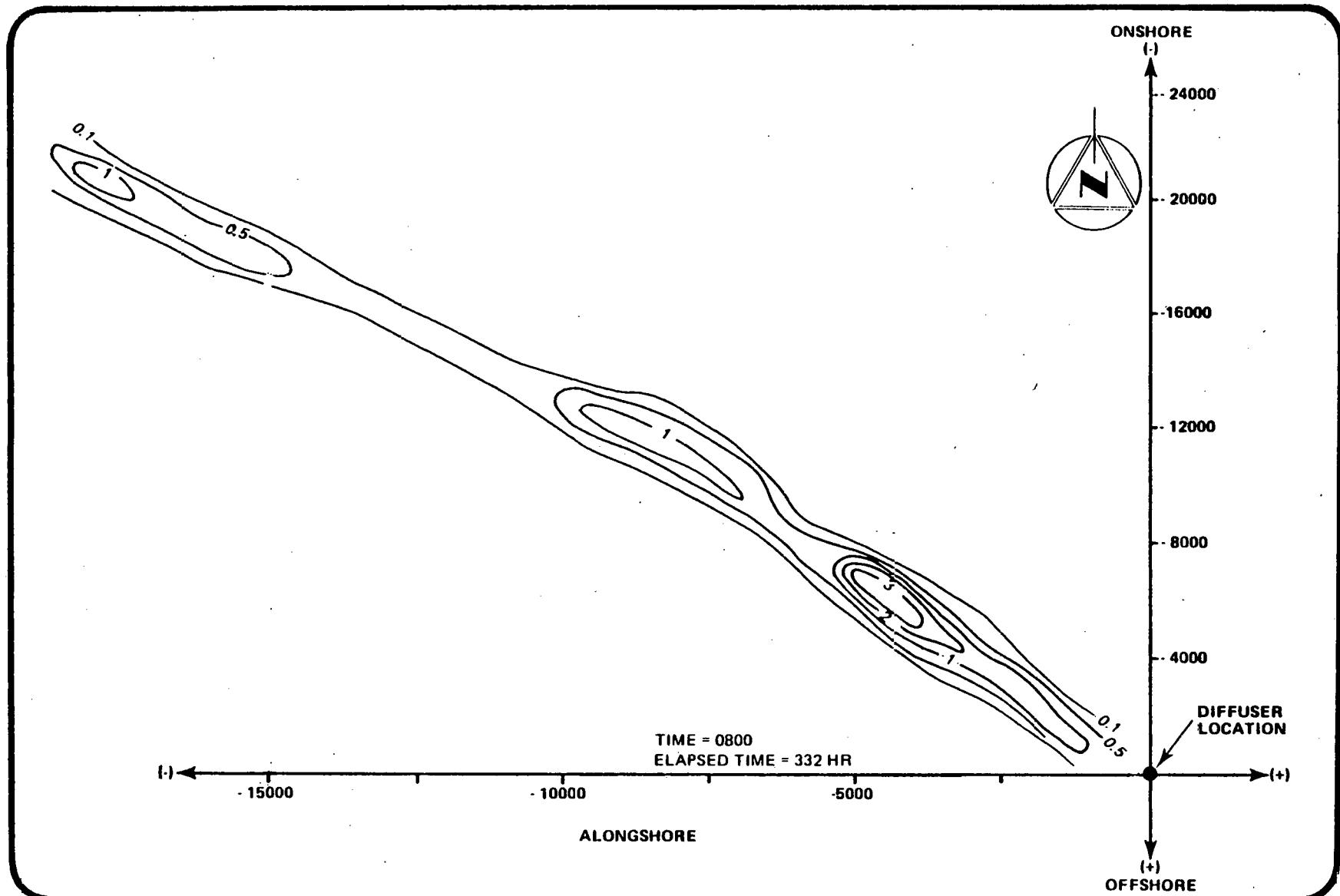
FIGURE 3-12   Contours of excess salinity concentration (ppt) at various distances (feet) from the proposed diffuser for Weeks Island Site A (using observed currents at 12 feet on December 29, 1977).
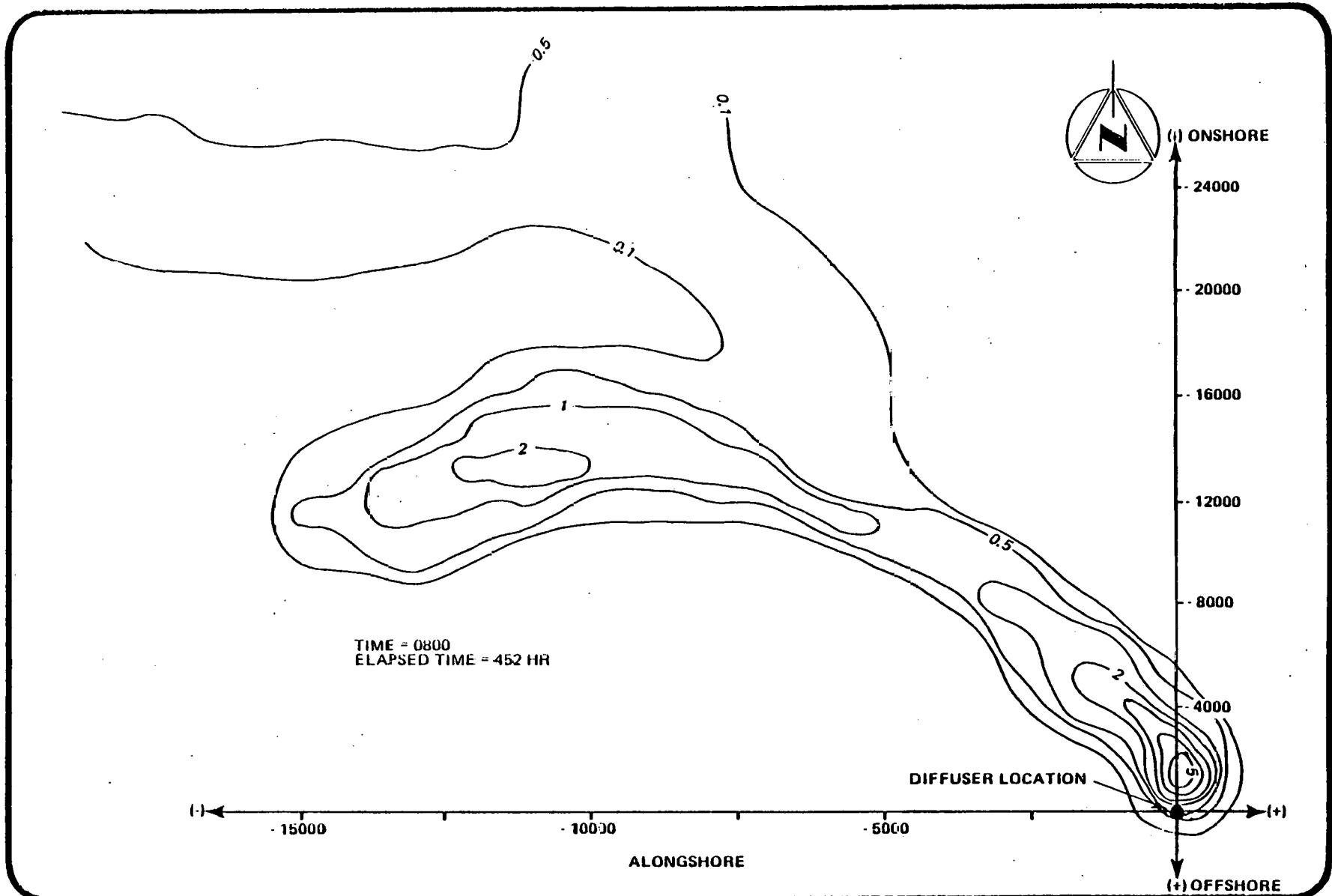
FIGURE 3-13 Contours of excess salinity concentration (ppt) at various distances (feet) from the proposed diffuser for Weeks Island Site A (using observed currents at 12 feet on January 3, 1978).

T_1 = 332 HR (DECEMBER 29, 1977)
T_2 = 452 HR (JANUARY 3, 1978)
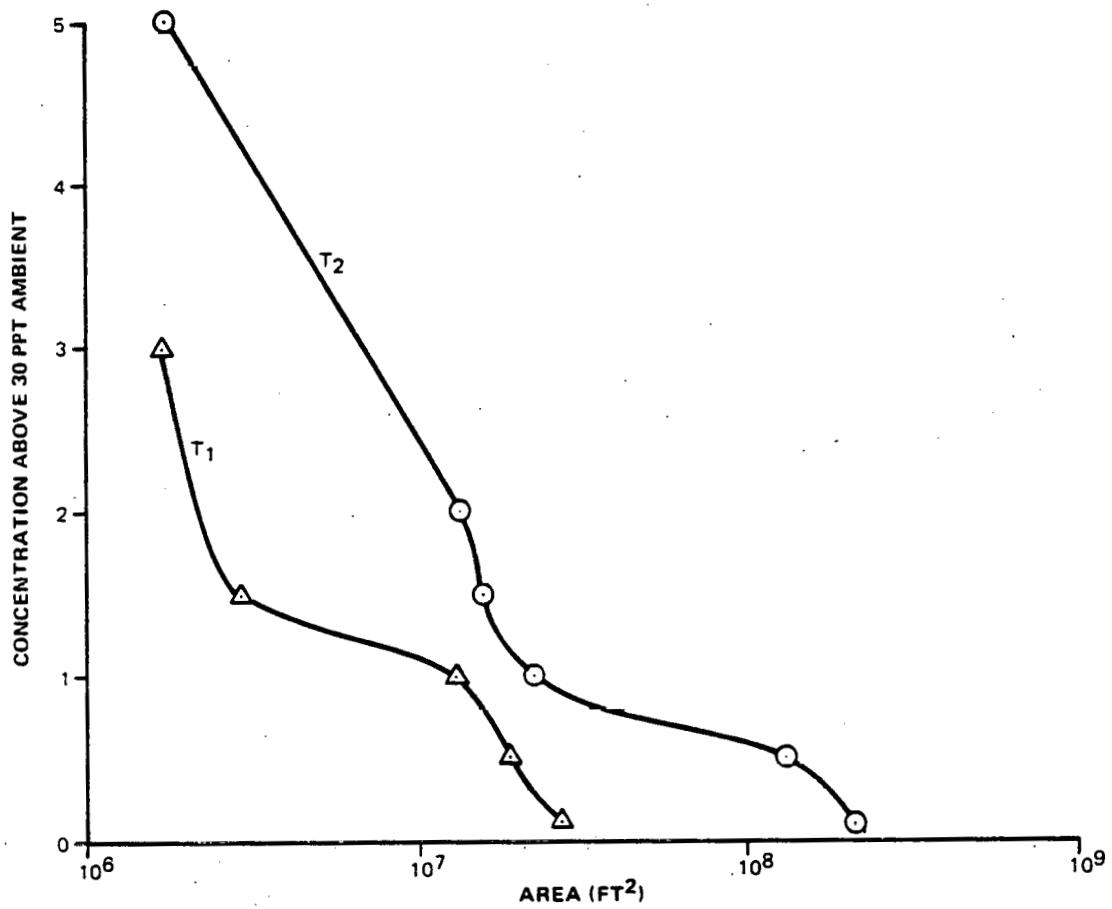
FIGURE 3-14   Excess salinity concentration versus bottom area for Weeks Island Site A, December 29, 1977 and January 3, 1978.

3.1.2.3.3 Site B, January - March 1978

Input to the model began on January 7. Snapshot outputs of salinity patterns are shown for January 25, February 5, and March 1 (Figures 3-15, 3-16, and 3-17); these plumes represent best, worst, and base cases, respectively. The velocity vectors corresponding to the times the plume model outputs were taken are shown in Figure 3-18. A plot of affected bottom area versus excess salinity concentration for the three cases is presented in Figure 3-19. During the passage of a storm on January 25, the plume would be diluted by high current velocities to such an extent that an increase of only 0.5 ppt above ambient would be expected within a boundary of 1.125×10^7 square feet (258 acres). According to the tidal circulation documented on February 5, an increase of 3 ppt above ambient may be expected within a boundary of 2.25×10^6 square feet (52 acres). An extended run (1283 hours) with approximately 2 months of current data input to the model was used to derive a base case condition, which predicts an increase of 2 ppt above ambient within a boundary of 4.5×10^6 square feet (103 acres).

3.1.2.3.4 Site B, March - April 1978

Figure 3-20 illustrates the current velocity vectors at 17 and 21.5 feet (5.2 and 6.6 meters), measured on April 10 and 27. Input to the model began on March 18. Figures 3-21 and 3-22 represent snapshot outputs of salinity patterns for April 10 (worst case) and 27 (best case), respectively. Under the worst case conditions (low current velocity and tidal-dominated circulation), an increase of 5 ppt above ambient may be expected within a boundary of 2.25×10^6 square feet (52 acres), (Figure 3-23). The lowest increase above ambient salinity (2 ppt) occurred under conditions of strong offshore currents.

3.1.2.3.5 Site B, May 1978

Figure 3-24 illustrates the current velocity vectors at 17 and 21.5 feet (5.2 and 6.6 meters), measured on May 12 and 22. Input to the model began on March 18.

Model outputs were selected to obtain two extreme conditions during the late spring. From May 6 through 12, there was a westerly drift current associated with the highest current speeds recorded during the month. Although the instantaneous velocity profile at 21.5 feet (6.6 meters)
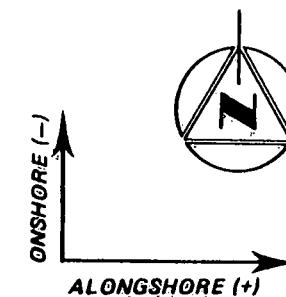
FIGURE 3-15   Weeks Island Site B current velocity vectors corresponding to the snapshot times for the plume model output, January 25, February 5, and March 1, 1978 (see Figures 3-16 through 3-18).
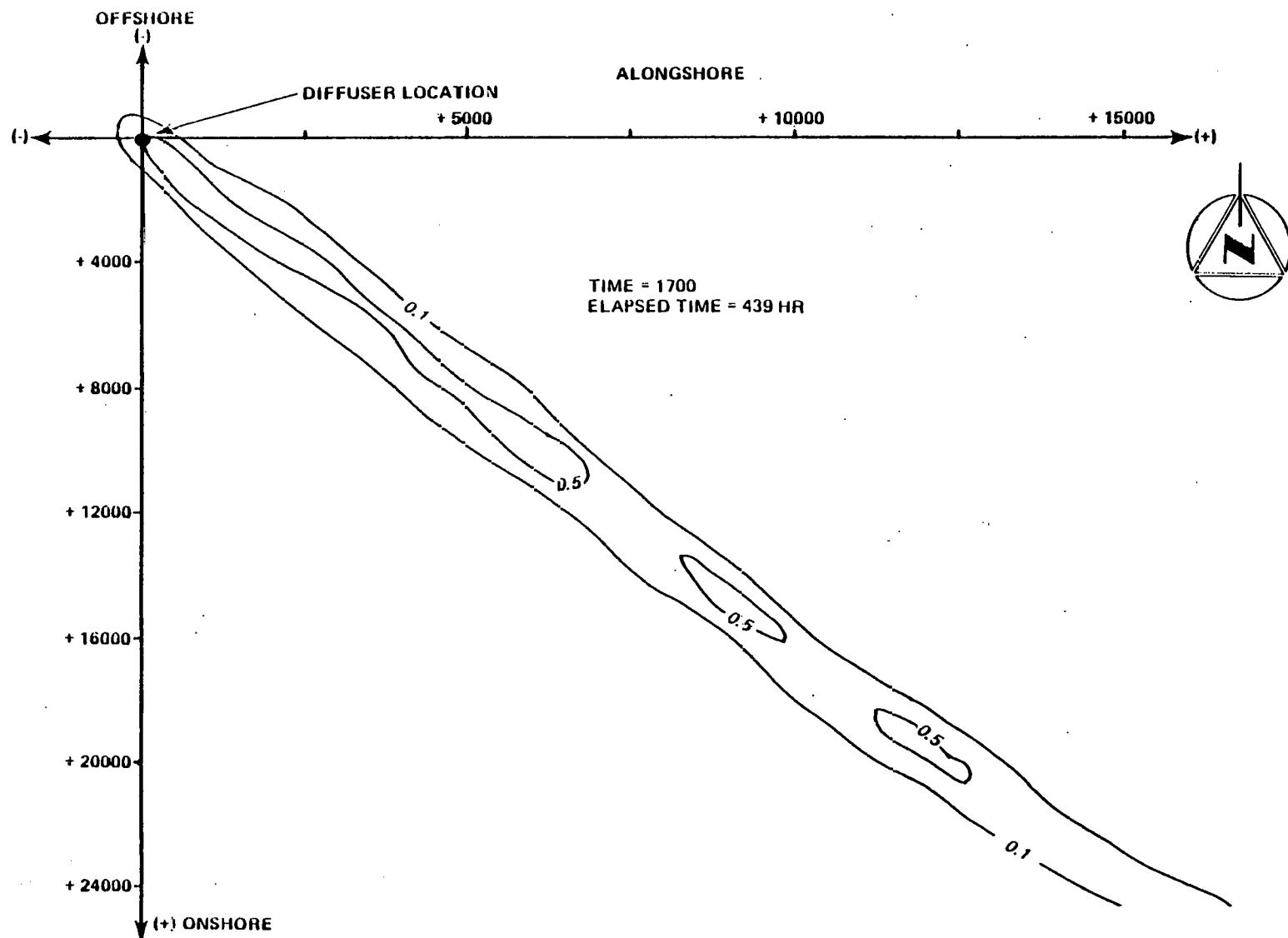
FIGURE 3-16   Contours of excess salinity concentration (ppt) at various distances (feet) from the proposed diffuser for Weeks Island Site B (using observed currents at 12 feet on January 25, 1978).
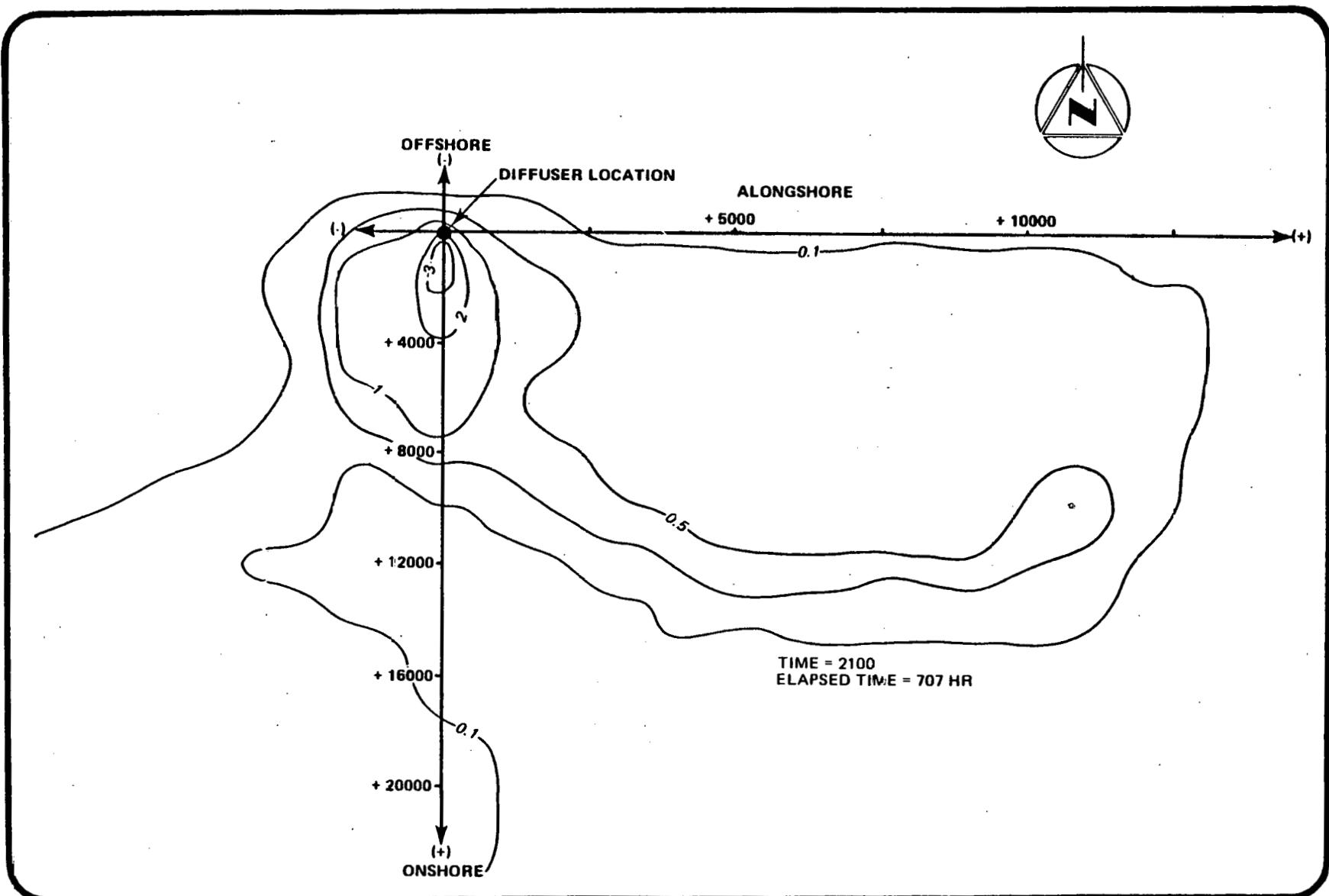
FIGURE 3-17   Contours of excess salinity concentration (ppt) at various distances (feet) from the proposed diffuser for Weeks Island Site B (using observed currents at 12 feet on February 5, 1978).

OFFSHORE
(-)

DIFFUSER LOCATION

-20000   -15000   -10000   -5000

ALONGSHORE

(-)   (+)

0.1   0.5   1   2

+ 4000

+ 8000

+ 12000

+ 16000

+ 20000

TIME = 2100

ELAPSED TIME = 1233 HR

ONSHORE (+)

3-26
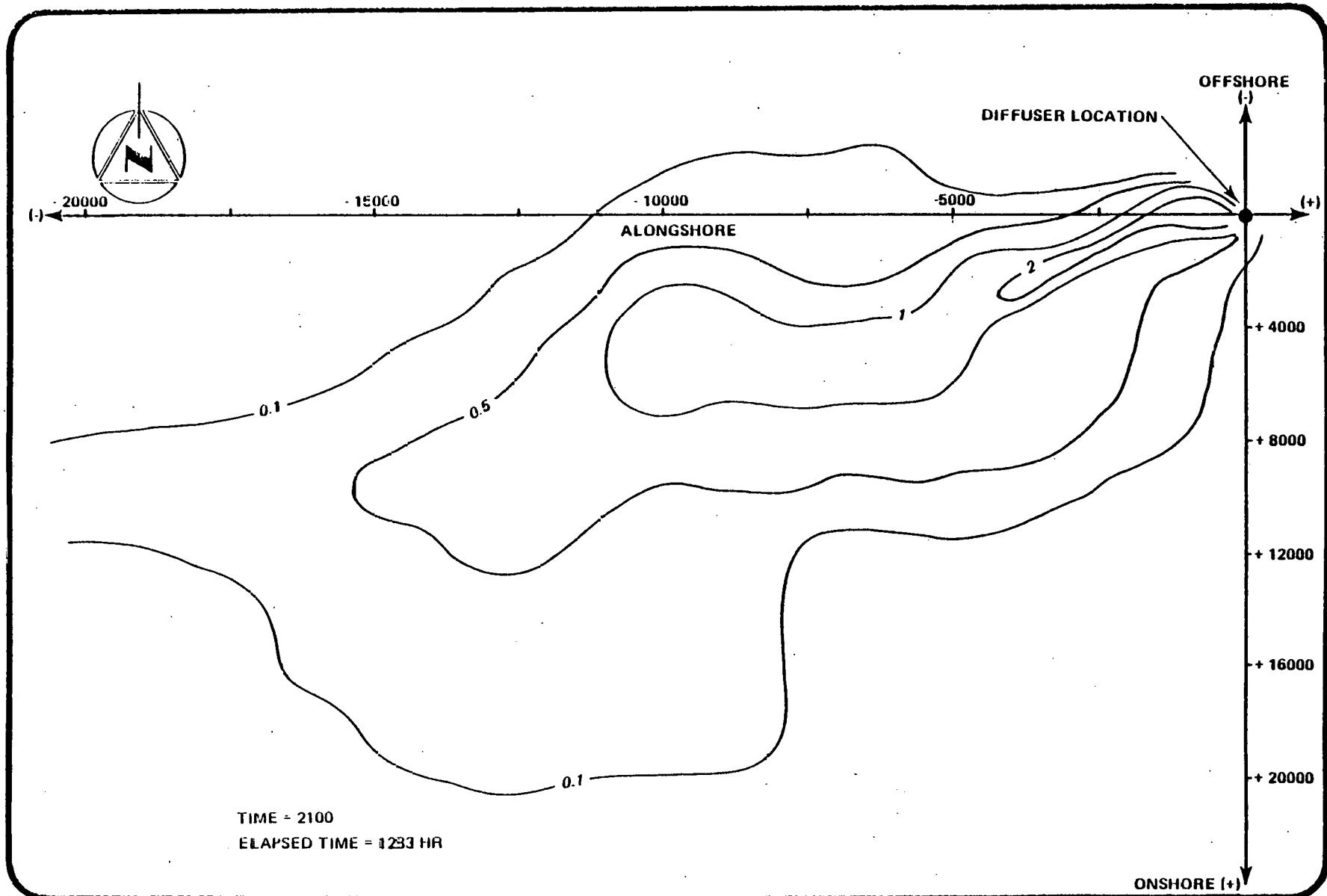
FIGURE 3-18   Contours of excess salinity concentration (ppt) at various distances (feet) from the proposed diffuser for Weeks Island Site B (using observed currents at 12 feet on March 1, 1978).
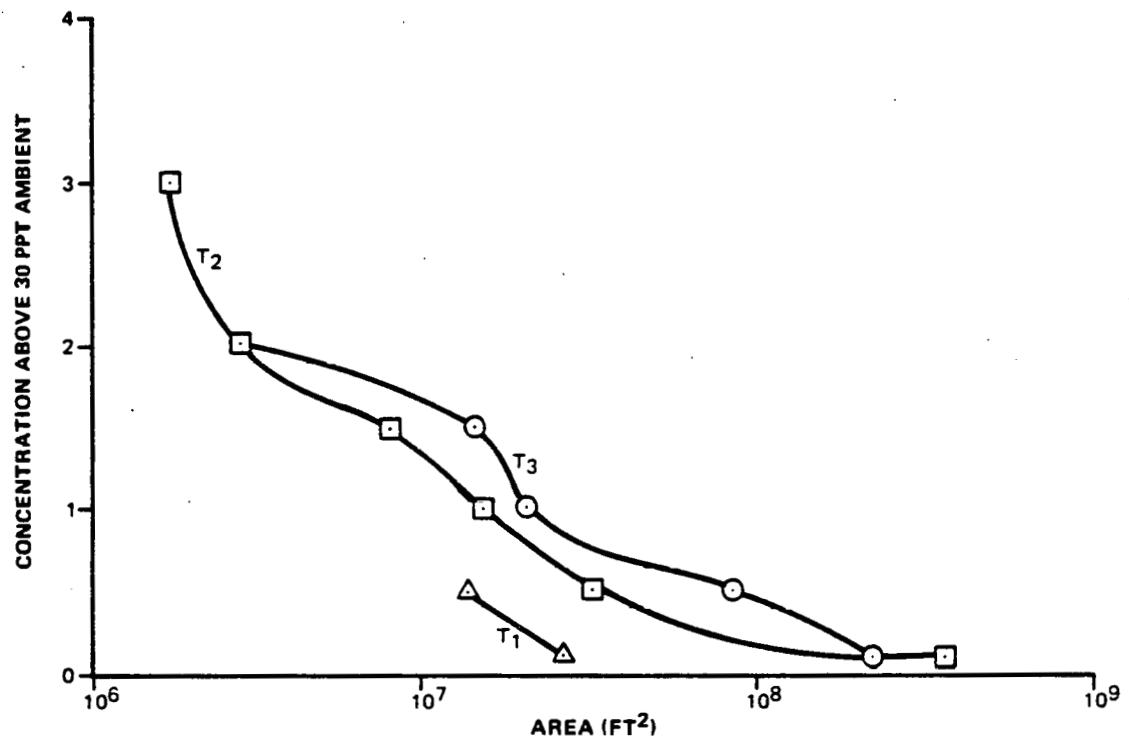
FIGURE 3-19 Excess salinity concentration versus bottom area for Weeks Island Site B, January 25, February 5, and March 1, 1978.

APRIL 10, 1978

TIME = 1500
17 ft, 18.4 cm/sec
21.5 ft, 12.4 cm/sec

APRIL 27, 1978

TIME = 0400
17 ft, 38.5 cm/sec
21.5 ft, 25.5 cm/sec

ONSHORE (-)

ALONGSHORE (+)

———————— 17 FEET

— — — — — — 21.5 FEET

0   10

SCALE : cm/sec
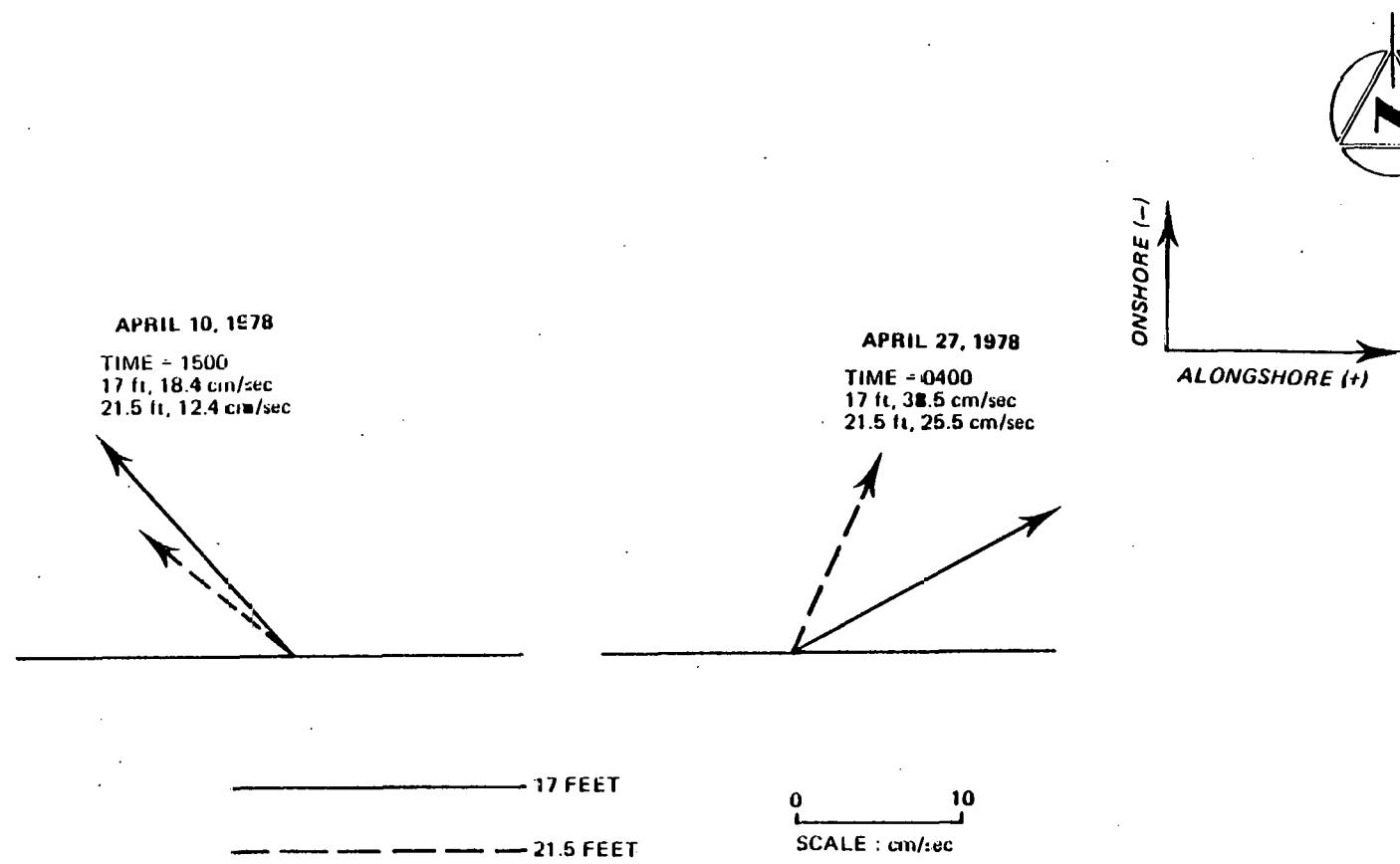
FIGURE 3-20   Weeks Island Site B current velocity vectors corresponding to the snapshot times for the plume model output, April 10 and 27, 1978 (see Figures 3-21 and 3-22).
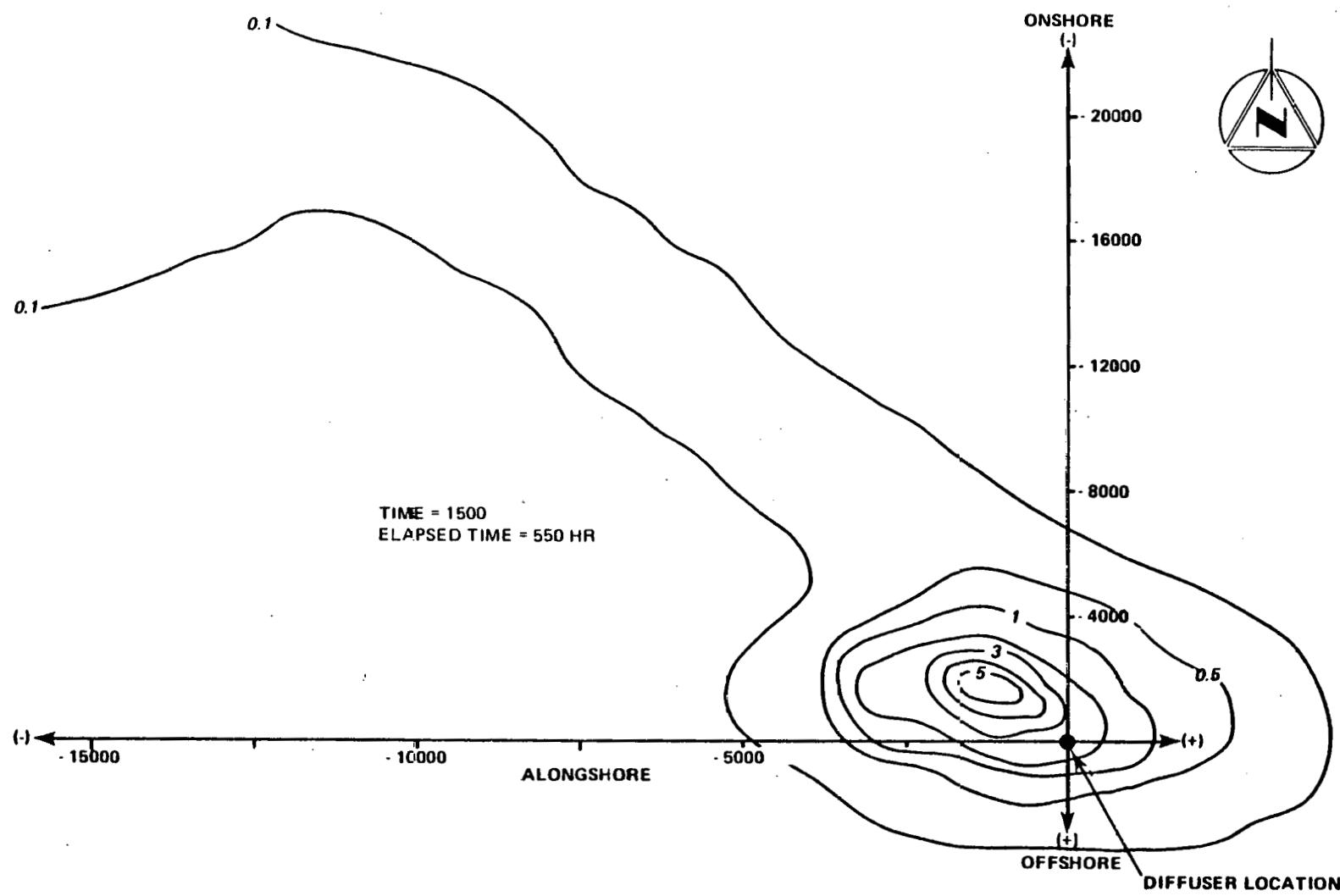
FIGURE 3-21   Contours of excess salinity concentration (ppt) at various distances (feet) from the proposed diffuser for Weeks Island Site B (using observed currents at 17 and 21.5 feet on April 10, 1978).
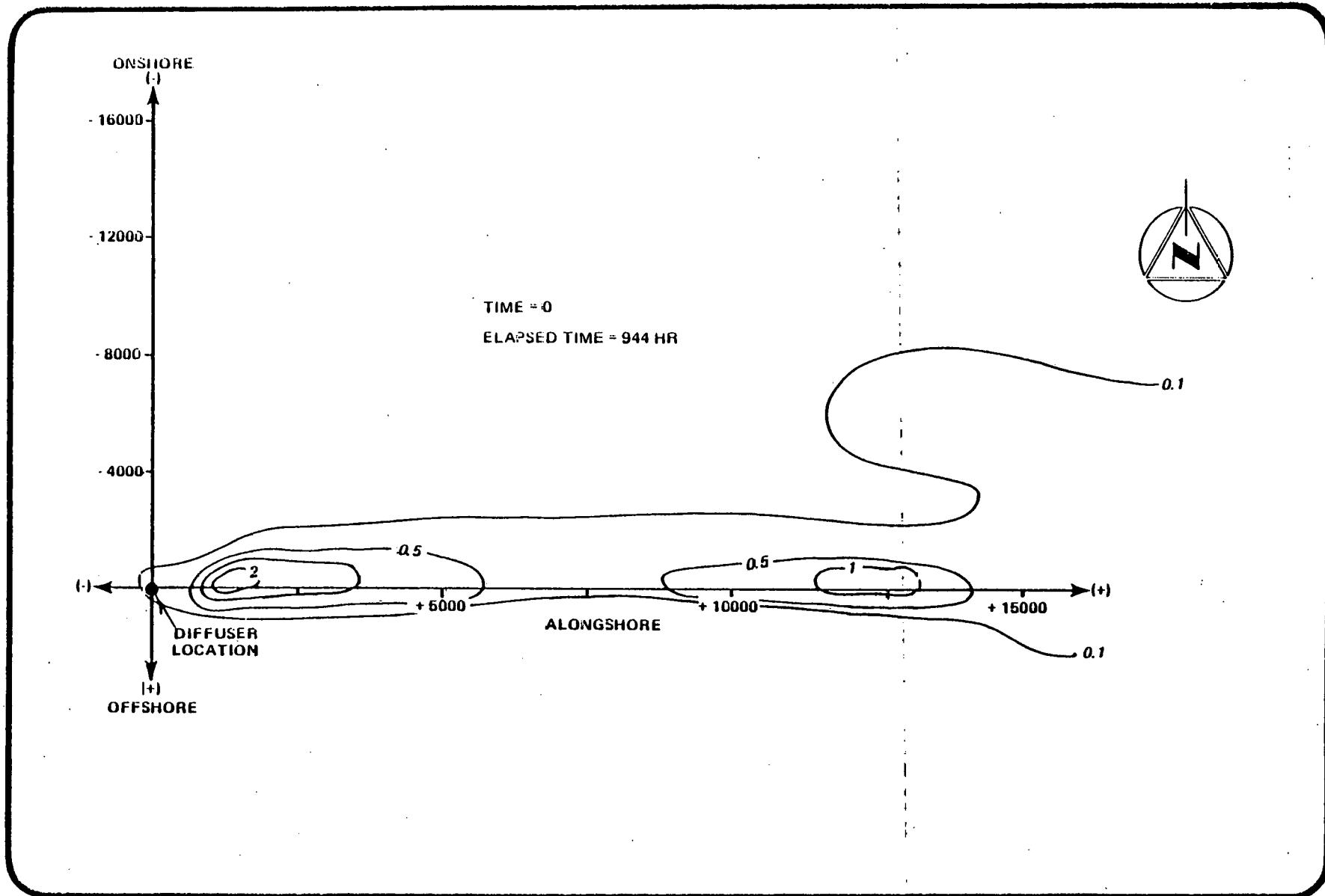
FIGURE 3-22   Contours of excess salinity concentration (ppt) at various distances (feet) from the proposed diffuser for Weeks Island Site B (using observed currents at 17 and 21.5 feet on April 27, 1978).
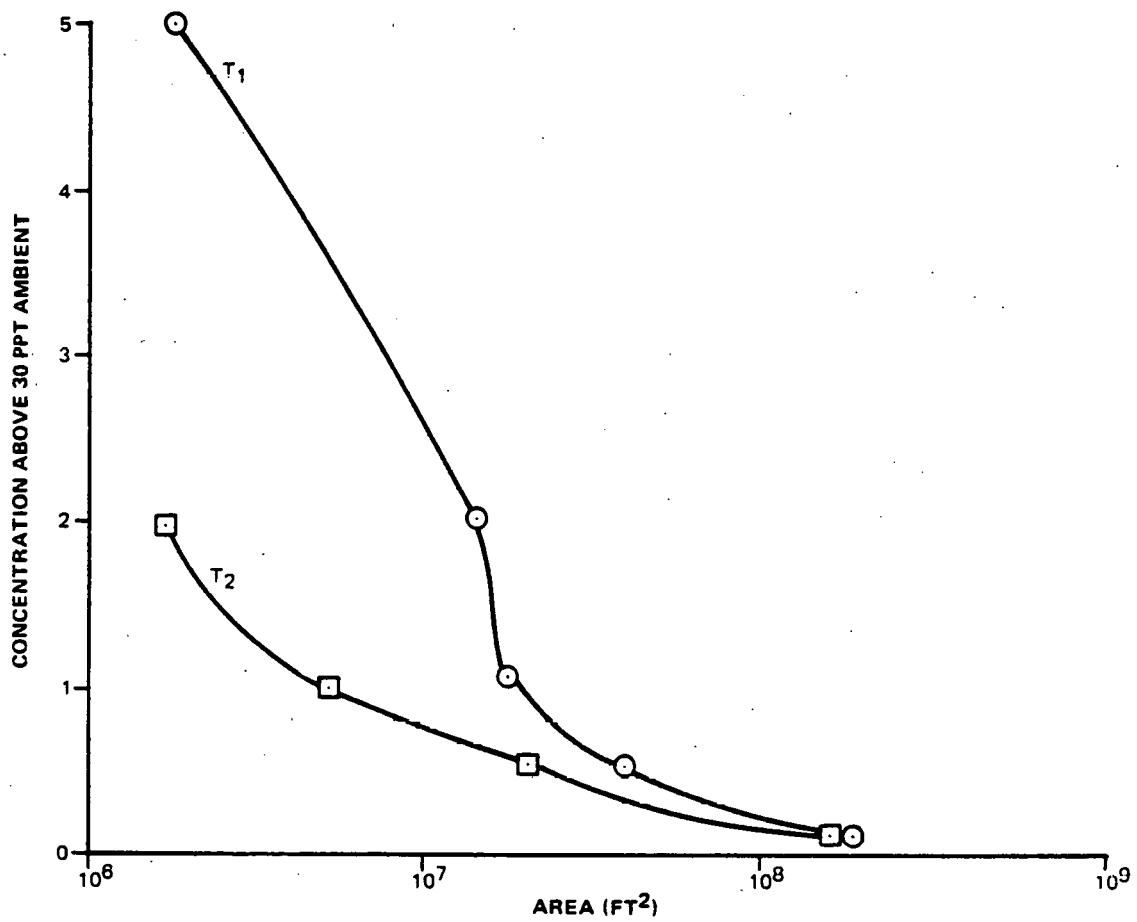
FIGURE 3-23   Excess salinity concentration versus bottom area for Weeks Island Site B, April 10 and 27, 1978.

ONSHORE (-)

ALONGSHORE (+)

MAY 12, 1978

TIME = 2100
17 ft, 24.9 cm/sec
21.5 ft, 19.5 cm/sec

MAY 22, 1978

TIME = 0300
17 ft, 17.5 cm/sec
21.5 ft, 9 cm/sec

————— 17 FEET

—————— 21.5 FEET

0   10

SCALE: cm/sec

3-32
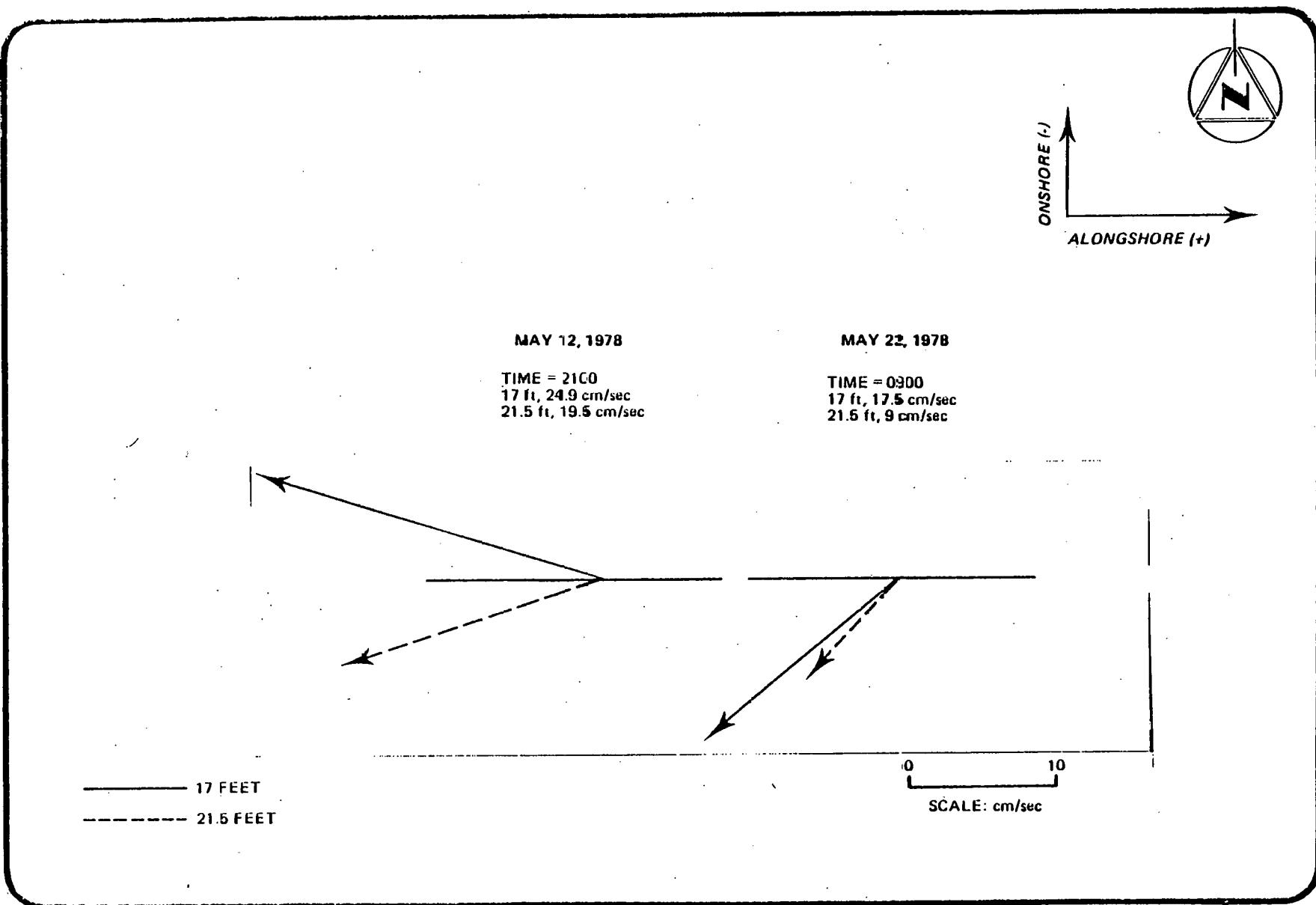
FIGURE 3-24   Weeks Island Site B current velocity vectors corresponding to the snapshot times
for the plume model output, May 12 and 22, 1978 (see Figures 3-25 and 3-26).

shows a northeasterly flow on May 12 (Figure 3-24), the plume follows the current direction and drifts westward (Figure 3-25). The shape of the plume is long and narrow with reduced salinity concentrations near the diffuser (<2 ppt above ambient). From May 19 to 25, there was little net drift with tidal circulation predominating. Under these conditions, the plume remains close to the diffuser with salinity concentrations increasing to 4 ppt above ambient (Figure 3-26).

Figure 3-27 shows a plot of excess salinity concentration versus affected bottom area. The best case (May 12) predicts that an area of 2.25×10^6 square feet would be subjected to salinities of 2 ppt above ambient. The worst case (May 22) predicts that an area of 3.375×10^6 square feet would be subjected to excess salinities of 4 ppt above ambient.

3.1.2.3.6 Site B, May - July 1978

Figure 3-28 shows the current velocity vectors at 17 and 21.5 feet (5.2 and 6.6 meters), measured on May 29, June 7, 25, 28, and July 8. Input to the model began on March 18, with snapshots of the plume taken on each of the 5 days. These outputs were selected to examine plume behavior under a variety of summer current conditions.

From May 25 to 31, current speeds attained a maximum speed of 1.4 ft/sec (43 cm/sec); net drift direction was to the northwest. The long narrow plume on May 29 represents a best case with very diluted salinities in the vicinity of the diffuser (Figure 3-29). The orientation of the plume also reflects the northwesterly drift direction. During the early part of June, current speed and direction were variable, but the net drift direction was to the northwest and current speeds were generally less than 0.7 ft/sec (20 cm/sec). The plume on June 7 represents a worst case analysis with high salinity values near the diffuser (Figure 3-30). Figure 3-30 shows that an increase of 4 ppt may be expected within a boundary of 2.25×10^6 square feet.

The two plumes on June 25 (Figure 3-31) and 28 (Figure 3-32) show the buildup of excess salinity concentration with time during a stagnation period (low current speed). Following several days of high current speeds (maximum 1.4 ft/sec (42 cm/sec)), there was a 5-day period (June 24 to 29) when current speeds were generally less than 0.3 ft/sec (10 cm/sec). The
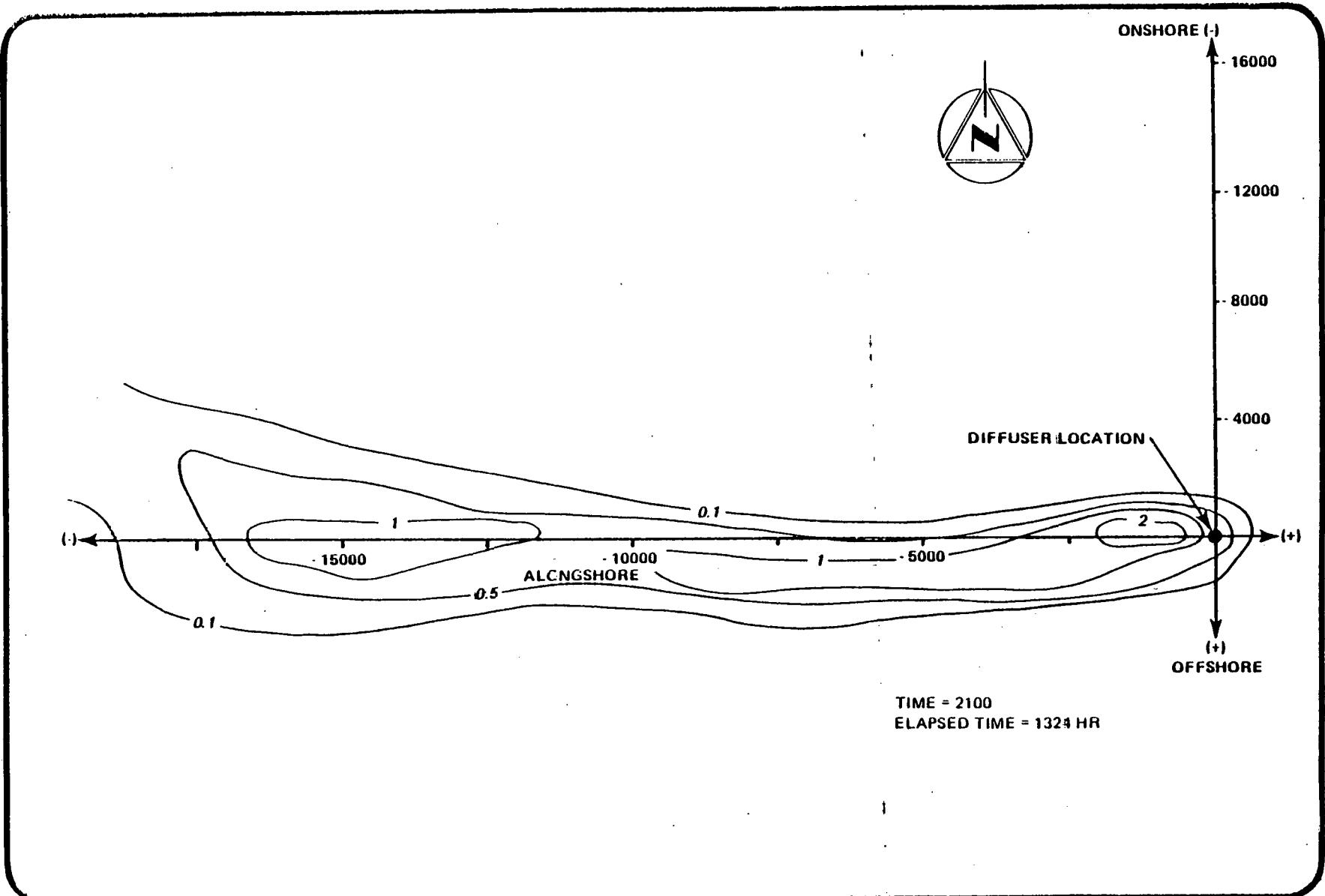
FIGURE 3-25   Contours of excess salinity concentration (ppt) at various distances (feet) from the proposed diffuser for Weeks Island Site B (using observed currents at 17 and 21.5 feet on May 12, 1978).
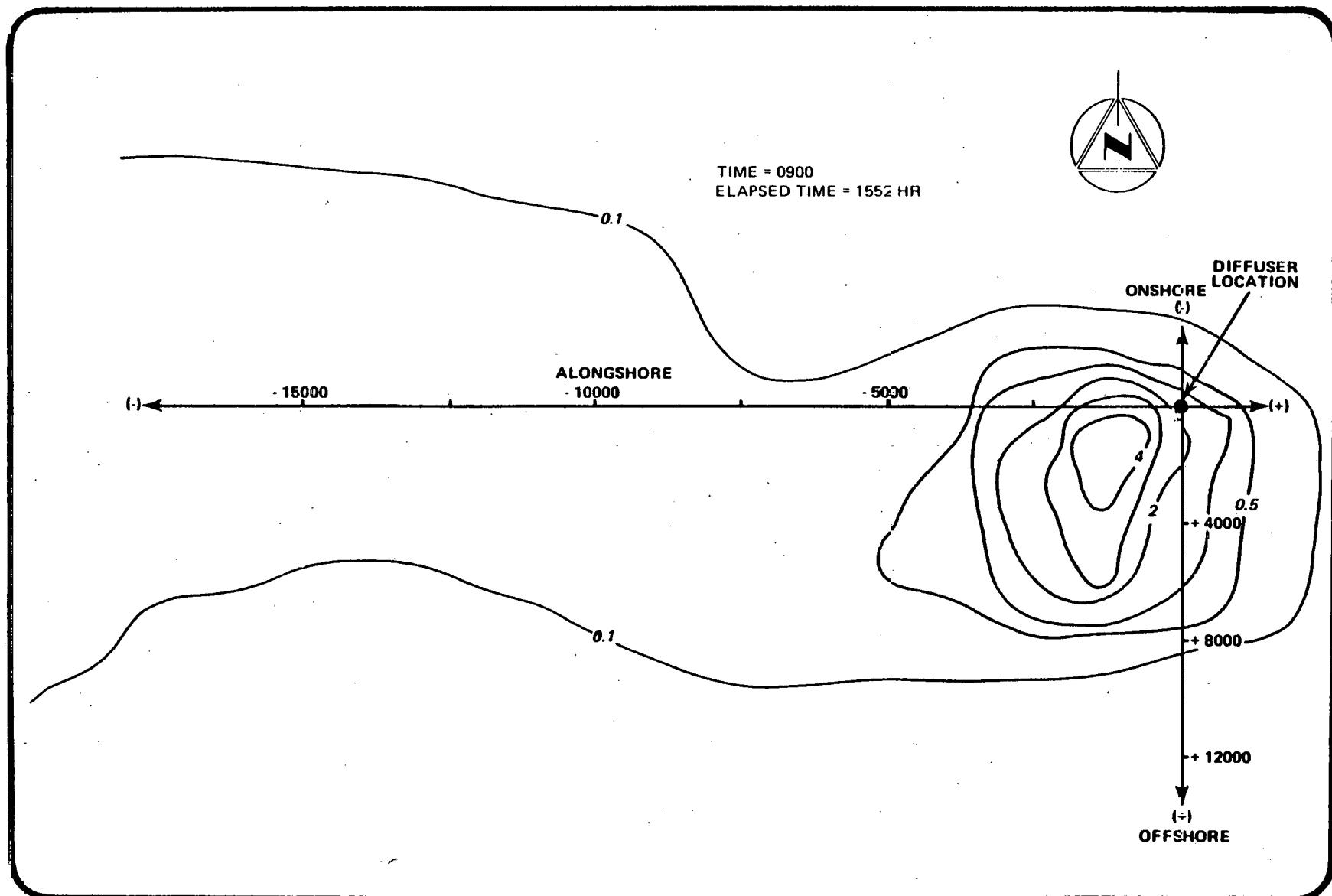
FIGURE 3-26   Contours of excess salinity concentration (ppt) at various distances (feet) from the proposed diffuser for Weeks Island Site B (using observed currents at 17 and 21.5 feet on May 22, 1978).
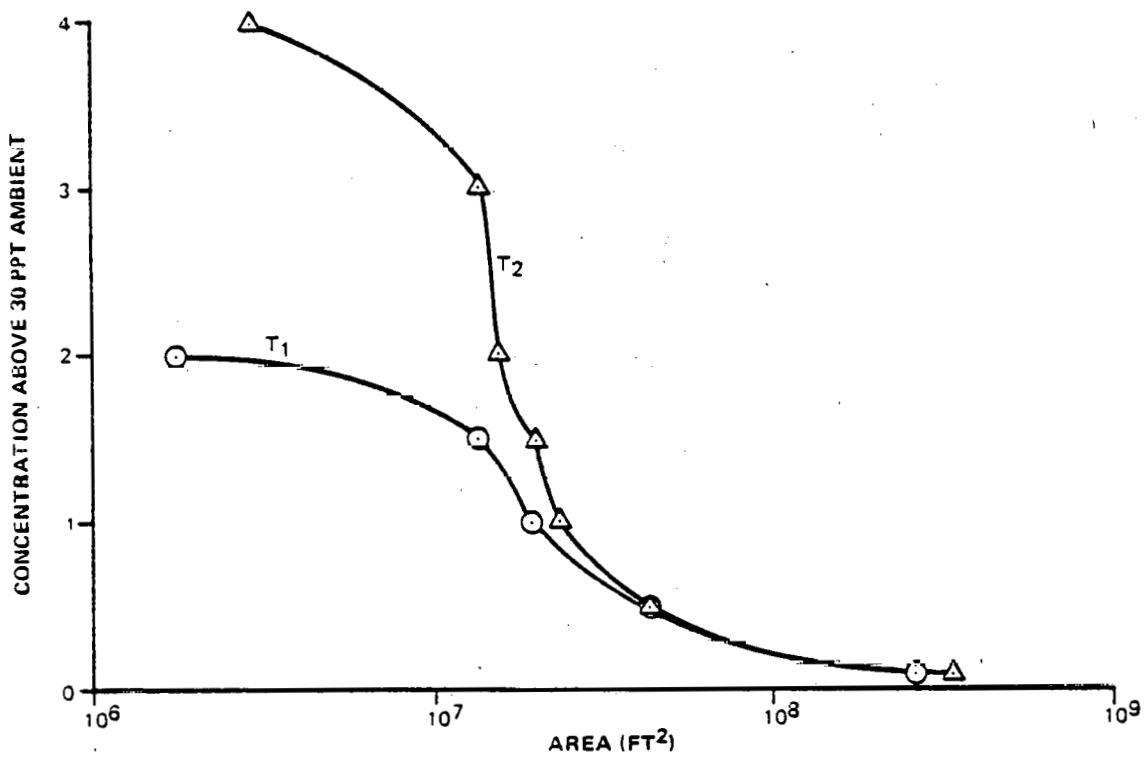
FIGURE 3-27   Excess salinity concentration versus bottom area for Weeks
Island Site B, May 12 and 22, 1978.

ONSHORE (−)

ALONGSHORE (+)

JUNE 28, 1978

TIME = 0600
17 ft, 19.4 cm/sec
21.5 ft, 7.5 cm/sec

MAY 29, 1978

TIME = 0300
17 ft, 32 cm/sec
21.5 ft, 23.4 cm/sec

JUNE 7, 1978

TIME = 1800
17 ft, 16.4 cm/sec
21.5 ft, 6.9 cm/sec

JULY 8, 1978

TIME = 1800
17 ft, 10.5 cm/sec
21.5 ft, 8.9 cm/sec

JUNE 25, 1978

TIME = 1800
17 ft, 4.5 cm/sec
21.5 ft, 6 cm/sec

0   10
SCALE : cm/sec

————————————— 17 FEET
— — — — — — — 21.5 FEET
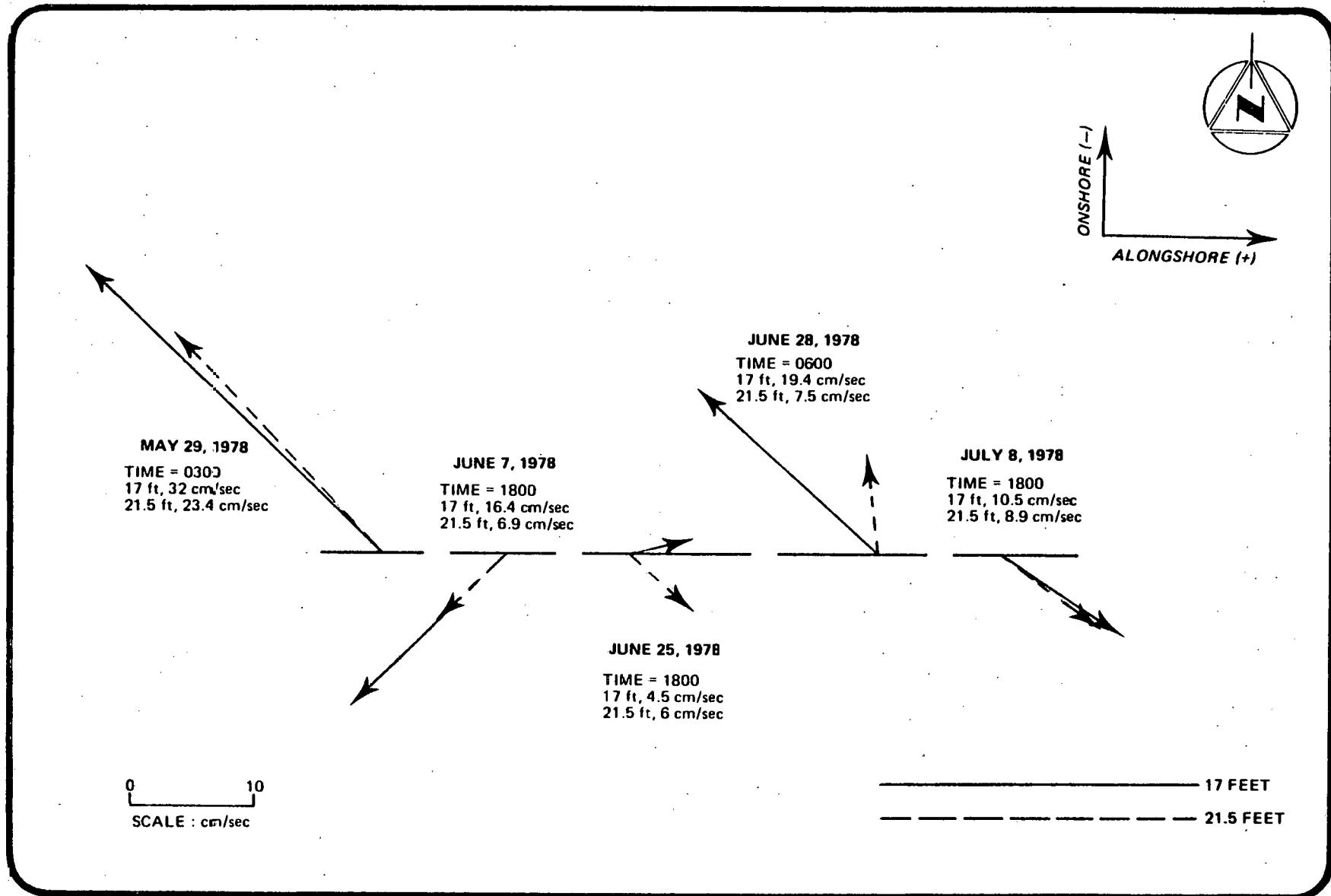
FIGURE 3-28   Weeks Island Site B current velocity vectors corresponding to the snapshot times for the plume
model output, May 29, June 7, 25, 28, and July 8, 1978 (see Figures 3-29 through 3-33).
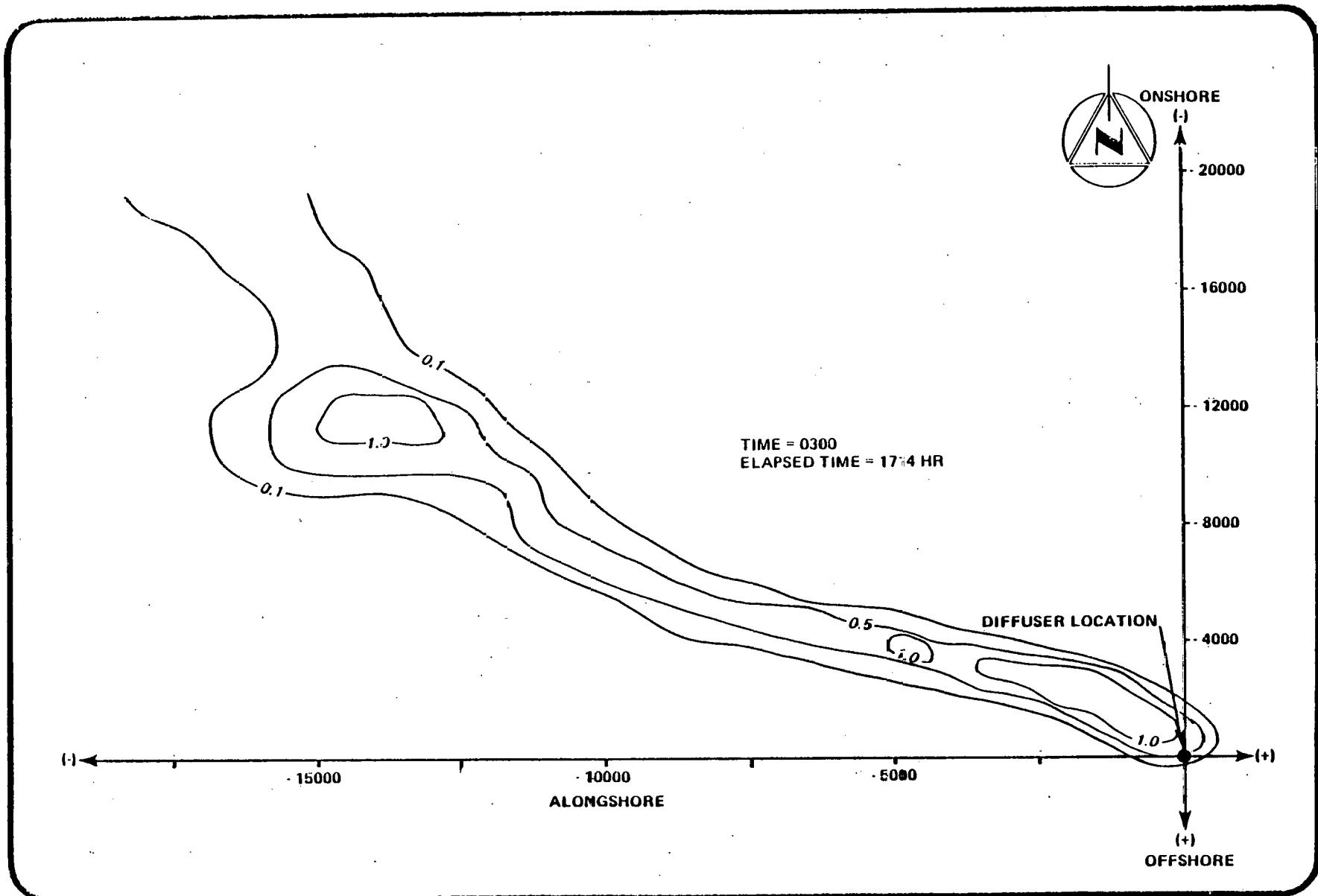
FIGURE 3-29   Contours of excess salinity concentration (ppt) at various distances (feet) from the proposed diffuser for Weeks Island Site B (using observed currents at 17 and 21.5 feet on May 29, 1978).
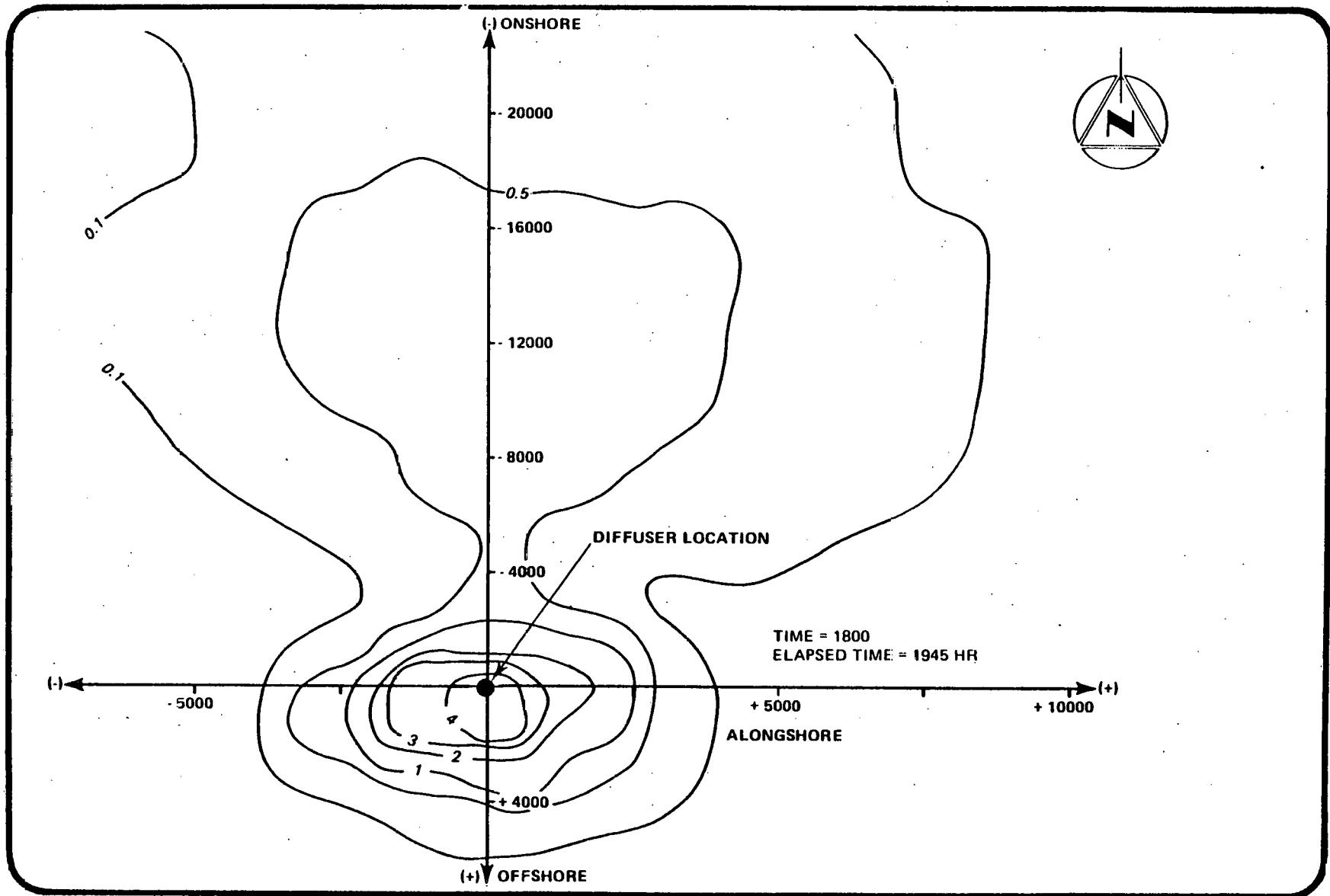
FIGURE 3-30   Contours of excess salinity concentration (ppt) at various distances (feet) from the proposed diffuser for Weeks Island Site B (using observed currents at 17 and 21.5 feet on June 7, 1978).

TIME = 1800
ELAPSED TIME = 2377 HR

DIFFUSER LOCATION
ONSHORE (-)

ALONGSHORE

+ 5000

+ 10000

(-)

(+)

2

1

0.5

+ 4000

+ 8000

+ 12000

0.1

+ 16000

(+)
OFFSHORE
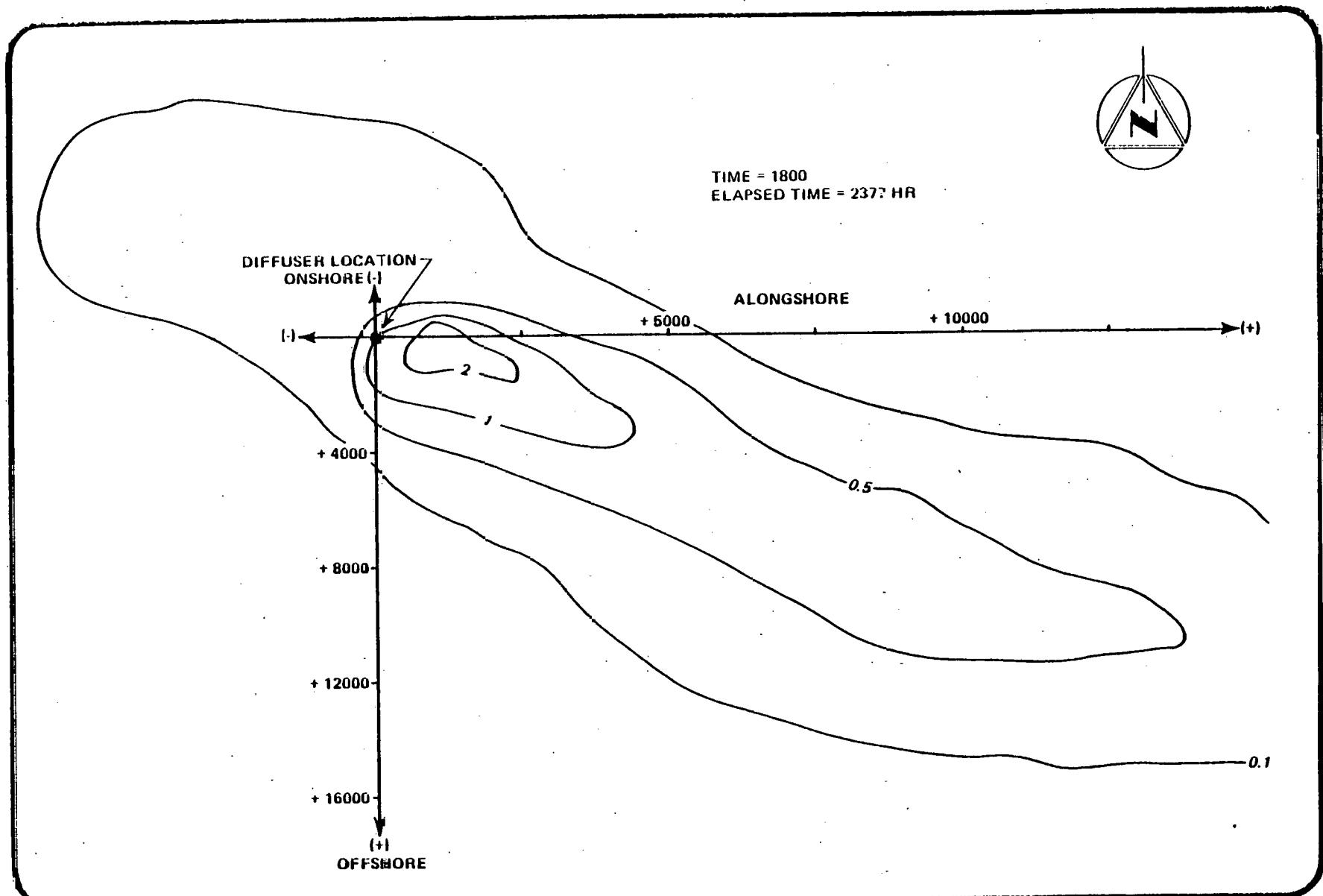
FIGURE 3-31   Contours of excess salinity concentration (ppt) at various distances (feet) from the proposed
diffuser for Weeks Island Site B (using observed currents at 17 and 21.5 feet on June 25, 1978).
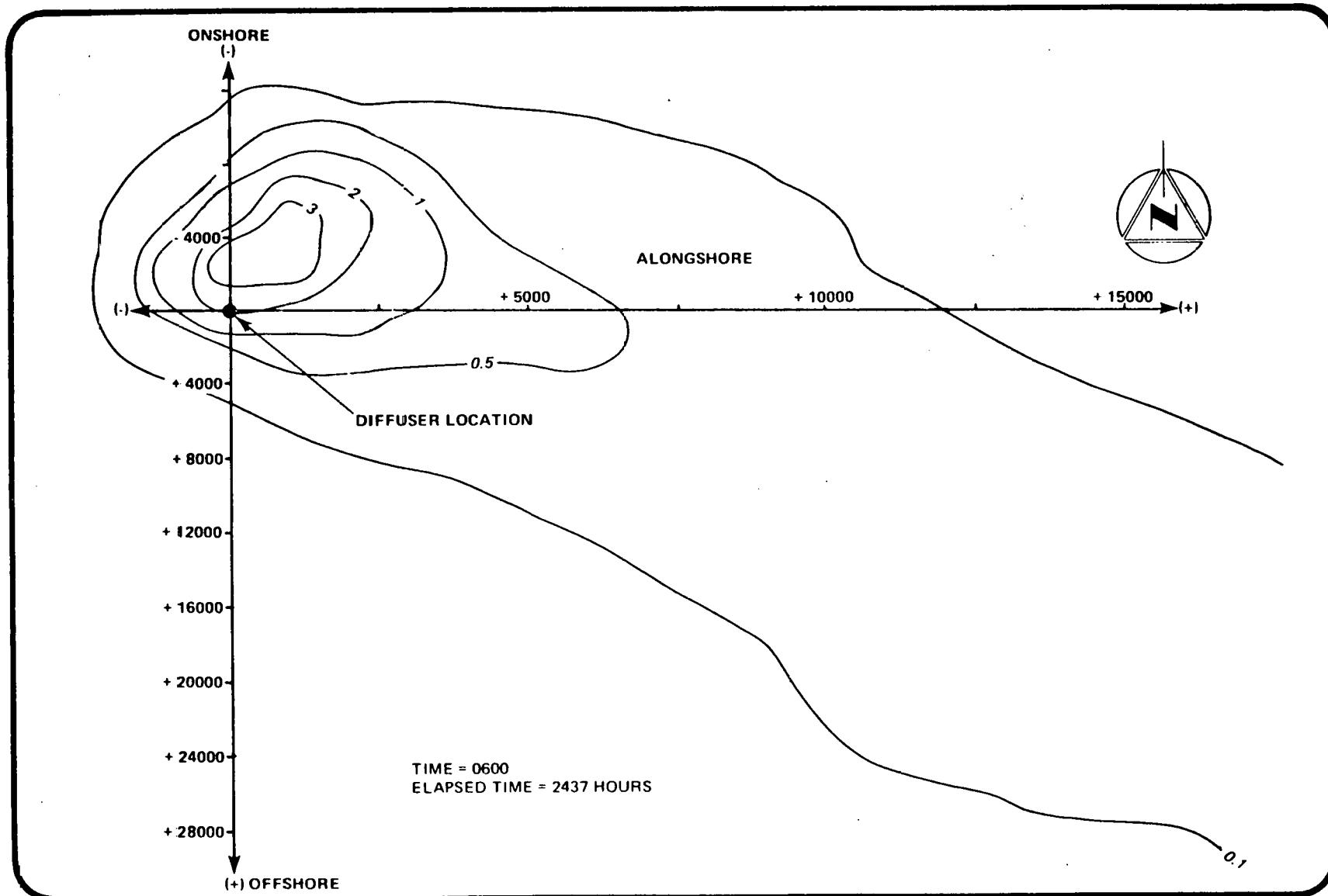
FIGURE 3-32 Contours of excess salinity concentration (ppt) at various distances (feet) from the proposed diffuser for Weeks Island Site B (using observed currents at 17 and 21.5 feet on June 28, 1973).

elongated plume of June 25 is partially representative of the high speed currents several days earlier (Figure 3-31). The salinity concentration, however, does not exceed 2 ppt above ambient. On June 28, the plume was closely centered around the diffuser with a maximum excess salinity concentration of 3 ppt (Figure 3-32) as a result of the stagnation effect. On June 25, an area of 1.125×10^7 square feet (258 acres) shows an increase in salinity of 1.15 ppt. By June 28, the expected salinity concentration increased to 3 ppt over the same area.

An extended run of 2689 hours was made using all the current meter data collected at Site B since March 18. Current speeds in early June were generally less than 0.7 ft/sec (20 cm/sec) with the predominant drift direction to the southeast. The model output on July 8 (Figure 3-33) shows an easterly trending plume with a maximum excess salinity concentration of 3 ppt. An increase of 3 ppt would be expected within a boundary of 2.25×10^6 square feet (52 acres), (Figure 3-34).

3.1.2.4 Comparison of Sites A and B

When the resultant plumes of Weeks Island Sites A and B are compared for similar periods of low current flow (but based on the limited data available from Site A), the low current velocities of 0.4 to 0.6 ft/sec (12 to 18 cm/sec) of January 3 at Site A and April 10 at Site B produced similar plumes (Figures 3-13 and 3-21). A maximum excess salinity of 5 ppt was characteristic of both plumes, with the high salinity water remaining close to the diffusers. The total bottom area affected for each plume (52 acres (21 hectares)) was nearly identical (Figures 3-14 and 3-23).

High current velocities (0.8 to 1.5 ft/sec (23 to 46 cm/sec)) on December 29 at Site A and on May 29 at Site B produced elongated plumes, but these plumes had significantly reduced salinity concentrations. The core of high salinity water (2 to 3 ppt) in the December 29 plume probably represents the remnants of a period of prior stagnation. The high current velocities in December were of short duration, whereas the currents in May were smaller in magnitude but persisted over a longer period before the plume "snapshot" was taken.

Based on these data it does not appear that there would be significant difference in the physical characteristics of brine disposal at Site A or B.
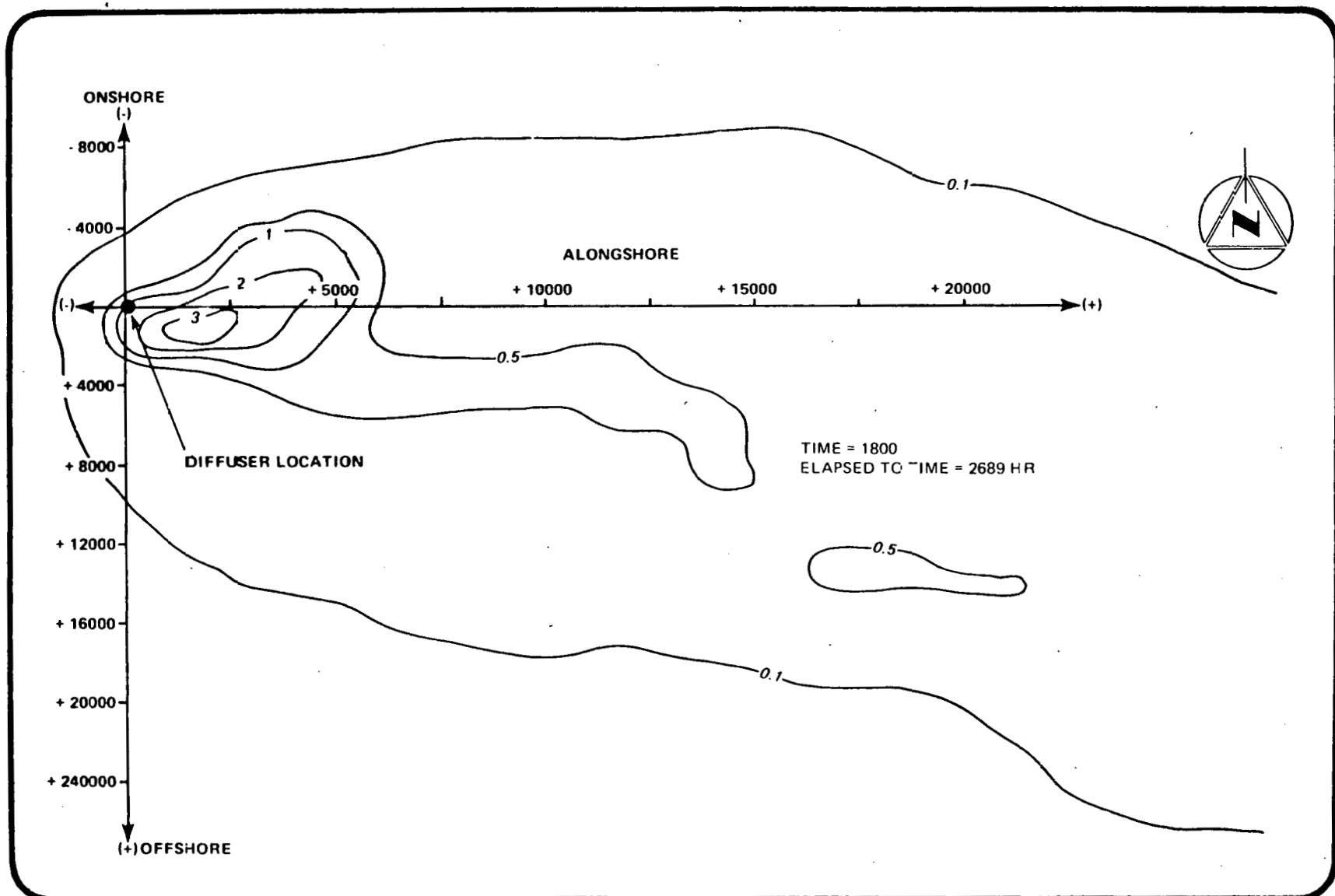
FIGURE 3-33   Contours of excess salinity concentration (ppt) at various distances (feet) from the proposed diffuser for Weeks Island Site B (using observed currents at 17 and 21.5 feet on July 8, 1978).
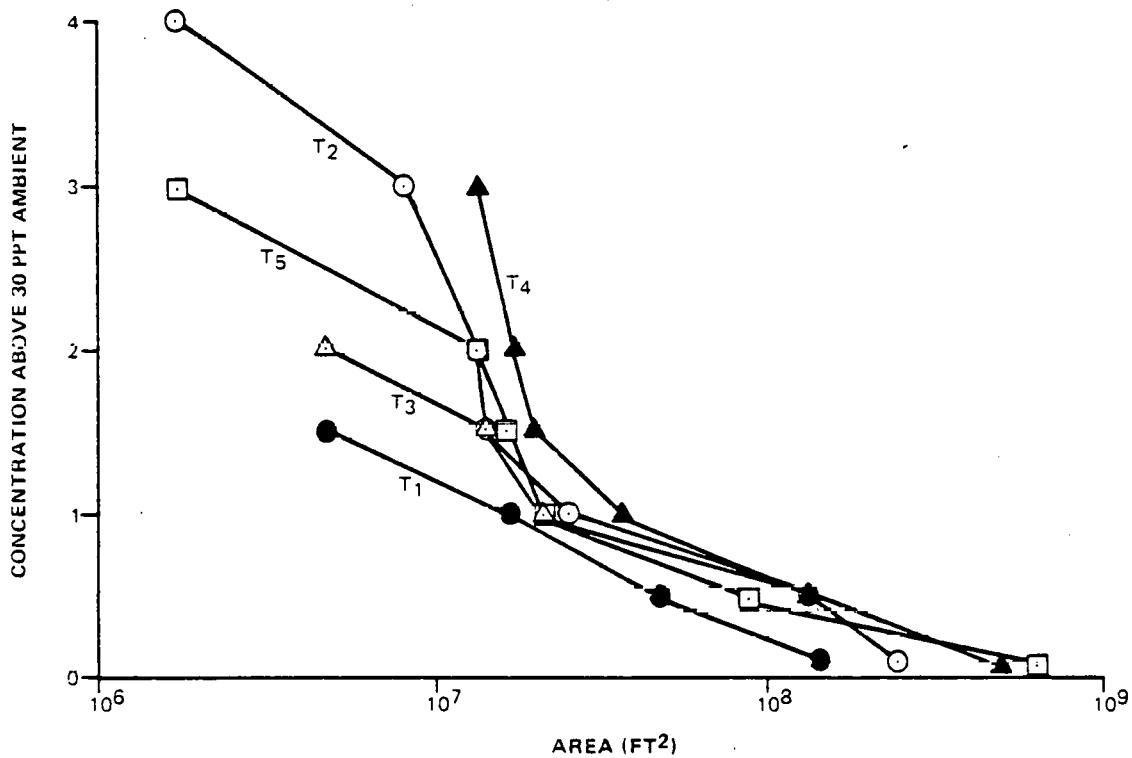
FIGURE 3-34   Excess salinity concentration versus bottom area for Weeks
Island Site B, May 29, June 7, 25, 28, and July 8, 1978.

3.1.2.5 Conclusions

The total area which could be potentially influenced by the brine discharge is illustrated in Figure 3-35. This envelope was determined by measuring the maximum extent of the +0.5-ppt isohaline from all predicted plumes under low current conditions. The MIT transient plume model limits the area of the grid to 30,000 feet (9144 meters) from the center of the diffuser. The shape of the envelope from the April 25 sample plume is skewed to the west due to the predominant westerly drift at the sites throughout the year.

The expected plume patterns, using the observed current data, closely parallel the patterns predicted by inputting estimated current data (U.S. Dept. of Commerce, 1977a). Conclusions drawn from the model outputs may be summarized as follows:

(1) The current sequence throughout a 24-hour tidal cycle has only a moderate effect on the maximum predicted concentration in the far field, but has a substantial effect on the shape of the plume. Strong ambient currents produce long, narrow plumes with relatively low salinity concentrations near the diffuser. During periods of weak ambient currents, the plume tends to remain close to the diffuser due to concentration build-up and poor near-field dilution.

(2) Salinity concentrations in the vicinity of the diffuser are not necessarily more dilute during strong ambient currents within a current cycle. Even though the instantaneous current speed may be high, the effects of prior stagnation or reverse current direction may be detected.

(3) A review of all the best and worst cases reflects similar trends within each group. In the best cases, ambient current speeds are generally 1.3 ft/sec (40 cm/sec) with a steady net drift; however, the actual direction may vary. In the worst cases, ambient current speeds are generally less than 0.8 ft/sec (25 cm/sec), with a rotary tide circulation and little net drift.

(4) There is no discernible seasonal pattern of salinity concentration. Although the greatest amount of dilution was predicted

ENVELCPE OF THE +0.E ISOHALINE

LOW CURRENT CONDITION

$\mathcal{U} \leq 0.2\,FT/SEC$

$Y \leq 0.2\,FT/SEC$

ONSHORE(-)

- 12000
- 8000
- 4000

ALONGS-IORE

- 20000 - 15000 10000 - 5000

(-)   (+)

+ 4000
+ 8000
+ 12000
+ 16000

SAMPLE PLUME, APR. L 25, 1978

TIME = 1000

(+)
OFFSHORE

$\Delta PPT = +0.5$
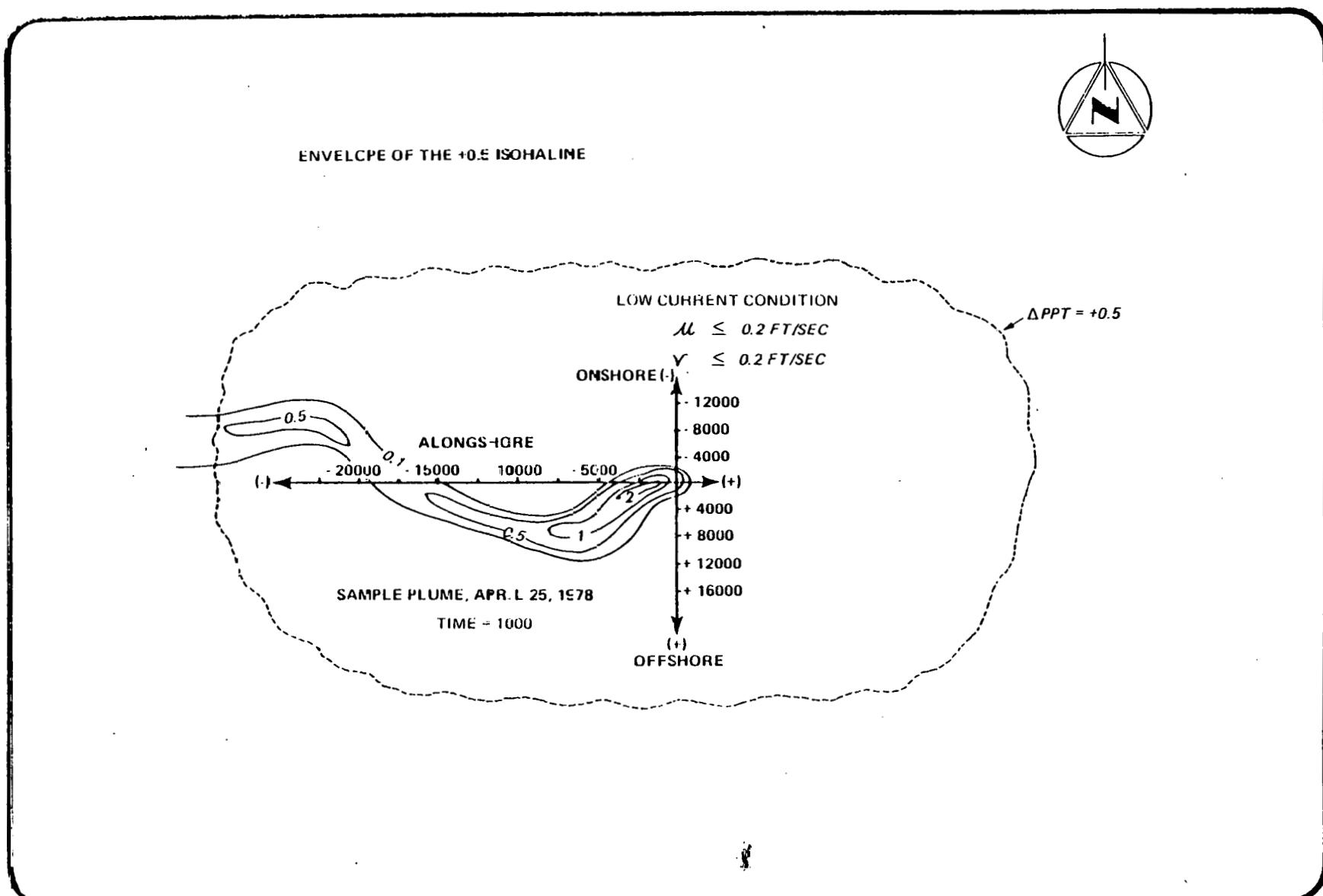
FIGURE 3-35   Sample plume of April 25, 1978, showing area potentially influenced by brine discharge.

during a winter storm in January (Figure 3-15), the highest salinity concentration was also predicted in January (Figure 3-12).

(5) The plots of affected bottom area versus excess salinity concentration for all the worst cases show an expected increase of 3 to 5 ppt over an area of 2.25×10^6 square feet (52 acres). During a 3-day stagnation period there was a 1.5-ppt increase in background salinity concentration over an area of 1.125×10^7 square feet (260 acres), (Figure 3-34).

(6) Based on a limited amount of plume data available from Site A, comparison of plume model outputs at times of comparable current velocity revealed no significant differences between Sites A and B.

3.1.3 Brine Plume Thermal Analysis

The brine to be discharged from Sites A and B (Figure 3-36) would originate either from the initial leaching of caverns or from water displacement of stored oil during a cavern fill period. Because of the earth's thermal influence in these deep caverns, the effluent brine would be subject to temperature elevations dependent on the depth of the leached caverns in the earth, the residence time in the caverns, the temperature of the displaced oil, the retention time of the brine in the holding pits, and any heat loss or gain in the pipeline to offshore. Although it has been conservatively estimated that the temperature of the brine will be $130^\circ F$ ($54^\circ C$), observations made for various flow rates at several operational salt domes (Table 3-2) show that the temperature before injection into a brine holding pit is likely to be less than $120^\circ F$ ($49^\circ C$).

TABLE 3-2. Observed temperature and flow rates for brine at three Gulf Coast salt domes.

Salt Dome	Brine Temperature ($^\circ F$)	Oil Temperature ($^\circ F$)	Flow Rate (BPH)	Well Number
Bryan Mound	120	80	1500	2
			1000	4
Bayou Choctaw	80 - 90	80	1250[a]	15
West Hackberry	80 - 90	80	1500	6
			1000	11

[a]Fill at Bayou Choctaw is intermittent; the average is 1250 BPH, but the actual injection rate is 2200 BPH.

Heat transfer properties in the proposed brine disposal pipeline were analyzed to determine the expected heat loss when the brine is pumped from the brine pit to the diffuser head (Figure 3-36). This analysis was carried out for conditions where the temperature of the brine at the inlet ranged from 70° to $140^\circ F$ (21° to $60^\circ C$), and ambient ground temperatures ranged from 50° to $70^\circ F$ (10° to $21^\circ C$). As shown in Table 3-3, the maximum temperature differential (ΔT) between the inlet and the outlet (i.e., the diffuser ports) would occur when the
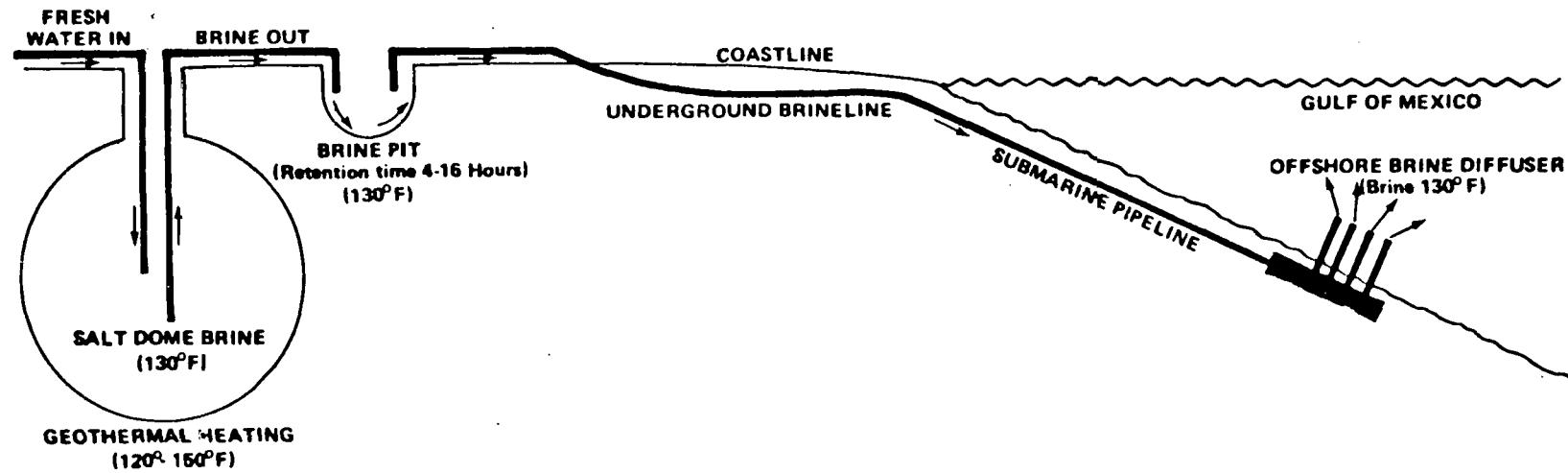
FIGURE 3-36   Schematic model for brine temperature analysis.

inlet temperature was 140°F (60°C) and the ground temperature was 50°F (10°C), but this difference would only amount to 3.2°F (-16°C) due to the insulating effect of the pipe coatings of tar wrap and concrete. Therefore, the temperature of the brine at the diffuser head considered below should conservatively remain within the range of 115° to 120°F (46° to 49°C).

TABLE 3-3 Brine temperature (°F) at the proposed diffuser port as a function of ground temperature and brine temperature at the pipeline inlet.

Brine Inlet Temperature (°F)	Ground Temperature (°F)		
	50	60	70
140	136.8	137.2	137.6
130	127.2	127.6	128.1
110	108.1	108.5	108.9
90	88.9	89.3	89.6
70	69.6	69.9	70

3.1.3.1 General Approach

A simplistic heat flow model (Figure 3-37) was used to estimate the impacts from excess temperatures which might result from discharge of brine to the Gulf of Mexico through a Capline Group diffuser. A correlation was made between excess temperature and excess salinity profiles, assuming 90°F (32°C) seawater (probable maximum) and brine temperatures varying from 90° to 150°F (32° to 66°C). The brine dispersion model, as discussed in Section 3.1.1, provided a basis for applying this correlation to expected mixing conditions at the diffuser site area in the Gulf of Mexico. The simplified analysis presented here does not account for buoyancy effects in the water column due to elevated brine temperatures. The analysis should be reasonably accurate within the mixing zone which is located close to the brine diffuser.

Since the temperature of the brine within the salt dome is not accurately known and will vary with residence time and the other factors described above, a parametric analysis was used to compare the difference between the brine (T_b) and ambient water (T_s) temperatures (ΔT_1), (Figure 3-38).

Seawater
effectively
entrained in
Brine
Diffuser

Q_s
C_s
C_{ps}
T_s

Submarine
Brine
Diffuser

Q_b
C_b
C_{pb}
T_b

Mixing Envelope

$- Q_m$
$- C_m$
$- C_{pm}$
$- T_m$

Mixing
Zone

Mixing envelope
corresponds to the
area as defined by
isopleths of salinity
in Brine Plume model
(U.S. Dept. of Commerce,
1977a)

Mixing Envelope

Q_s
C_s
C_{ps}
T_s

where: Q = flow rate (ft^3/sec)

C = salinity concentration (ppt)

C_p = specific heat ($BTU \cdot lbm^{-1} \cdot {}^o F^{-1}$)

T = temperature (${}^o F$)

FIGURE 3-37   Schematic model of mixing zone relationships for brine plume temperature analysis.

3.1.3.2 Salinity Dilution Calculation

The basic analysis for the salinity dilution effects corresponds to the area at the diffuser site defined by the MIT model (Section 3.1.1); in this analysis salt is conserved throughout mixing zones such that:

$$\rho_m Q_m C_m = \rho_b Q_b C_b + \rho_s Q_s C_s$$

where

$$\rho_m Q_m = \rho_b Q_b + \rho_s Q_s$$

and ρ is the specific gravity of the corresponding fluid. Therefore,

$$C_m = \frac{\rho_b Q_b C_b + \rho_s Q_s C_s}{\rho_b Q_b + \rho_s Q_s}.$$

Define:

$$\Delta C_1 = C_m - C_s = \frac{\rho_b Q_b C_b + \rho_s Q_s C_s}{\rho_b Q_b + \rho_s Q_s} - C_s$$

or

$$\Delta C_1 = \frac{\rho_b Q_b (C_b - C_s)}{\rho_b Q_b + \rho_s Q_s}.$$

Solve for Q_s:

$$Q_s = \frac{\rho_b Q_b (C_b - C_s) - \rho_b Q_b (\Delta C_1)}{\rho_s \Delta C_1}.$$

Define:

$$C_b - C_s = \Delta C_2 = \text{constant.}$$

Then:
$$Q_s = Q_b \left(\frac{\Delta C_2}{\Delta C_1} - 1 \right) \frac{\rho_b}{\rho_s}.$$
Eq (1)

3.1.3.3 Heat Dilution Calculation

Assume conservation of energy in mixing zone:

$$\rho_m \, Q_m \, C_{pm} \, T_m = \rho_b \, Q_b \, C_{pb} \, T_b + \rho_s \, Q_s \, C_{ps} \, T_s$$

where

$$\rho_m \, Q_m = \rho_b \, Q_b + \rho_s \, Q_s$$

and within most of mixing zone,

$$C_{pm} \simeq C_{ps} \quad \text{(i.e., substantial dilution).}$$

Also, assume that heat capacity per unit volume is nearly independent of salinity,

or

$$\rho_s \, C_{ps} = \rho_b \, C_{pb} = \rho_m \, C_{pm}.$$

Then:
$$T_m = \frac{\rho_b \, Q_b \, C_{pb} \, T_b + \rho_s \, Q_s \, C_{ps} \, T_s}{(\rho_b \, Q_b + \rho_s \, Q_s) \, C_{pm}} = \frac{\rho_s \, C_{ps} \, (Q_s \, T_s + Q_b \, T_b)}{C_{pm} \, (\rho_b \, Q_b + \rho_s \, Q_s)}.$$

Define:
$$\Delta T = T_m - T_s = \frac{\rho_s \, Q_b \, T_b - \rho_b \, Q_b \, T_s}{\rho_s \, Q_s + \rho_b \, Q_b}.$$

Using Equation (1): $\Delta T = \dfrac{\Delta C_1}{\Delta C_2} \left(\dfrac{\rho_s}{\rho_b} \, T_b - T_s \right).$
Eq (2)

Using Equations (1) and (2) and site-specific data for Q_b, C_b, C_s, ρ_s, ρ_b, and T_s, we can solve for Q_s and ΔT, as a function of T_b and ΔC_1.

3.1.3.4 Application to Capline Group Diffusers

The following data have been applied to the diffuser at Weeks Island:

$$Q_b = 42 \text{ ft}^3/\text{sec}$$

$$\Delta C_w = 240 \text{ ppt}; \quad C_b = 270 \text{ ppt}; \quad C_s = 30 \text{ ppt}$$

$$T_s = 32^\circ C = 90^\circ F$$

$$\rho_s = 1.02$$

$$\rho_b = 1.2.$$

Then, from Equation (1):

$$Q_s = Q_b \frac{240}{\Delta C_1} - 1 \frac{1.2}{1.02} = f(\Delta C_1)$$

and from Equation (2):

$$\Delta T = \frac{\Delta C_1}{240} (0.85 T_b - 90) = f(\Delta C_1, T_b).$$

Therefore, using the salinity change profiles (ΔC_1), as calculated in Section 3.1.3.2, Q_s can be calculated, and for various assumed brine temperatures, T_b, ΔT can be correlated with ΔC_1.

Figure 3-38 plots correlations calculated between ΔC_1 and ΔT, for a range of T_b from 150° to $90^\circ F$ (66° to $32^\circ C$) and for an assumed $T_s = 90^\circ F$.

To apply these results, the profiles of excess salinity which appear in Section 3.1 can be replotted for excess temperature profiles. Within the range of ΔC_1 as plotted, ΔT will be less than $1^\circ F$ ($0.6^\circ C$), which indicates that a very small area will be affected by elevated brine temperatures. Concentration profiles of salinity excess would
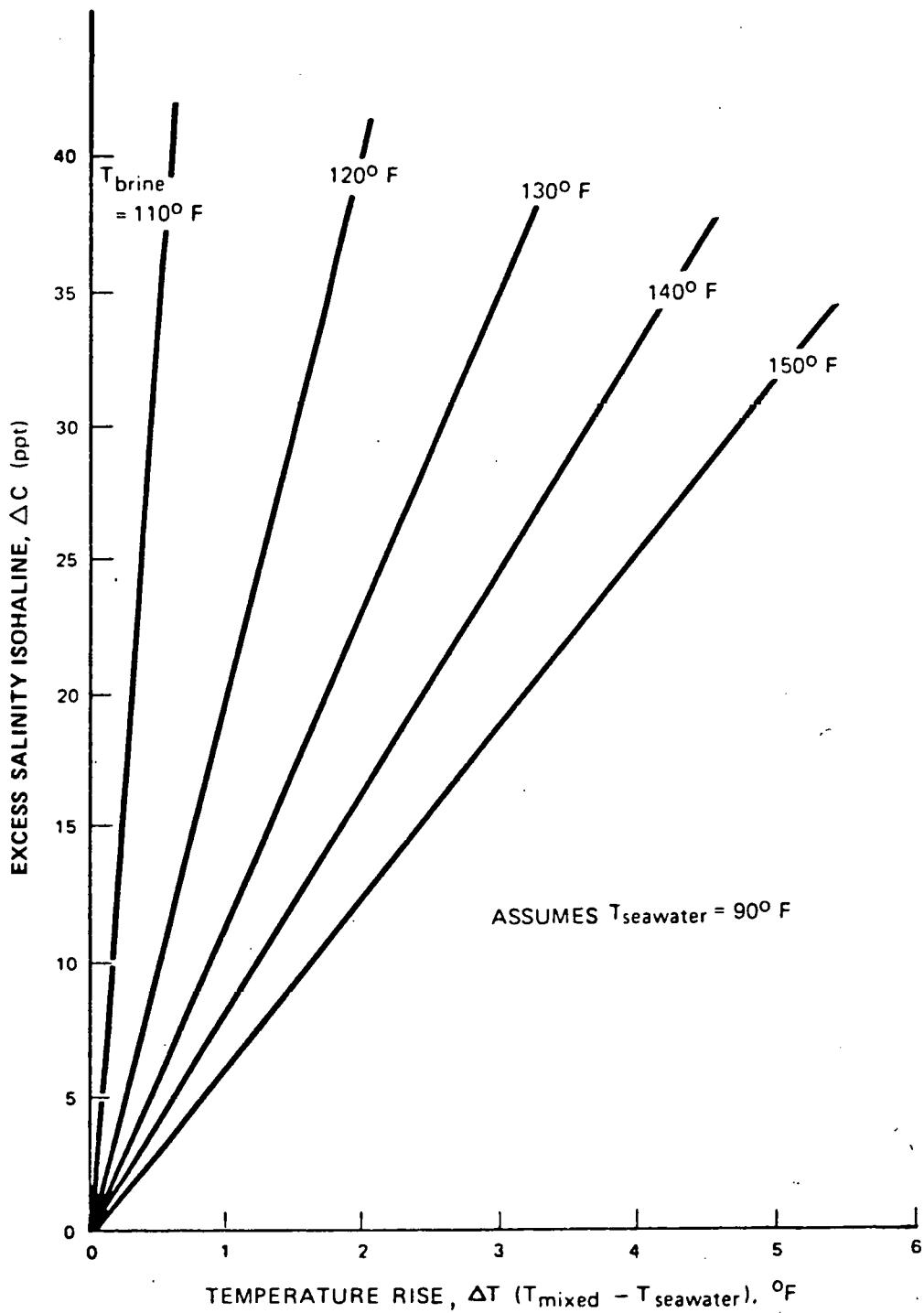
FIGURE 3-38 Temperature rise (ΔT) vs excess salinity (ΔC) correlation.

be needed in the near field to show the area of possible thermal impact. Therefore, under worst case conditions it is expected that at the boundary of the 25-acre mixing zone, an increase of less than 1^OF (0.6^OC) would occur during summer temperature maxima.

The presence of a strong thermocline or halocline at the diffuser site might inhibit the vertical movement of the plume discharge water and thus increase the area affected by elevated temperatures. The condition would most likely occur in the spring when freshwater inflow is at a maximum due to high river flow and when the surface waters are beginning to warm.

3.2 Impacts on Water Quality

Impacts on water quality in the Gulf of Mexico during brine discharge could include increased salinity, hydrocarbon, and trace metal levels, disruption of seawater ion proportions, and alterations in chemical constituent solubilities. Construction and operation impacts would differ in that, during operation, water used for oil displacement would be in contact with oil and would be in the cavern for a longer period. As a result, displacement water would be warmer and more saline and would also contain petroleum hydrocarbons.

The areal extent of the brine plume has been predicted using a mathematical model and current patterns observed at the Weeks Island disposal sites (Section 3.1). Excess salinity contours of the predicted plumes are assumed to be tracers reflecting the distribution of other components that may be discharged during brine diffusion.

Louisiana has established specific water quality criteria which may be applicable at the proposed brine diffuser location. The Gulf of Mexico, identified as segment 12 in Table 3-4, is the area directly affected, but other segments may be indirectly affected. The U.S. Environmental Protection Agency (EPA) has also proposed numerical water quality criteria that is listed in Table 3-5.

3.2.1 Brine Chemistry

Five hundred salt domes are located in the Gulf of Mexico coastal basin. These domes originated from the Louann salt layer of the Triassic-Jurassic Age, which underlies virtually the entire Gulf Coast basin. Because of their common origin, the chemical composition of the salt domes, except as noted for Bayou Choctaw, is similar (Table 3-6).

Approximately 99 percent of salt dome brine consists of sodium chloride; most of the remaining 1 percent is calcium sulfate. Brine in existing caverns is a saturated solution of water and salt (317 g/l or 263 ppt) with respect to sodium chloride; for new caverns this saturation level is expected to occur only during the operation phase. During the initial solution mining process for new caverns, residence time for the brine would be relatively short; therefore, the levels of total dissolved solids (270

TABLE 3-4 State of Louisiana specific water quality criteria.

Agency Number		Primary Contact Recreation	Secondary Contact Recreation	Propagation of Fish And Wildlife	Domestic Raw Water Supply	Chloride (mg/l) Not to exceed	Sulphate (mg/l) Not to exceed	Dissolved Oxygen (mg/l) Not less than	pH Range	Coliform	Temperature (°C)	Total Dissolved Solids (mg/l) Not to exceed
	1. ATCHAFALAYA BASIN											
010010	Atchafalaya River - Headwaters (Barbre Landing) to Mile 118 (1.2 miles below mouth of Bayou Boeuf). (Includes Grand Lake and Six Mile Lake)	X	X	X	X	65	70	5	6.5 - 8.5	200	33	440
010020	West Atchafalaya Borrow Pit Canal (St. Landry and St. Martin Parishes)	X	X		X	100	75	5	6 - 8.5	200	32	500
010030	Atchafalaya River - Mile 118 to Atchafalaya Bay (tidal)	X	X	X				8	6.5 - 9	200	35	
010040	Intracoastal Waterway (north-south) - Bayou Sorrel to Morgan City		X	X		150	75	5	6 - 8.5	1000	32	600
010050	Intracoastal Waterway (east-west) - Bayou Boeuf Locks to Wax Lake Outlet		X	X		150	75	5	6 - 8.5	1000	32	500
010060	Wax Lake Outlet (tidal)		X	X				4	6.5 - 9	1000	35	
010070	Atchafalaya Bay (tidal)		X	X				5	6.5 - 9	70	35	
	2. BARATARIA BASIN											
020010	Bayou Verett (includes Bayou Chevereuil, Bayou Citamon and Grand Bayou, etc.)	X	X	X		1000	500	5	6 - 8.5	200	32	2000
	4. MERMENTAU - VERMILION - TECHE BASIN											
040120	Vermilion River - Origin to Intracoastal Waterway	X	X	X		230	36	5	6 - 8.5	200	32	350
040130	Vermilion River - Intracoastal Waterway to Vermilion Bay (tidal)		X	X				4	6.5 - 9	1000	35	
040140	Bayou Tigre - Origin to Vermilion Bay (tidal)		X	X				4	6.5 - 9	1000	35	
040150	Lake Peigneur (tidal)		X	X				4	6 - 8.5		35	
040190	Bayou Teche - Headwaters to Keystone Locks and Dam	X	X	X	X	43	32	5	6 - 8.5	200	32	220

TABLE 3-4 (cont'd).

Agency ID Number		Primary Contact Recreation	Secondary Contact Recreation	Propagation of Fish And Wildlife	Domestic Raw Water Supply	Chloride (mg/l) Not to exceed	Sulphate (mg/l) Not to exceed	Dissolved Oxygen (mg/l) Not less than	pH Range	Coliform	Temperature (°C)	Total Dissolved Solids (mg/l) Not to exceed
040200	Spanish Lake	X	X	X		250	75	5	6 - 8.5	200	32	500
040210	Bayou Teche - Keystone Locks and Dam to Charenton Canal	X	X	X	X	80	50	5	6 - 8.5	200	32	350
040213	Tete Bayou	X	X	X	X	80	50	5	6 - 8.5	200	32	350
040214	Loreauville Canal	X	X	X	X	80	50	5	6 - 8.5	200	32	350
040215	Lake Fausse Point (Including Dauterive Lake)	X	X	X	X	80	50	5	6 - 8.5	200	32	350
040216	Charenton Canal - Lake Fausse Point to Bayou Teche	X	X	X	X	80	50	5	6 - 8.5	200	32	350
040220	Bayou Teche - Charenton Canal to Wax Lake	X	X	X	X	125	68	5	6 - 8.5	200	32	500
040225	Charenton Canal - Bayou Teche to Intracoastal Waterway	X	X	X		250	75	5	6 - 8.5	200	32	500
040226	Charenton Canal - Intracoastal Waterway to West Cote Blanche Bay (tidal)	X	X	X				4	6.5 - 9	200	35	
040230	Vermilion Bay (tidal)		X	X				4	6.5 - 9	70	35	
040240	West Cote Blanche Bay (tidal)		X	X				4	6.5 - 9	70	35	
040250	East Cote Blanche Bay Waterway (tidal)		X	X				4	6.5 - 9	70	35	
040270	Intracoastal Waterway (east-west) - Vermilion Lock		X	X				4	6.5 - 9	1000	35	
050020	5. MISSISSIPPI BASIN Mississippi River from Old River Control Structure to Huey P. Long Bridge above New Orleans		X	X	X	75	120	5	6.5 - 9	2000	32	400
110010	11. TERREBONNE BASIN Lake Verret	X	X	X		100	75	5	6 - 8.5	200	32	350

TABLE 3-4 (cont'd).

Agency ID Number		Primary Contact Recreation	Secondary Contact Recreation	Propagation of Fish And Wildlife	Domestic Raw Water Supply	Chloride (mg/l) Not to exceed	Sulphate (mg/l) Not to exceed	Dissolved Oxygen (mg/l) Not less than	pH Range	Coliform	Temperature (°C)	Total Dissolved Solids (mg/l) Not to exceed
		Water Uses				**Criteria**						
110020	Lake Palourde	X	X	X	X	100	75	5	6 - 8.5	200	32	300
110030	Bayou Boeuf - Lake Palourde to Morgan City	X	X	X	X	100	75	5	6 - 8.5	200	32	300
110040	Intracoastal Waterway (east-west) - Morgan City to Larose	X	X	X	X	250	75	5	6 - 8.5	200	32	500
110050	Bayou Black - Intracoastal Waterway to Houma	X	X	X	X	250	75	5	6 - 8.5	200	32	500
110060	Bayou Terrebonne - Thibodaux to Bourg	X	X	X		230	55	5	6 - 8.5	200	32	875
110100	Bayou Choctaw - Headwaters to Intracoastal Waterway		X	X		250	75	5	6 - 8.5	1000	32	500
110110	Bayou Grosse Tete - Headwaters to Intracoastal Waterway		X	X		25	25	5	6 - 8.5	1000	32	200
110120	Bayou Plaquemine - Headwaters to Intracoastal Waterway		X	X		250	75	5	6 - 8.5	1000	32	500
110130	Upper Grand River and Lower Flat River - Headwaters to Intracoastal Waterway		X	X		250	75	5	6 - 8.5	1000	32	500
110140	Intracoastal Waterway (north-south) - Port Allen to Bayou Sorrel		X	X		250	75	5	6 - 8.5	1000	32	500
110150	Lower Grand River and Bell River - Bayou Sorrel to Lake Palourde (Includes Bayou Goula and Grand Bayou)		X	X		250	75	5	6 - 8.5	1000	32	500
110190	Bayou du Large - Houma to Bay Junop (tidal)	X	X	X				4	6.5 - 9	70	35	
110200	Lake Hache, Lake DeCade, Lost Lake, and Four-League Bay (tidal)		X	X				4	6.5 - 9	70	35	
110210	Bayou Penchant and Lake Penchant - Morgan City to Lake DeCade (Scenic River), (tidal)	X	X	X				4	6.5 - 9	70	35	

TABLE 3-4   (cont'd).

		Water Uses				Criteria						
Agency ID Number		Primary Contact Recreation	Secondary Contact Recreation	Propagation of Fish And Wildlife	Domestic Raw Water Supply	Chloride (mg/l) Not to exceed	Sulphate (mg/l) Not to exceed	Dissolved Oxygen (mg/l) Not less than	pH Range	Coliform	Temperature (°C)	Total Dissolved Solids (mg/l) Not to exceed
110220	Caillou Bay		X	X				5	6.5 - 9	70	35	
110280	Bayou Lafourche - Donaldsonville to Larose	X	X	X		70	55	5	6 - 8.5	200	32	50
110290	Bayou Lafourche - Larose to Gulf of Mexico (tidal)	X	X	X				4	6.5 - 9	200	35	
	12. GULF OF MEXICO Gulf of Mexico and other open coastal waters not specifically identified in the table	X	X	X				5	6.5 - 9	70	32	

SOURCE: The Bureau of National Affairs, 1976.

TABLE 3-5   Proposed EPA numerical criteria for water quality.

Parameter	Public Water Supply Intake (ug/l)	Marine Water Constitutents (Aquatic Life), (ug/l)[a]	Freshwater Aquatic Life (ug/l)[b]
Arsenic	50	50	
Cadmium	10	10	30 (hardness >100 ug/l) 4 (hardness <100 ug/l)
Chromium	50	100	50
Copper	1000	50	1/10 LC 50
Lead	50	50	30
Mercury	2	1	0.2
Nickel		100	1/50 LC 50
Zinc	5000	100	5/1000 LC 50
Cyanides	200	10	1/20 LC 50 (0.005 ug/l)
Aldrin	1	5.5	0.01
DDT	50	0.6	0.002
Dieldrin	1	5.5	0.005
Chlorodane	3		0.04
Endrin	0.2	0.6	0.002
Heptachlor	0.1	8	0.01
Heptachlor epoxide	0.1		
Lindane	4	5	0.02
Phenols	1		1/20 LC 50 (0.1 ug/l)
Oil and grease		(a)	(b)
pH		6.5 - 8.5	6 - 9
Ammonia		400	1/20 LC 50 (20 ug/l)
Hydrogen sulfide		10	
Sulfides			2
Dissolved oxygen		6 ug/l	4 ug/l (>31°C)
Phosphorous		0.1	
Diazinon			0.009
Malathion			0.008
Parathion			0.001
Suspended and settleable solids			80 ug/l
Turbidity and light penetration			10% change in compensation pT
Color			10% change in compensation pT
Toxaphene	5	0.1	0.01

[a](a) = Not detectable as a visible film, as sheen discoloration of the surface, or by odor; does not cause tainting of fish or invertebrates or damage to biota; does not form an oil deposit on the shores or bottom of the receiving body of water.

[b](b) = None visible on surface; 1000 ug/kg hexane extractable substances in sediments; 1/20 LC 50.

SOURCE: U.S. Environmental Protection Agency, 1973.

TABLE 3-6   Preliminary analysis of brine in various salt domes of the Gulf coast.

Element or Ion	BC-6	BC-17	BC-19	BM-5	SK-10	SU-2	WH-11	Sea Water[b]	Weeks Island Site A[c]	Weeks Island Site B[d]
			Brine Sample[a]							
Na^e	102,800	121,200	120,400	117,600	120,800	121,600	120,300	10,561	6,200	9,465
K^e	7,420	194	19	296	3	3	5	380	222	754
Ca^e	5,300	420	330	720	370	910	420	400	250	372
Mg^e	4,880	10	9	9	2	4	5	1,272	750	115
Cl^e	200,000	200,000	196,000	194,000	198,000	196,000	200,000	18,980	11,430	16,900
SO_4^e	1,480	1,340	800	1,960	800	2,200	1,440	2,649	1,520	2,515
$Ag^{f,g}$	<10 (<4)	<10 (<4)	<10 (<4)	<10 (<4)	<10 (<4)	<10 (<4)	<10 (<4)	0.3		
$As^{f,g}$	<2 (<200)	10 (<200)	6 (<200)	2 (<200)	<2 (<200)	<2 (<200)	4 (<200)	15		
$Ba^{f,g}$	<400	<400	<400	<400	<400	<400	<400	50		
$Cd^{f,g}$	100 (96)	2 (<20)	2 (<20)	<2 (<20)	2 (<20)	8 (<20)	<2 (<20)			
$Cr^{f,g}$	8 (<20)	<2 (<20)	<2 (<20)	<2 (<20)	<2 (<20)	<2 (<20)	<2 (<20)			
$Cu^{f,g}$	14 (25)	20 (17)	16 (54)	2 (<10)	<2 (<10)	<2 (<10)	<2 (<10)	5		
Hg^f	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.4	0.03		
Mn^f	40,000	420	320	100	140	280	160	5		
$Ni^{f,g}$	<2 (6)	2 (4)	2 (6)	2 (<4)	<2 (<4)	<2 (24)	<2 (<4)	0.1		
$Pb^{f,g}$	34 (40)	26 (20)	26 (24)	2 (<20)	12 (<20)	<2 (<20)	2 (<20)	4		
$Sb^{f,g}$	<2 (<20)	<2 (<20)	<2 (<20)	<2 (<20)	<2 (<20)	<2 (<20)	<2 (<20)			
Se^f	<2	<2	<2	<2	<2	<2	<2	4		
Zn	16,000	80	400	80	4	32	<2	5		

TABLE 3-6   (cont'd).

^aSample code (cavern number follows the name code):   BC = Bayou Choctaw, BM = Bryan Mound,
SK = Starks, SU = Sulfur Mines, WH = West Hackberry.

^bSea water analyses: Sverdrup, Johnson, and Fleming, 1942.

^cAverage of mean surface and bottom sample concentrations during September 1977.

^dAverage of mean surface and bottom sample concentrations during February 1978.

^eUnits: brine samples in mg/l, seawater samples in mg/kg.

^fTrace element units: brine samples in µg/l, seawater samples in µg/kg.

^gFor brine samples, values in parentheses were obtained by emission spectography; those not in
parentheses were obtained by atomic absorption.

g/l or 230 ppt) would be less than the levels discharged during oil storage operations.

Compared to normal seawater (Table 3-6), the concentrations of sodium and chloride in the brine solution are an order of magnitude higher, but magnesium is two orders of magnitude lower. Calcium and sulfate concentrations are similar to those in seawater, while potassium is slightly lower.

Of the trace metals analyzed in brine, manganese and zinc levels are higher than in seawater (Table 3-6). However, in most cases, the heavy metal concentrations in brine are within the acceptable EPA standards (Table 3-5).

The water chemistry of the Intracoastal Waterway (ICW) must also be considered since it is the proposed source for raw solution water at the storage sites, and thus its chemical constituents would also be eventually discharged at the diffuser. The Gulf of Mexico is an alternative to the ICW; however, water quality levels from sampling stations in the Capline region (Table 3-7) are well within EPA recommended guidelines and should not restrict the use of either the proposed or the alternative water sources.

3.2.2 Impacts

A major impact of brine discharged in to the Gulf of Mexico would be the increased salinity levels within the plume (Section 3.1.2). Associated with this increase would also be an alteration in the constant composition of seawater; in particular, the calcium/magnesium ratio, which is normally about 0.3 for seawater. This ratio would be at least two orders of magnitude greater in the brine.

Water quality impacts at Sites A and B should be similar since the main chemical effects of brine disposal would be of a much greater magnitude than any ambient water quality differences between the two sites.

A model used to predict the concentration of chemical components at various excess salinity contours in the Texoma Group (FEA, 1977b), (Table 3-8) forecasts that many of the free chemical components would assume near normal levels within the 10-ppt excess salinity contour. At Weeks Island, at any one time, an area of 52 acres (21 hectares) would be encompassed in

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TABLE 3-7 Water quality data (µg/l) from sampling stations in the Capline Group.

	Atchafalaya River (Main Channel) at Myette Point		Lower Atchafalaya River at Morgan City		Wax Lake Outlet at Calumet		Atchafalaya Bay at Eugene Island		Vermilion River at State Hwy 3073 Near Lafayette		Bayou Teche at Keystone Lock Near St. Martinsville		Vermilion Bay at Cypremort Point		Intracoastal Waterway at Vermilion Lock (East)	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
As	3	1	4	1	5	2	11	1			3		3	1	12	1
Dissolved As	2		2		2		2		5	4	2		2		2	
Total Cd	2		2		3		3						6		3	
Dissolved Cd	2		2		2				3				1			
Total Cr	20	6	20		30	<10	60	<10			<10		30	<10	40	<10
Hexavalent Cr																
Total Cu	6	4	11	3	12	4	13	3			8		9	2	14	1
Dissolved Cu	6	1	7	2	6	1	10		12	5	8		5	1	7	1
Total Pb	8		12		14		14				3		12		18	3
Dissolved Pb	8		2		2		2		3						7	
Total Hg	0.6		0.3		1.5		0.9		0.9	0.3			0.3		0.6	
Suspended Hg	0.2		0.3		1.2		0.6						0.1		0.3	
Dissolved Hg	0.2		0.1		0.3		0.3						0.2		0.5	
Total Ni	13	2	16	3	22	3	20	3					21		16	2
Dissolved Ni	3		5		6		4						4		4	
Total Zn	140		80	10	80	20	90	10			30		100	10	90	10
Dissolved Zn	20		20		20		20		30	7	10		20		20	

TABLE 3-7   (cont'd).

	Mississippi River at Plaquemine		Mississippi River at Union		Bayou Penchant at Bayou Chene		Bayou Lafourche at Intracoastal Waterway at Larose	
	Max	Min	Max	Min	Max	Min	Max	Min
As	4	2	8	2	6	1	6	1
Dissolved As	2	1	2	1	3		2	1
Total Cd	1		2		3		12	
Dissolved Cd	1				1			
Total Cr	30		30		30	<10	30	<10
Hexavalent Cr								
Total Cu	65	4	27	4	9	3	18	4
Dissolved Cu	5	2	6		6	1	10	1
Total Pb	12		16		20		18	3
Dissolved Pb			3		3		4	
Total Hg	0.6		0.4		0.9		1.1	
Suspended Hg	0.5		0.8		0.8		0.9	
Dissolved Hg	0.3		0.3		0.2		0.5	
Total Ni	24	3	13	4	15		10	5
Dissolved Ni	2		2		7		6	
Total Zn	130	20	90	10	80	10	110	10
Dissolved Zn	40		20		20		50	

TABLE 3-8   Free component concentrations at the various excess salinity contours as predicted by modeling.

	Excess Salinity (ppt)				
Component	0	10	30	60	159.4
Barium	1.4 µg/l	1.6 µg/l	2.2 µg/l	3.1 µg/l	6.6 µg/l
Cadmium	0.009 µg/l	0.005 µg/l	0.002 µg/l	0.0007 µg/l	0.0001 µg/l
Calcium	359.5 mg/l	376.8 mg/l	404.8 mg/l	448.9 mg/l	400.8 mg/l
Chloride	19.36 g/l	26.63 g/l	41.48 g/l	64.52 g/l	118.06 g/l
Chromium	N[a]	N	N	N	N
Copper (II)	0.8 µg/l	0.8 µg/l	0.8 µg/l	0.8 µg/l	0.8 µg/l
Iron (III)	N	N	N	N	N
Lead	0.2 µg/l	0.3 µg/l	0.2 µg/l	0.1 µg/l	0.004 µg/l
Magnesium	505.5 mg/l	508 mg/l	503.1 mg/l	488.5 mg/l	432.6 mg/l
Manganese (II)	3.1 µg/l	112.1 µg/l	201.6 µg/l	212.6 µg/l	148.9 µg/l
Mercury	N	N	N	N	N
Nickel	1.2 µg/l	1.7 µg/l	2.6 µg/l	3.5 µg/l	4.6 µg/l
Potassium	371.8 mg/l	402.7 mg/l	465.3 mg/l	567 mg/l	797.6 mg/l
Silver	N	N	N	N	N
Sodium	10.51 g/l	15.24 g/l	25.06 g/l	40.23 g/l	75.41 g/l
Sulfate	1,095.1 mg/l	920.2 mg/l	697.4 mg/l	480.3 mg/l	226.7 mg/l
Tin (II)	N	N	N	N	N
Zinc	1.4 µg/l	4.8 µg/l	4.8 µg/l	4.8 µg/l	3.2 µg/l

[a]N specifies zero or essentially zero-free concentration.

the 3-ppt excess salinity contour during best and worst case conditions, as predicted by the MIT model (Section 3.1.1). Over a long period, with currents shifting the plume, an area of 3600 acres (1457 hectares) would be touched by the 3-ppt excess isohaline. Furthermore, changes in the calcium-to-magnesium free concentration ratios are predicted to be small.

Levels of trace metals in the discharge would be related more to the leachwater source than to the salt of the dome. As shown in Table 3-7, the quality of the solvent water is well within recommended criteria. During flood or low-flow periods, heavy metal concentrations in the intake water could increase, possibly exceeding EPA recommended discharge levels, and resulting in brine heavy metal levels which could exceed the ambient levels found at the diffuser site (Tables 2-20 and 2-22). However, a portion of the particulate heavy metals would settle out in the salt cavern, thereby decreasing the metal levels in the brine. Once discharged, the Texoma model predicts that free concentrations of heavy metals would generally be less at elevated salinities due to formation of greater amounts of heavy metal-chloro complexes and other soluble species. At low excess salinities, concentrations of free heavy metals would be high; however, because of expected overall low levels in the solvent water, little impact may be anticipated from trace metals discharged in the brine.

The number of precipitate types would be the same throughout the brine plume, but the concentrations of most precipitates would decrease with a decrease in the brine salinity of the plume. The high levels of dissolved and precipitated solids would tend to have an affinity for the surface of existing particulates (i.e. adsorption). The formation and the settling of these particulates could influence the sessile marine life in the disposal area (FEA, 1977b).

The elevated salinity and temperature levels of the brine water would result in low levels of dissolved oxygen in the discharged water. Anoxic waters are known to occur in this area, especially during the spring and summer (Section 2.3.1). However, jet dilution at the diffuser site would help to produce a rapid increase in oxygen to near ambient levels. There is little BOD or COD associated with the brine. Predictions from other brine disposal studies have estimated reductions of oxygen levels from ambient by 0.6 mg/l within the 20-ppt excess salinity contour, 0.1 to 0.2

mg/l within the 4-ppt excess salinity contour, and 0.06 mg/l within the 2-ppt excess salinity contour (FEA, 1977a; U.S. Dept. of Energy, 1978). Wind mixing in the shallow waters of Sites A and B would also aid in re-oxygenation. Impacts from low DO values would occur only in the immediate vicinity of the diffuser. None of the brine constituents should affect pH levels in the recurring water column.

Brine discharge rates during leaching at Weeks Island would be approximately 600 MBCD over 4 years; discharge rates during oil fill would be 190 MBCD over 1.5 years. Although salinities in the leachwater would be about 15 percent lower, impacts during this phase would be greater than during operation because of higher rates of brine discharge over longer periods.

During the operational phase, petroleum hydrocarbons dissolved in the brine would be discharged. The equilibrium concentration of crude oils in brine is 31 ppm, but there would be insufficient time, turbulence, and circulation to allow the oil to reach this concentration. Modeling studies (FEA, 1977a) indicate that the hydrocarbon concentration in brine discharged to the surface control facility would average 16 ppm for the later stages of the initial oil fill; a concentration gradient of 0 to 31.4 ppm would exist in the cavern, with the top 50 feet (15 meters) of brine becoming saturated with oil. During subsequent oil refills, a dense refractory layer would have time to form, reducing diffusion and dissolution of oil into the brine. The brine transferred to the surface control facility during subsequent refills would contain an average hydrocarbon content of 6 ppm. Depending on cavern geometry, the oil concentration would vary from 4 to 15 ppm. However, vaporization of light hydrocarbons during brine discharge would reduce oil concentration to approximately 6 ppm.

Historical data on the content of hydrocarbons discharged from similar brine cavern oil storage operations in Manosque, France, show that discharged oil-in-brine levels were 4.6 ppm (range, 0 to 13.8 ppm) in operational caverns and 3.3 ppm (range, 0 to 10 ppm) in the solution mining of new caverns. In Etzel, Germany, the hydrocarbon concentration of the brine discharge was less than 1 ppm (FEA, 1977a).

The predicted hydrocarbon discharge level is an order of magnitude greater than ambient hydrocarbon concentrations measured at Sites A and B. If hydrocarbons are diluted as rapidly as ionic components, however, elevated oil levels would occur only in the immediate vicinity of the diffuser site. It is expected that local mixing and dispersal mechanisms would have a moderating effect.

Many of the chemical constituents of the brine discharge have been predicted to be diluted rapidly to near-ambient levels within a small area surrounding the diffuser. Outside of this area, no one chemical component should be in concentrations high enough to be toxic, but a number of compounds could act synergistically. Seasonal factors such as temperature and river input may also act synergistically with the brine plume. These impacts would mostly affect the biology and ecology of the site area (Section 3.3).

3.3 Impacts on the Biological Environment

3.3.1 Impact of Changes in Salinity and Temperature on Aquatic Organisms

The temperature and salinity regimes of the marine environment exert a major influence on the distribution of marine organisms. Water temperature controls the lives of most aquatic animals since they are poikilotherms with their body temperatures at or near the temperature of the water environment. In the Gulf of Mexico, the average summer maximum surface water temperature rarely exceeds $85^{\circ}F$ ($29^{\circ}C$). In the winter, coastal water temperatures average about $13^{\circ}C$. At a depth of 1000 feet (305 meters) the water temperature remains fairly constant at about $41^{\circ}F$ ($5^{\circ}C$). Salinity values in the study area during the year can range from 15 to 35 ppt.

Aquatic organisms are best suited, physiologically, to an optimum salinity range. Fauna and flora with a limited range in salinity tolerance are termed stenohaline; those with wide salinity tolerance are termed euryhaline. Although these organisms exhibit optimum salinity ranges, they often can live in waters outside these ranges. Within the estuarine and neritic ecosystems, aquatic organisms encounter a variety of salinity regimes. Estuaries and other coastal water bodies, where seawater is measurably diluted with freshwater and seasonally undergoes wide salinity variations, are usually inhabited by euryhaline organisms, while open ocean areas are generally occupied by stenohaline organisms.

An organism's response to salinity stress will vary during particular stages of its life cycle. Narrow salinity ranges are required for spawning and rearing of larvae, but organisms in adult stages are more adaptable. Hence, a species may change from stenohaline to euryhaline during its life cycle, and even within a certain life stage may tolerate different and often nonoptimum salinity ranges. This is exemplified by the life cycle of many Gulf of Mexico marine species which live in the coastal regions and alternate between environments of low and high salinity. Much of the spawning activity occurs in the Gulf, while the nearshore and estuarine habitats with lower salinities are used as nursery areas.

Environmental temperature changes have pronounced effects on an organism's response to variations in salinity. Aquatic organisms exhibit maximum tolerance to salinity variations when the temperature of their environment is within their optimum physiological temperature range.

Within the Gulf coastal waters and estuaries, seasonal variations in water temperatures may be extreme, particularly in the summer and winter months and therefore slight variations in salinity during these seasons may cause excessive physiological stress on these organisms.

As determined from the computer model runs (Section 3.1.2.3), Table 3-9 lists approximate acreage for areas within above-ambient isohalines at Sites A and B during nonslack and 8-day slack periods, best/worst conditions for those cases examined, and stagnation periods, and within isohaline envelopes. The isohaline envelope is based on 9 months of current data obtained at the sites from October 1977 to July 1978 and represents the area around the diffuser within which the respective isohalines remain. The worst case conditions, which show the maximum acreage affected by low currents, occur predominantly during the late spring to early summer (May to June) at Site B. It is during this period of stagnation that given isohalines generally occupy the maximum area--an exception was noted for an 8-day slack in the nontidal longshore currents when the isohalines covered a rather large area (2900 and 400 acres (1174 and 162 hectares) for the 1- and 2-ppt isohalines, respectively).

For the purposes of this report, the area within the 4-ppt isohaline has been considered as the high-impact zone, where salinities would range up to 264 ppt and lethal and sublethal impacts to the biota would probably occur. At any one time, this area would encompass the worst case conditions of May 22, almost 60 acres (24 hectares), while the envelope surrounding the diffuser within this isohaline would cover about 440 acres (178 hectares). It is also within this area that brine temperatures will approach $120^\circ F$ ($49^\circ C$).

3.3.2 Impact on Plankton

Because of the high density of the brine plume and the limited mobility of plankton, only plankters in the lower half of the water column will be subject to such entrainment. The duration of exposure or "residence time" of plankton in the plume during nonslack periods is not likely to exceed several hours. Only a very small portion of this time would be spent in the sector of the plume near the diffuser, where extreme salinity levels (up to 230 ppt above ambient) and temperatures (up to $120^\circ F$ ($49^\circ C$) above ambient) would occur. Plankton entrained during a worst case or

TABLE 3-9 Approximate acreage for the areas within excess isohalines at Weeks Island Sites A and B during nonslack, 8-day slack, best/worst, and stagnation periods.

Isohaline Above Ambient	Nonslack Period	8-Day Slack Period	Site A			Site B										All Sites
			Oct 28	Dec 29	Jan 3	Jan 5 (Best)	Feb 25 (Worst)	Apr 10 (Worst)	Apr 27 (Best)	May 12 (Best)	May 22 (Worst)	May 29 (Best)	June 7 (Worst)	June 25 (Stagn.)	June 28 (Stagn.)	Envelope
4		30									57		38			440
3	40	100	73	50	50		50				180		188		192	3,600
2	250	400	222	50	260		200	50		20	380		298	115	535	9,700
1.5				100	400		200	50				180	321			
1	500	2,900	629	260	775		400	150	575	450	685	367	574	600	1,320	35,700
0.5			1,366	600	2,500	300	1,200	675	1,425	1,120	1,070	1,079	2,870	3,300	2,650	
0.1			2,168	680	7,280	980	12,810	4,600	6,428	>2,000	>5,590	3,214	5,510	11,500	15,200	

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stagnation period, due to very low (~1 cm/sec) current velocities, could remain in the plume for up to 1 week. It is assumed that recovery from salinity or temperature shock would commence when the plankton are carried out of the immediate area of the plume. It is possible that during the cooler seasons, temperatures within sectors of the plume could temporarily stimulate plankton life processes (e.g., photosynthesis, feeding, metabolism).

As discussed in Section 3.3.1, at any one time, the high impact area will be within the 4-ppt isohaline and under worst conditions, cover about 60 acres (24 hectares), while the entire envelope around the diffuser will encompass about 440 acres (178 hectares) (Table 3-9). It is within the high impact area that plankton will be subjected to the greatest impact. The high salinity-temperature sector of the plume will be considerably larger during the worst-case 8-day slack period or stagnation periods, but will remain for shorter periods. Assuming a discharge temperature of $120^\circ F$ ($49^\circ C$), it has been estimated that the temperature at the 4-ppt isohaline would be less than $1^\circ F$ ($0.6^\circ C$) above ambient. The plankton biomass entrained in this sector of the plume during a stagnation period (~1 cm/sec) would be comparatively small.

Salinity tolerances of several plankton species common to the diffuser site are shown in Figure 3-39. Within given tolerance ranges, these species have physiologically optimum salinity ranges. Above and below these ranges, life processes may be adversely modified.

Bioassay analyses (U.S. Dept. of Commerce, 1978a) were conducted to assess the impact of various brine concentrations at selected temperatures ($72^\circ F$ ($22^\circ C$) and $86^\circ F$ ($30^\circ C$)) on several plankton and nekton species over a 9-day period. Of the three phytoplankton species studied, only Skeletonema costatum was common to the diffuser sites. The conclusions drawn from these bioassay studies were: (1) that each algal species exhibited characteristic responses to concentrations of brine, with Tetraselmis chuii the most tolerant, Hymenomonas carterae tolerant, and Skeletonema costatum the most sensitive; (2) that no growth occurred in a 40 percent (143 ppt) brine solution for any species, and concentrations of 20 percent (94 ppt) and 10 percent (64 ppt) were inhibiting to varying degrees (Table 3-10); (3) that a 5 percent brine concentration is the
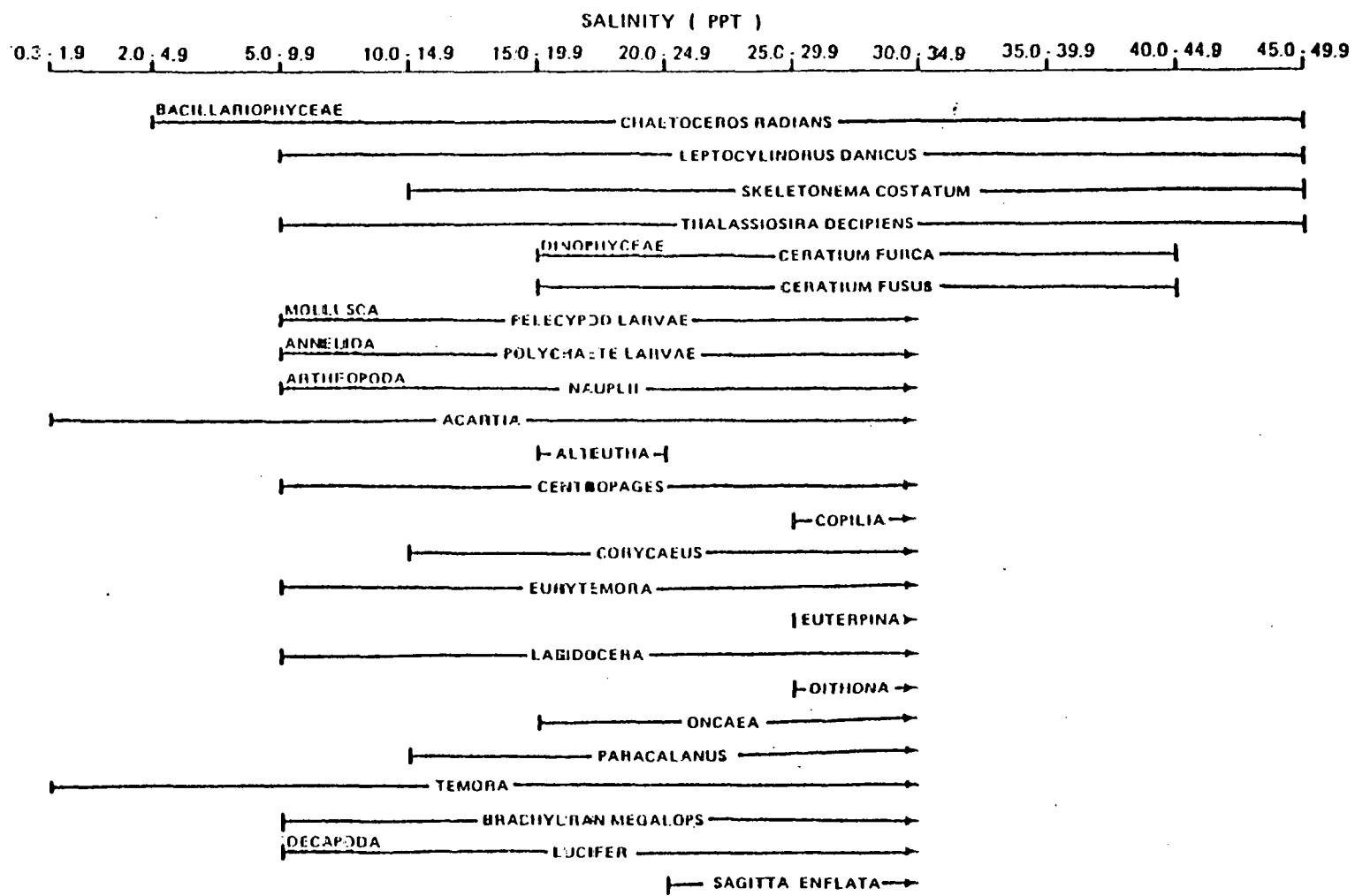
FIGURE 3-39   Salinity tolerances of several organisms which may be encountered at Weeks Island Sites A or B.

highest amount of brine at which phytoplankton may reasonably be expected to survive; and (4) that an increase in temperature (from 72° to 86°F (22° to 30°C)) had no significant effect on the growth of any of the algae tested for brine concentrations of up to 5 percent.

TABLE 3-10   Response of photoplankton species to various brine concentrations.[*]

% Brine	Salinity (ppt)	H. carterae	S. costatum	T. chuii
0.0	30.0	(a)	(a)	(a)
0.1	31.0	(a)	(b)	(a)
0.2	31.5	(a)	(a)	(a)
0.5	32.0	(a)	(a)	(a)
1.0	34.0	(a)	(a)	(a)
2.0	39.0	(a)	(c)	(c)
5.0	46.0	(a)	(c)	(c)
10.0	64.0	(d)	(d)	(c)
20.0	94.0	(d)	(d)	(d)
40.0	143.0	(d)	(d)	(d)

[*](a) = similar to control; (b) = better than control; (c) = less than control; (d) = no growth.

Impact assessment of brine disposal on the marine phytoplankton in the study areas indicates that (1) all phytoplankton in the plume where concentrations are greater than 46 ppt would be killed, (2) because of the relatively small size of the (bottom-flowing) plumes under consideration, a proportionately small percentage of the total phytoplankton biomass in the coastal shelf waters would be entrained and thus impacted. (3) the residence time of phytoplankton entrained in the plume produced during periods of normal current and tidal flow would be brief and amount to no more than a few hours.

Figure 3-40 presents a 2-year salinity record (1963-1964) of Louisiana coastal waters (Gagliano, 1973) in the vicinity of Sites A and B. The maximum salinity value recorded during this period was approximately 33.5 ppt in December 1963. In general, maximum values were noted in the

STRESS OR GROWTH INHIBITED
(S. COSTATUM; T. CHUII) 39 ppt

MAXIMUM SALINTY ~ 33.5 ppt

SALINITY (ppt)

50
45
40
35
30
25
20
15
10
5
0

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
1963   1964
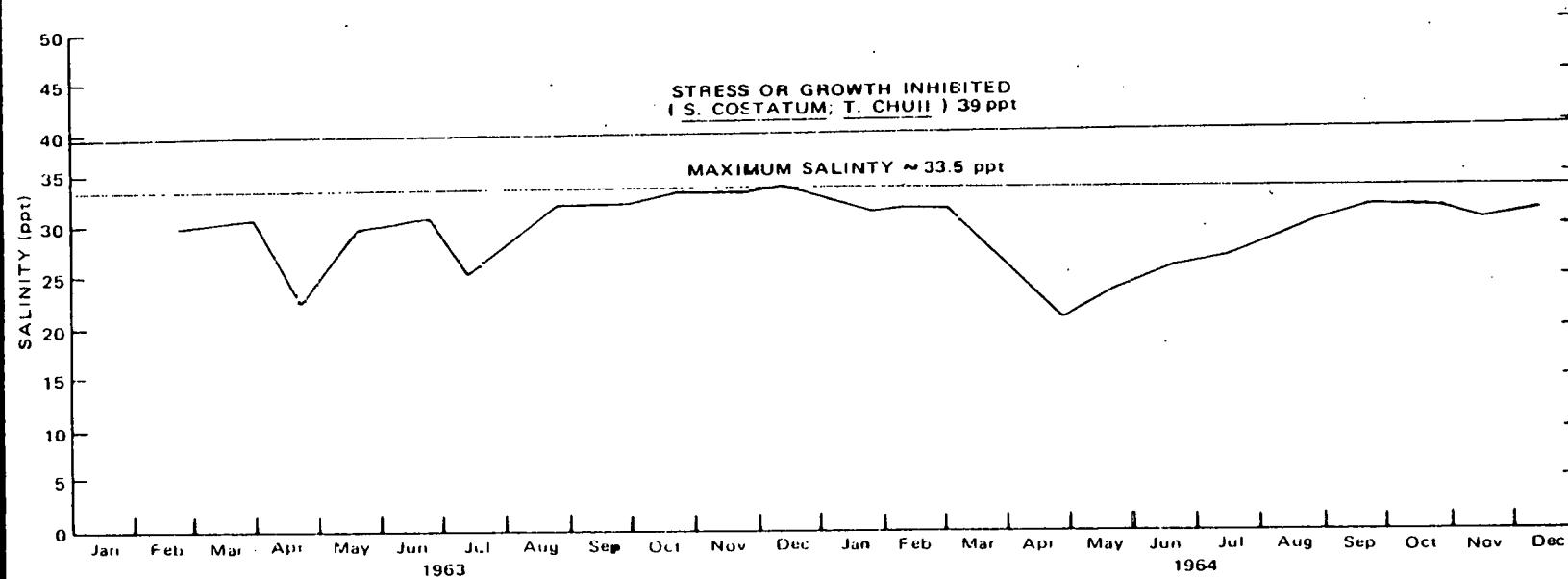
SOURCES: Gagliano, 1973; Cox, 1978.

FIGURE 3-40   Salinity record (1963-1964) in the vicinity of Weeks Island Sites A and B, showing the brine
concentration at which phytoplankton are stressed or growth is inhibited.

winter and early spring months. Based on salinity tolerances obtained from bioassays, as noted above, the salinity level at which growth was retarded for _Skeletonema_ _costatum_ and _Tetraselmis_ _chuii_ was approximmately 39 ppt. Based on this, the brine discharge area that could potentially kill or retard the growth of these phytoplankton would be within the 5.5-ppt excess isohaline during months when salinities approached maximum values. When ambient salinities are lower, this high stress zone would be substantially smaller. If an 8-day slack in the nontidal longshore currents should occur, this area would become considerably larger, but the probability of such an occurrence is low (Section 2.1).

Assuming that the plankton entrained in the plume would be killed due to the transitory effects of high salinity (up to 264 ppt) and high water temperature (up to 130°F (54°C)), and using the average phytoplankton cell densities in the bottom samples taken from the Weeks Island area, the following estimates were made. At Site A (September to December 1977), 2547×10^4 phytoplankton cells and 349 zooplankton would be destroyed per cubic meter of water entrained in the plume. At Site B (February to April 1978), $82,330 \times 10^4$ phytoplankton cells and 15 zooplankton would be destroyed per cubic meter of water entrained in the plume. These values would vary throughout the year and would probably be greater during the winter or early spring months when plankton biomass generally attains maximum values (Green, 1978). In the far-field sector of the plume where salinity and temperature values are near ambient conditions, plankton productivity may be temporarily reduced.

Figure 3-41 illustrates a Langrangian model output based on currents considered characteristic of the proposed Seaway brine diffuser site off Freeport, Texas (U.S. Dept. of Commerce, 1978). This output was used to approximate the amount of time the plankton would be entrained in the intermediate field of the plume--within a region of 300 to 400 feet (91 to 122 meters) from the diffuser. In the Langrangian presentation, phyto-plankton, fish larvae, eggs, and other zooplankton were assumed to be carried with the ambient waters and entrained in the diffusing brine effluent plume. These organisms would be exposed to excess salinity as a function of their location in the plume and the prevailing diffusion rate of excess brine. The excess salinity (>30 ppt) calculations are shown with average and maximum exposure durations. As illustrated, the maximum
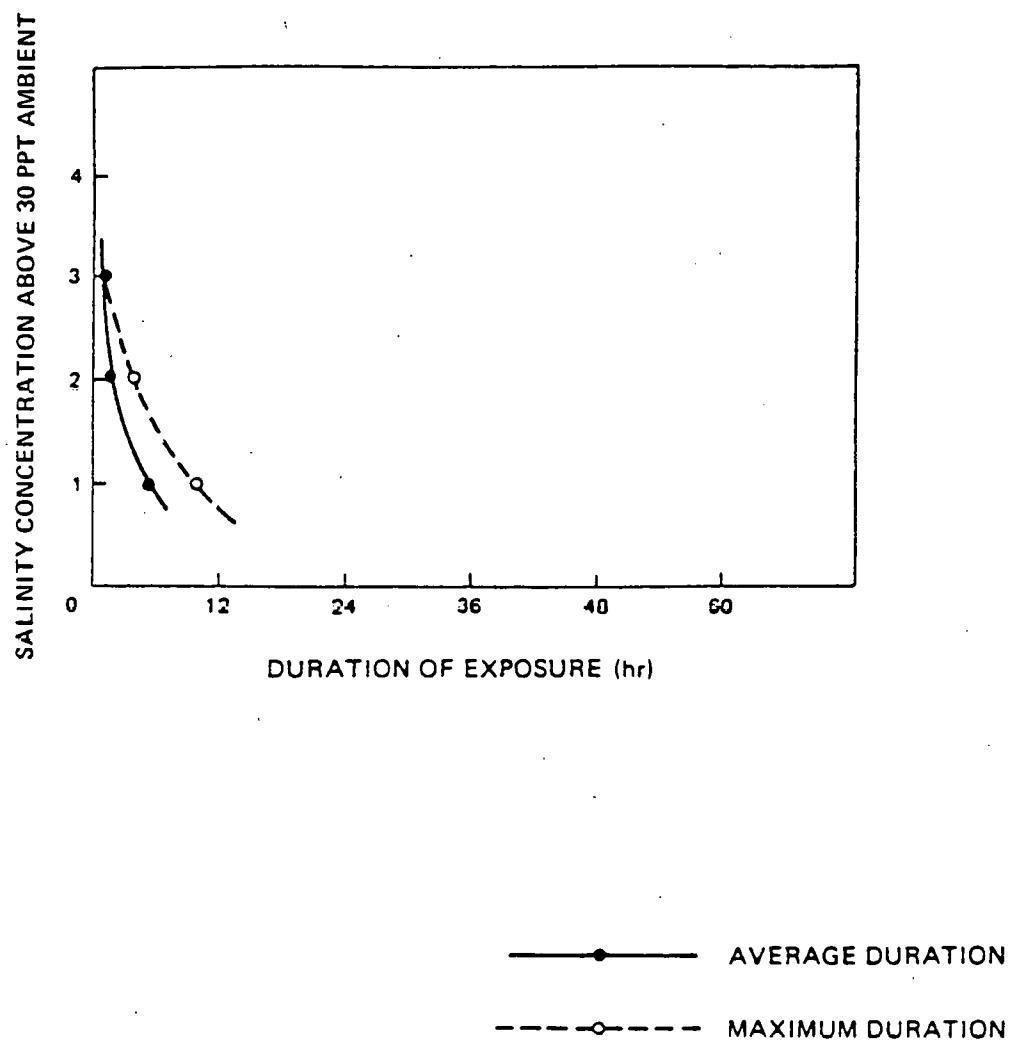
FIGURE 3-41   Excess salinity versus duration of exposure for drifting
planktonic species entrained in the brine plume.

SOURCE: U.S. Dept. of Commerce, 1978a.

exposure to more than a 1-ppt excess is about 10 hours. The bioassay results and plume model suggest that only elevated salinity levels within the near-field region of the plume are expected to significantly retard growth of phytoplankton (U.S. Dept. of Commerce, 1978).

In addition to brine impacts, other chemical impacts would be expected as a result of brine discharge into the Gulf of Mexico (Section 3.2.2). For example, ion ratios in the discharge plume would also be expected to be altered, especially the calcium/magnesium ratio. These changes could be expected to induce physiological stress on the plankton community entrained in the plume. The concentrations of several heavy metals (Pb, Hg, Zn, and Mn) in the plume may exceed EPA recommended discharge levels. Plankton entrained in the plume may adsorb or absorb these metals, thus providing an accessible source of heavy metals to other components of the food web. If turbidity is increased as a result of brine discharge, light penetration would be reduced, thus temporarily reducing primary productivity. In addition, DO concentrations may decrease in the vicinity of the diffuser, leading to a further temporary reduction in primary productivity.

It has been estimated (Section 3.2.2) that 6 ppm of oil would be contained in the brine discharge. Plankton are threatened primarily by a floating slick or water-soluble hydrocarbons within the plume. Bioassays undertaken to assess the sublethal effects of petroleum products on marine organisms (Hyland and Schneider, 1976) have indicated that phytoplankton, when exposed to various hydrocarbons in concentrations of 10^{-4} to 38 ppm, illustrate a depression in growth rate or a reduction in photosynthesis. When exposed to a range of crude and fuel oils in concentrations of 1 to 200 ppm, mixed phytoplankton populations of Monochrysis lutheri, Phaeodactylum tricornutum, Skeletonema costatum, and Chlorella sp., among others, showed a reduction in growth rate and photosynthesis. Venezuelan crude oil in concentrations of 10 to 30 µg/L induced a stimulation in photosynthesis. The copepod Calanus helgolandicus, when exposed to suspended oil droplets at concentrations of 10 ppm, showed a decrease in feeding and metabolic activities. Plankton entrained in the brine discharge containing oil concentrations of 6 ppm therefore could experience a short-term reduction in their metabolic activity (e.g., metabolism, photosynthesis). Major changes in the plankton community due to oil

contamination have not been reported in the literature (Hyland and Schneider, 1976).

Because of their low discharge concentrations no single chemical constituent should be present in concentrations toxic to marine life outside the high salinity-temperature sector of the plume. However, these chemicals may act synergistically to induce adverse impacts on the biological community, but the degree of this impact is unknown.

For the worst case 8-day slack period in longshore currents, the area within the 4-ppt excess isohaline would extend to about 30 acres (12 hectares) and thus would enclose a high salinity-temperature area causing severe physiological stress on the plankton.

3.3.3 Impact on Benthos

Brine disposal in the Gulf of Mexico would have a significant effect on certain components of the benthic invertebrate community especially nonmotile forms. The area of greatest stress would be within the 4-ppt isohaline and many of the sessile (nonmotile) organisms living within the range of this contour would be killed (U.S. Dept. of Commerce, 1977a). Mortality would occur particularly in areas near the diffuser where salinities may approach values of up to 264 ppt and excess temperatures would be as high as $120^{\circ}F$ ($49^{\circ}C$) above ambient.

Assuming total mortality in this immediate area of the diffuser, 2.1×10^6 benthic invertebrates per acre would be killed at Site A and 27.4×10^6 per acre would be killed at Site B. These estimates are based on mean density values measured at the five stations sampled nearest the proposed diffuser for each site (Appendix C). Based on worst-case current conditions for plume dispersion, almost 60 acres (24 hectares) would be covered by the 4-ppt excess isohaline at any one time (Section 3.3.1). Using 9 months of field data, (October 1977 to July 1978) the 4-ppt excess isohaline has been predicted by the plume model to affect a maximum 440 acres (178 hectares) when the plume oscillates back and forth in response to the local changes in currents.

The brine plume would have the greatest impact on the benthos at both sites during the spring when faunal densities are at their highest. Polychaetes, in particular, Streblospio and Cossura at Site A; Mediomostus,

Paraprionospio, and Magelona at Site B; and Spiophanes at both sites--
would be the benthic organisms most affected by the plume, but this
impact would be moderated since these organisms have a high tolerance
to environmental perturbations. Mollusks and crustaceans would also be
impacted to a high degree by the plume. During late spring and summer
natural mortality, predation, and the effect of the anoxic layer will
also reduce the number of organisms in the benthic populations. In the
far field areas (less than 4 ppt) the salinity increase is unlikely to
have a significant adverse impact on the benthic community near the site.

Bioaccumulation of several heavy metal precipitates (copper hydrox-
ide, iron hydroxide, strontium sulphate, and aluminum hydroxide) may
occur in the food web as a result of ingestion of the metals directly
or indirectly by detritivores and filter-feeding benthic organisms.
Ingestion of these metals by benthic organisms could disturb their
metabolic processes. Discharged hydrocarbons may also accumulate in the
benthos, altering metabolic processes and tainting tissue of shrimps or
crabs. Neanthes can acclimate to relatively high concentrations of
petroleum hydrocarbons; though there is a reduction in fecundity, it is
partially compensated for by increases in oocyte maturation and decreases
in brood mortality. Ingestion of these organisms by carnivorous food fish
may result in tainting of their tissue and reduce their acceptability as
sea food.

Physiologically, benthic organisms adapt to salinity changes in a
variety of ways. Most polychaetes and mollusks are osmoconformers, which
means the ionic concentration of their body fluids change with alterations
in ambient salinities and thus they are able to compensate for ionic
changes with complex metoblic adaptions. Crustaceans, on the other hand,
are often physiologically adapted to osmoregulate. Benthic organisms also
react to environmental extremes by avoidance, shell closure, and burrow-
ing. These mechanisms are successful up to a point, since benthic
organisms have been reported to survive salinity levels from 24 to 82 ppt
(Table 3-11), but chronic salinity conditions would stress the adaptive
abilities of the organism, especially among eggs, larval, and juvenile
stages, and the weakly motile species. Invertebrates, particularly
polychaetes, are capable of quick recovery, even after large communities
are killed off by adverse salinity changes (Gunter, et al., 1974).

TABLE 3-11 Salinity ranges for benthic invertebrates in the northwestern
Gulf of Mexico (with a recorded occurrence in salinities above
45 ppt).

Organism	Salinity (ppt)
POLYCHAETE (WORMS)	
Nereis pelagica	25 - 75
Polydora ligni	25 - 75
CIRRIPEDIA (BARNACLES)	
Balanus eburneus	25 - 80
Balanus amphitrite	25 - 80
AMPHIPODA (SCUDS)	
Gammarus mucronatus	20 - 50
Podocerus brasiliensis	50 - 80
Grandidierella bonneroides	45 - 80
PELECYPODA (BIVALVES)	
Mulinia interalis	30 - 45
Anomalocardia cuneimeris	30 - 70

SOURCE: Hedgpeth, 1967

Bioassay studies (Neff, 1978) have revealed that the adult benthic polychaete Neanthes arenaceodentata has median 96-hour tolerance limits to brine of 46.9 to 51.9 ppt at 68°F (20°C) and of 40.0 to 47.4 ppt at 86°F (30°C), depending on organism size. These adult worms were also better able to survive in seawater with salinity comparable to that of brine at 68°F (20°C), indicating that altered ion composition may have a detrimental effect. However, this trend was not apparent at 86°F (30°C). When subjected to brine, the immature stages of this species had a higher survival rate than the adults, though their growth was slightly inhibited. At 68°F (20°C), the younger life stages were more apt to survive in brine than in natural seawater of comparable salinity. At 68°F (20°C), Nereis limbata had a 96-hour LC$_{50}$ (the concentration lethal to 50 percent of the organisms tested over a 96-hour exposure) of 44.2 and 51.5 ppt for brine and artificial seawater, respectively.

Assuming that the results of these bioassays are representative of other benthic infauna, it may be concluded that brine will have a greater impact during the summer when the water is warm, and on the younger life stages. It may also be concluded that mortalities are a result of altered ion composition as well as increased salinity. Also, the salinities lethal to these organisms would only be encountered in the immediate area surrounding the diffuser. Due to the transient nature of the brine plume, a Eulerian approach has been used with the MIT model and typical currents (0 to 1.5 knots) to determine how long a benthic organism would be exposed to a particular excess isohaline (Figures 3-42 and 3-43). Generally, the higher the excess isohaline, the shorter the duration of exposure. The degree of this impact depends on distance and direction from the plume.

Although many of the benthic invertebrates are of little or no direct economic value, they occupy an important position in the trophic structure of the marine fossil web. The infauna depend on plankton as a food source and may be indirectly impacted if the plankton are destroyed by the brine. Furthermore, since the benthos are preyed upon by many commercially important finfish and shellfish, any pollutant bioaccumulation or reduction in benthic productivity would also be reflected in these higher trophic levels. It is estimated that a reduction in benthic productivity would be minimal in all areas except in the immediate area of the diffuser. No threatened or endangered benthic species (Section 2.4.3) or unique
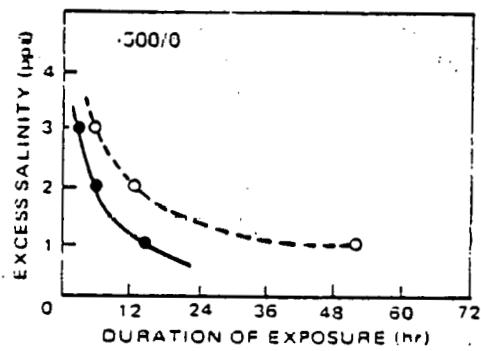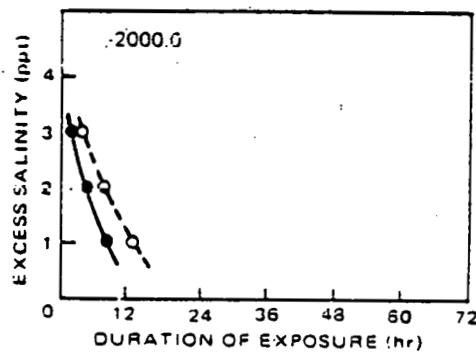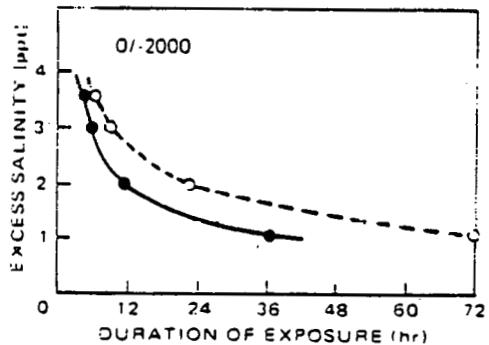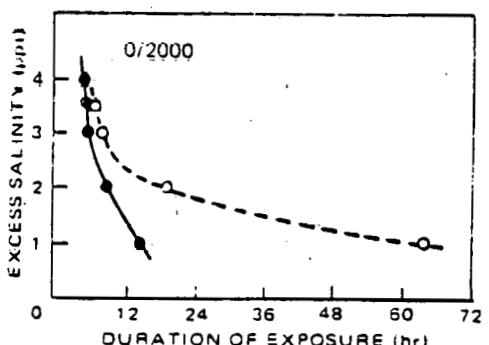
FIGURE 3-42   Excess salinity versus duration of exposure at indicated grid points.
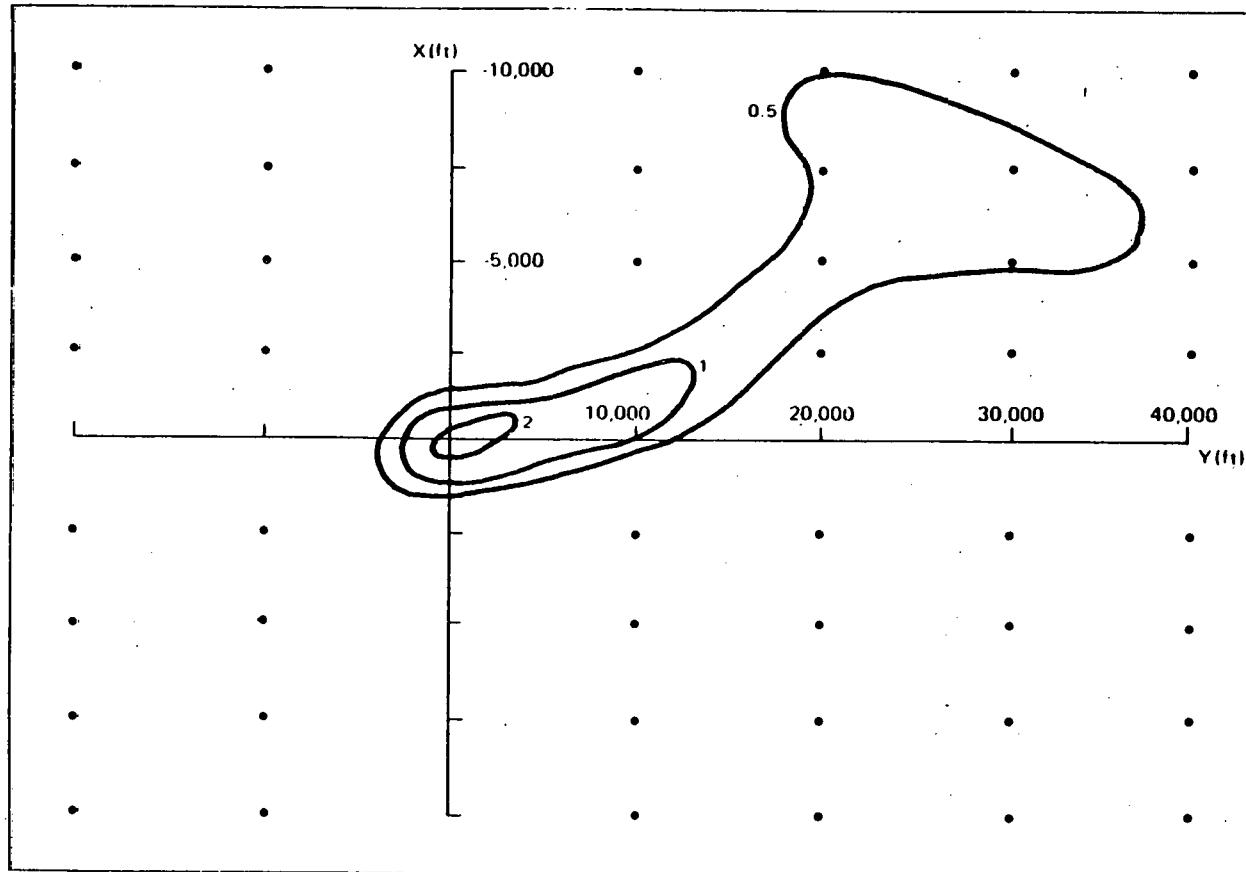
FIGURE 3-43   Idealized brine plume and analysis region shoreward (X direction) and alongshore (Y direction) from the diffuser (excess salinity contours in ppt).

communities are located within the excess 4-ppt isohaline. On a regional basis the environmental loss of the benthic community within this brine plume is not expected to be significant.

3.3.4 Impact on Nekton

The impacts of the brine discharge on nekton depend on various factors including the season, the life stage of the organism, and its life history. Generally, the impacts of brine on the adult stages of the nekton are estimated to be minimal since these organisms are active swimmers and most nekton, because of their salinity preference levels, would avoid the plume's area of high impact. However, the adults of certain species, such as shrimp and crab, depend on the bottom for burrowing, food, cover, and breeding and would be impacted to a greater extent than fish. Many of the nekton in the Louisiana coastal region are an economically important species and include the brown and white shrimp, blue crab, menhaden, and the Atlantic croaker. A major impact on these commercial species would result in a severe blow to the area's economy.

The planktonic eggs and larvae of nektonic organisms would be entrained in the plume and tend to be more sensitive to environmental perturbations than adults. The impacts on these early life stages would be greatest during the spring and summer when spawning is at a maximum and eggs and larvae are at their greatest abundance. Sudden changes in salinity which impede migration or do not permit normal osmoregulatory processes to function can kill adult euryhaline fishes.

Similar to the plankton and benthos, the greatest impact of brine discharge on nekton would be due to the effects of increased salinity and temperature, although increased turbulence, particulates, and hydrocarbon concentrations, decreased DO levels, and an altered calcium/magnesium ratio also would produce additional environmental stress. The area of greatest stress would be within the 4-ppt above-ambient isohaline where high salinity and temperature values would occur. Most of the nekton would tend to avoid these areas. Based on conservative estimates, about 60 acres (24 hectares) would be covered at any one time during a worst-case condition, whereas a total of 440 acres (178 hectares) would be covered over a period of time by the 4-ppt envelope as the plume oscillates due to changes in the current direction. Normal (nonslack) conditions would have a much

smaller area enclosed by the 4-ppt isohaline. The far-field area will have a temperature which is expected to approach ambient levels; however, an excess salinity gradient of about 1 ppt may extend several miles from the diffuser, but no significant impact to the nekton would be anticipated in this area.

Ninety-eight percent of the commercial species in the Gulf of Mexico inhabit both the estuaries and offshore coastal waters. Spawning typically occurs in the high salinity waters of the Gulf coast during some part of each species life cycle. The young migrate to the estuaries to grow and nurture and subsequently the juveniles return to the open waters of the Gulf to complete the cycle. Because of these migrations, the variation in total biomass is quite pronounced for a given area and marked seasonal changes in species composition or size and age composition are common. Therefore, a brine discharge which could affectively block the migration route of these fishes during their life cycle would have a significant impact on the nekton community and in turn adversely effect any commercial fishing at the discharge sites (See Section 3.3.4.1).

Hydrocarbons, which would be released only during the oil refill phase of the project, are expected to average 6 ppm. Bioassay data for a variety of marine organisms show the lethal level for soluble petroleum fractions to range from 1- to 100-ppm soluble for adult stages and to range from 0.1 to 1 ppm for larval and juvenile life stages. Adverse sublethal physiological impacts have been found to occur for petroleum concentrations from 1 to 10 ppb (Hyland and Schneider, 1976).

Jet dilution at the discharge site is expected to reduce hydrocarbon levels rapidly; however, nekton which have not avoided or rapidly traversed the region may be subjected to physiological dysfunction, such as disruption of normal feeding and reproductive patterns possibly due to an imbalance in chemotactic sensing. Low-level hydrocarbon pollution has been found to result in decreased growth, delayed hatching, and abnormal behavior and development in fish and macroinvertebrate eggs and larvae (Hyland and Schneider, 1976). Incorporation of petroleum hydrocarbons in marine organisms may result in tainting of edible species, and would be a significant adverse impact for this high-yield commercial fisheries area.

Nektonic populations affected by water-soluble hydrocarbons could recover relatively quickly by recruitment of larval and adult immigrants from outlying areas. Nektonic organisms dependent on the benthos as a food source would be affected to a greater extent because, in sediments, hydrocarbons could accumulate to higher levels and persist for a longer period of time than hydrocarbons in the water column.

An increase in turbidity due to increased amounts of dissolved and precipitated solids could indirectly affect the nekton by causing a decrease in productivity, thus decreasing available food sources in the near-field area. Settling of the particulates could affect benthic organisms by direct toxicity, burial, and bioaccumulation, thus reducing their availability as a food source for nekton. Low DO levels would affect sessile organisms and produce a local decrease in food for nekton, but nektonic organisms would tend to avoid these low oxygen areas.

The calcium/magnesium ratio, which is normally 1:3 in seawater, is at least two orders of magnitude greater in brine. When discharged, the alteration of ion balance in the water column may affect muscular activity and nerve transmission in nektonic organisms.

The exit velocity of water from the diffuser ports has been designed for 25 ft/sec (7.6 m/sec) to facilitate jet mixing. This turbulence could produce mortality in fish and macroinvertebrate eggs or larvae entrained in the jet.

3.3.4.1 Shrimp

Bioassays performed on three life stages of white shrimp--eggs, nauplii, and early protozoeal--show that the brine concentration between 2.45 and 3.2 percent volume (36.5 to 38 ppt) at 82°F (28°C) was lethal to the embryonic shrimp (Wilson et al., 1978). These studies also indicated that the 24-hour LD_{50} (lethal dose to 50 percent of the test organisms) of postlarvae was between 6.3 and 6.5 percent brine (49 ppt). At increased temperatures of 87.8°, 89.6°, and 91.4°F (31°, 32°, and 33°C) the 24-hour LD_{50}'s decreased to 5.9, 4.75, and 4.4 percent brine, respectively (approximately 48, 43, and 42 ppt). Thus, it appears that salt dome brine is less toxic to nauplii than to embryos or early postlarvae, but the affect of brine increases as temperature increases. Although the nauplii survive, they may not metamorphose to the first protozoeal stage after

3-90

exposure to concentrations under 3 percent brine (39 ppt). Furthermore, if exposed from the time of egg cleavage to protozoeal stage, development may be inhibited at brine concentrations under 3 percent.

In other studies (FEA, 1977a), the salinity preference of postlarval brown and white shrimp (Table 3-12) has been examined in gradient tanks with salinity ranges from 0 to 70 ppt and 0 to 50 ppt, respectively. The results indicate that the shrimp preferred lower salinity levels than those that would be normally expected in the open Gulf. It was hypothesized that the shrimp key in on salinity gradients to navigate during their migration to the less saline inshore nursery grounds. Statistical analysis of the data revealed that a seasonal variation in salinity preference by the postlarvae was being expressed, especially by the brown shrimp, which preferred highest salinities in the spring. White shrimp postlarva showed a seasonal preference only when exposed to low salinities.

At temperatures of 73^0 to 78^0F (23^0 to 26^0C), postlarvae of brown shrimp grew equally well at salinities of 2 to 40 ppt. Postlarvae of white shrimp produced twice as much tissue at intermediate salinities (10 to 15 ppt) compared to conditions at 20 and 35 ppt and temperatures above 77^0F (25.5^0C). Postlarvae of brown shrimp produced the most tissue at salinities of 30 ppt and 90^0F (32^0C), (FEA, 1977a). These data indicate that postlarvae penaeid shrimp are tolerant of both salinity and temperature variations.

Several studies have indicated that adult white shrimp generally are less tolerant of high salinity than adult brown shrimp, but other studies have shown no differences in salinity preference. For example, adult white shrimp have been collected under conditions where salinities ranged from 0.2 ppt to more than 47 ppt; and brown shrimp have been taken in areas where salinities ranged from 0.1 to 69 ppt. This wide range of salinity indicates that these two penaeid shrimp are of the euryhaline species (FEA, 1977a). The preferred temperature range (based on catch data) for adult white and brown shrimp is 68^0 to 86^0F (20^0 to 30^0C) and 68^0 to 95^0F (20^0 to 35^0C), respectively (Copeland and Bechtel, 1974).

TABLE 3-12   Salinity preference (ppt) of postlarvae of brown and white shrimp.

	P5[a]	P25	P50	P75	P95	P75-P25	P95-P5
Summer							
Brown	41.4	28.9	20.6	13.9	7.2	15	34.2
White	43.5	34.5	28	21.1	11.1	13.4	32.3
Fall							
Brown	47.3	36	27.4	19.2	10	16.8	37.3
White	41	28.5	21.1	13.6	5.8	14.9	35.2
Spring							
Brown	49.1	38.1	29.9	21.9	11.4	16.2	37.7

[a]P5 represents the salinity value at or above which the top 5 percent of the members most tolerant to salinity are found. P50 would be tne median value where 50 percent of the members are above and 50 percent are below the indicated salinity values.

SOURCE: Keiser and Aldrich, 1976.

Experiments on the susceptibility of white shrimp to oilfield brine showed that, for one case, all shrimp died within 2 hours after exposure to a brine concentration of 42 ppt; white shrimp survived indefinitely when similarly exposed to evaporated bay water with salinities of 45 ppt. The conclusion was that the ionic composition of the brine may exert a greater influence on organisms than brine concentrations (FEA, 1977a).

There is limited information on how ionic composition affects shrimp. Exposure of penaeid shrimp to toxic pollutants may reduce their capacity to resist salinity stress, and concentrations not toxic at normal salinities might become harmful as salinities decrease. Cadmium in the brine discharge can be bioaccumulated by shrimp through their food source or directly from the water. The 96-hour LC_{50} for pink shrimp is 3.5 mg Cd/1. For white shrimp, the toxicity of mercury is 17 mg/1 for a 96-hour LC_{50}; the toxic effects do not vary with shrimp size (7 to 35 millimeters). Exposure to mercury for 60 days at concentrations of less than 1 mg/1 did not affect respiration, growth, or molting rates of postlarval shrimp (Green et al., 1976). There is no direct evidence of lead toxicity or bioaccumulation by penaeid shrimp. Raw chitin has been shown to adsorb lead over a range of salinities (Yoshinari and Subramanian, 1976). If the chitin of shrimp acts similarly, accumulation of lead might constitute a human health hazard.

Toxicity studies undertaken to assess the impact of hydrocarbons on marine organisms show that polar compounds in petroleum are the most soluble in water and are the most toxic. The metabolites of poly-nuclear aromatic hydrocarbons may be much more toxic than the original parental compounds. In addition, low concentrations of petroleum products can affect feeding and reproduction in crustaceans.

Since temperature and salinity are expected to approach $130^{\circ}F$ ($54^{\circ}C$) and 264 ppt, respectively, within the high impact area of the brine plume (60 acres (24 hectares)), about 4.55 shrimp could be impacted for each acre of substrate entrained in the plume--assuming that the shrimp do not show an avoidance reaction to this sector of the plume. Outside of this area, the brine would probably not have significant adverse impact on adult shrimp (Figure 3-44). In contrast, the planktonic

stages of shrimp temporarily entrained in the near-field sector of
the plume could be adversely impacted. Due to their greater sensitivity,
planktonic shrimp could also be harmed outside of the near-field plume
area (Figure 3-44).

3.3.4.2 Blue Crabs and Oysters

Adult blue crabs have a wide range of salinity tolerance (0.7
to 88 ppt) but prefer to spawn in waters with relatively high salinities
(Jaworski, 1972). In contrast, the blue crab egg yolk was destroyed
in a 5 percent (44 ppt) brine at 82°F (28°C), (Johnson and Williams,
1978). Blue crab larvae migrating to the estuaries may be temporarily
damaged if they become entrained in the high temperature/salinity sector
of the brine plume.

Oysters, another commercially important species in coastal Louisiana,
develop and grow in low salinity waters (under 15 ppt). This species
will not be impacted by the plume since they are not found in the region
of the proposed diffuser sites.

3.3.4.3 Fish

Adult fish would be subject to minimal impact from brine disposal
at either Sites A or B since they tend to avoid areas with adverse
salinity concentrations. Although salinity tolerances for marine fish
vary, it is usually the younger developmental stages that would be
expected to be least tolerant. However, some marine teleost eggs can
tolerate wide ranges of salinity. Atlantic herring eggs have hatched
under laboratory conditions in salinities up to 90 ppt, and the eggs
of the sheepshead minnow have hatched in salinities of 110 ppt _in situ_.
Yolk sac larvae of the Atlantic herring survive and remain active for
at least 24 hours at salinities of 60 to 65 ppt. The larvae of Gulf
menhaden have metamorphosed in the laboratory at salinities of 25 to
40 ppt (FEA, 1977a).

Bioassays conducted on spotted seatrout eggs and larvae when exposed
to salt dome brine for 48 hours at 80.6°F (27°C) resulted in significantly
increased mortalities at a concentration equivalent to 40 ppt. These
mortalities did not differ from those of comparable salinities using
artificial seawater, indicating that the differences in ionic composition

24 HOUR LD-50 FOR POSTLARVAL WHITE SHRIMP (82°F) 49 ppt

INHIBITION OF DEVELOPMENT AND NAUPLII METAMORPHOSIS OF WHITE SHRIMP 39 ppt

24 HOUR LD-50 FOR EGGS OF WHITE SHRIMP (82°F) 36-38.5 ppt

MAXIMUM SALINTY ~ 33.5 ppt

SALINITY (ppt)

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
1963   1964
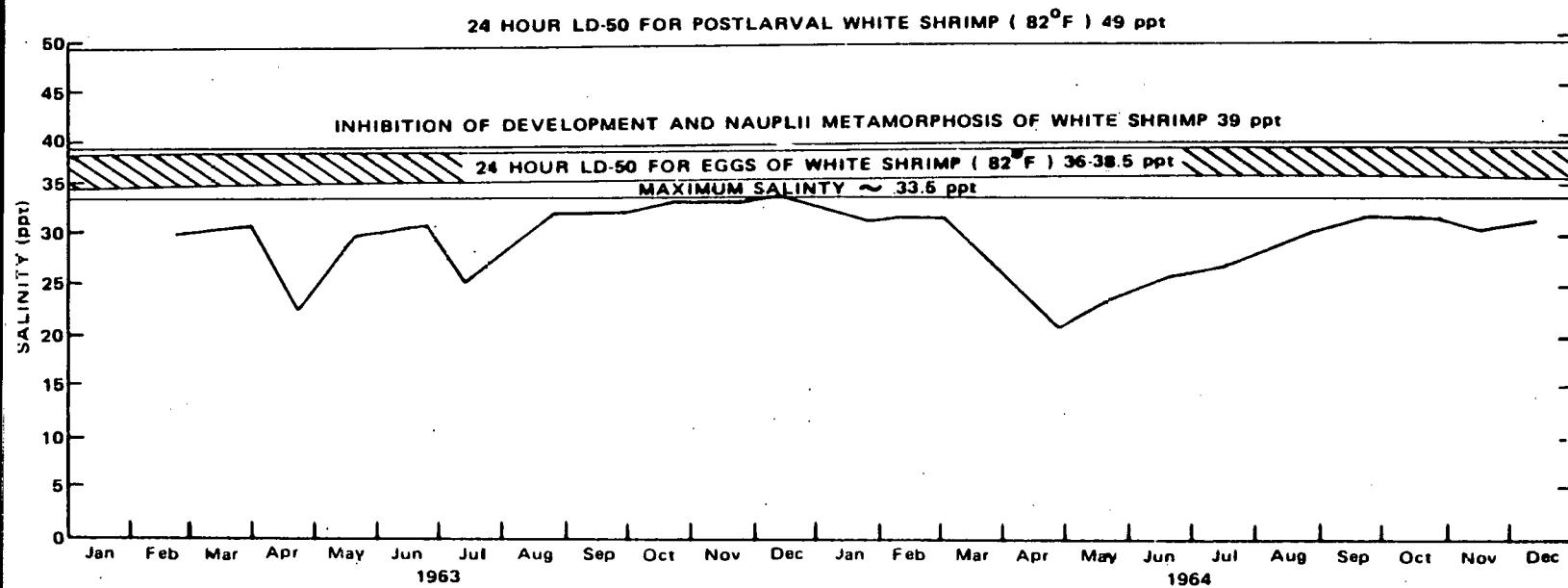
SOURCES: Gagliano, 1973; Wilson et al., 1978.

FIGURE 3-44   Salinity record (1963-1964) in the vicinity of Weeks Island Sites A and B, showing the brine concentrations at which white shrimp eggs, larvae, and postlarvae are stressed or killed.

of brine may not have an additional effect (Johnson and Williams, 1978).
The planktonic life stages entrained in the plume would be exposed
to excess salinities for only a few hours. Planktonic organisms within
a region 300 to 400 feet (91 to 122 meters) from the diffuser would
be exposed to a salinity excess of 1 ppt and would be entrained for
less than 12 hours (U.S. Dept. of Commerce, 1978a).

Brine bioassays of larval spotted seatrout were performed for
exposure periods of 1 and 2 hours (Table 3-13). The 48-hour LD_{50} of
a 1-hour exposure to the brine was about 48 ppt (6.2 percent by volume);
for a 2-hour exposure it was about 41 ppt (3.5 percent by volume).
When entrained under the conditions depicted in Figure 3-45, the brine
discharge exposures are expected to be lethal to less than 10 percent
of spotted seatrout larvae.

Supranormal salinities may cause changes in growth rates and energy
expenditure, leading to gill tissue damage and asphyxiation, and they
may affect metabolic rate, activity, and neuromuscular functions.
Since the DO level decreases as salinity increases, the physiological
effects may be indirect. This is revealed by growth rate experiments
involving desert pupfish (FEA, 1977a). As salinity increased, develop-
ment was progressively retarded. These results were attributed to
low oxygen levels in the water.

The expenditure of energy in marine organisms may result from
both direct and indirect effects of salinity. It has been shown that
within a certain optimum salinity range, a minimum amount of energy
needs to be expended to maintain osmotic gradients; large amounts of
energy can then be directed toward growth. Above the optimum salinity
range, an increase in metabolic process is generally accompanied by
an increase in uptake of oxygen. Above 34 ppt, the oxygen uptake rate
in the starry flounder increased 15 percent. Additional energy is
expended to sustain osmotic and ionic regulation at above-optimal salin-
ity regimes (FEA, 1977a).

The majority of the fish expected in the vicinity of Sites A and
B are euryhaline, and hence have a high tolerance to wide salinity
ranges (from 5 to 37 ppt), (Table 3-14). The maximum in situ salinity
at the sites was 33.6 ppt (Figure 3-44). Assuming that ambient salinities

SALINITY CONCENTRATION ABOVE 30 PPT AMBIENT

DURATION OF EXPOSURE (hr)

SEE CAPTION NOTE

10%

AVERAGE DURATION

MAXIMUM DURATION
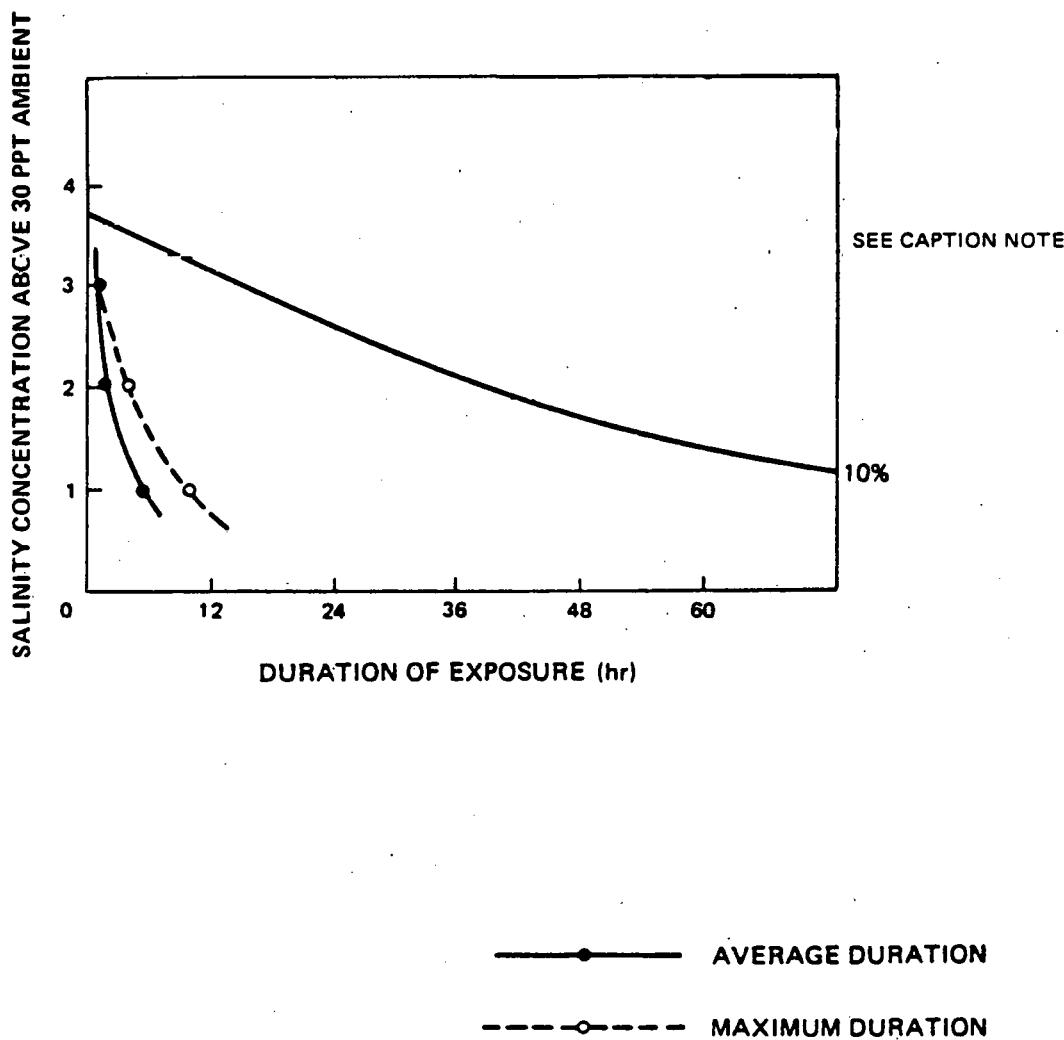
SOURCE: U.S. Dept. of Commerce, 1978a.

FIGURE 3-45   Excess salinity versus duration of exposure for drifting
planktonic species entrained in the brine plume. (Area above
the 10 percent line denotes environmental conditions lethal
to at least 10 percent of laboratory-tested larval spotted sea-
trout specimens.)

TABLE 3-13 Average mortality of 1-hour posthatch larval spotted seatrout from short-term exposure to salt dome brine (based on four replicates).

Percentage (Volume/Volume)[a]		Exposure Time (hr)	Total Test Time (hr)	Mortality[b] (%)	Exposure Time (hr)	Total Test Time (hr)	Mortality[b] (%)
10	(55)	1	24	3 (2.57)	1	48	58.83 (16.91)
5	(44)	1	24	2.07 (2.11)	1	48	25.65 (11.87)
2	(36)	1	24	2.56 (0.76)	1	48	16.4 (8.5)
1	(34)	1	24	2.47 (2.48)	1	48	12.03 (3.27)
0.5	(33)	1	24	2.85 (2.33)	1	48	4.53 (1.33)
0	(30)	1	24	0.68 (0.78)	1	48	4.9 (1.24)
10	(60)	2	24	80.55 (8.33)	2	48	98.75 (1.5)
5	(48)	2	24	10.13 (1.44)	2	48	53.9 (7.94)
2	(42)	2	24	3.78 (1.03)	2	48	48.75 (28.69)
1	(39)	2	24	4.18 (2.19)	2	48	17.25 (14.8)
0.5	(38)	2	24	4· (2.14)	2	48	6.75 (2.33)
0	(36)	2	24	2.35 (1.65)	2	48	4.83 (1.54)

LC_{50} = 1 hr - 24 hr = >10% V/V,   1 hr - 48 hr = 8.4 ± 2.2% V/V
       2 hr - 24 hr = 7.5 ± 2.5% V/V, 2 hr - 48 hr = 3.5% V/V

[a]( ) = measured salinity in ppt.

[b]( ) = one standard deviation.

SOURCE: Johnson and Williams, 1978.

TABLE 3-14   Salinity tolerances of some common coastal Louisiana fishes.

| | Salinity (ppt) | | | | |
	Range	Greatest Abundance	Highest Recorded Salinity Tolerance	Reference[a]	Comments
Ladyfish			75	Gunter, 1967	Die at 100 ppt
Gulf menhaden	0 - 30	5 - 24.9		LWL&FC, 1971	
	<1 - >60			Reintjes and Pacheco, 1966	Die at 80 ppt
Striped anchovy	>29.9	>15		LWL&FC, 1971	
			75	Gunter, 1967	Die at 100 ppt
Gizzard shad			60	Copeland and Moseley, 1967	Brine dominated system
Sea catfish	0 - >30	>10		LWL&FC, 1971	
	2 - 36.7	>30		Gunter, 1945	
Sheepshead minnow			75	Gunter, 1967	Die at 100 ppt
			60	Copeland and Moseley, 1967	Brine dominated system
			142.4	Simpson and Gunter, 1956	
Gulf killifish			55.1 - 58.6	Renfro, 1969	
Longnose killifish			75	Gunter, 1967	Die at 100 ppt
Tidewater silverside			75	Gunter, 1967	Die at 100 ppt
			55.1 - 58.6	Renfro, 1960	
Rock seabass	>5 - >30			LWL&FC, 1971	
Pinfish	———		75	Gunter, 1967	Die at 100 ppt
	15 - 26[b]			Corps, 1976	
Sand seatrout	0.2 - >30			LWL&FC, 1971	
Spotted seatrout			75	Gunter, 1967	Die at 100 ppt
		15 - 35	77	Tabb, 1966	
	15 - 45[b]			Corps, 1976	
Banded drum	5 - >30	>15		LWL&FC, 1971	
Spot	0.2 >30	>10		LWL&FC, 1971	
	0 - 33.9			Nelson 1969	
Southern kingfish	2 ->30	10		LWL&FC, 1971	
Atlantic croaker	0 - >30			LWL&FC, 1971	
			75	Simmons, 1957	
			75	Gunter, 1967	Die at 100 ppt
	15 - 35[b]			Corps, 1967	

TABLE 3-14 (cont'd)

| | | Salinity (ppt) | | | |
	Range	Greatest Abundance	Highest Recorded Salinity Tolerance	Reference[a]	Comments
Black drum	0.2 - 24.9			LWL&FC, 1971	
			75	Gunter, 1967	Die at 100 ppt
			80	Simmons and Breuer, 1962	Eyes are glazed
	15 - 45[b]			Corps, 1967	
Red drum	5 - 29.9			LWL&FC, 1971	
	0.0 - 37.6			Kilby, 1955	
			50	Simmons and Breuer, 1962	
	15 - 40[c]			Corps, 1976	
Striped mullet	0 - >30	5 - 19.9		LWL&FC, 1971	
			60	Copeland and Mosely, 1967	Brine dominated system
			75	Gunter, 1967	Die at 100 ppt
			55.1 - 50.6	Renfro, 1969	
	25 - 85[b]			Corps, 1976	
Atlantic threadfin	1.6 - 29.9	20		LWL&FC, 1971	
Atlantic cutlassfish	0.2 - >30	>15		LWL&FC, 1971	
Blackfin searobin	10 - 24.9			LWL&FC, 1971	
Fringed flounder	5 - 29.9	20		LWL&FC, 1971	
Southern flounder	0 - >30			LWL&FC, 1971	
	0 - 50			Corps, 1976	
	12 - 35[b]			Corps, 1976	
Blackcheek tongue-fish	0.3 - 29.9	>10		LWL&FC, 1971	
		>30		Gunter, 1945	

[a]LWL&FC = Louisiana Wildlife and Fisheries Commission; Corps = U.S. Army Corps of Engineers.

[b]Ideal salinity range.

SOURCE: FEA, 1977.

are at this level during brine discharge, the upper salinity range for euryhaline species could be found at the 3.4-ppt above-ambient isohaline within the brine plume discharge. Outside this isohaline, impact to the adults should be minimal; within the isohaline, where salinities can approach 264 ppt at the diffuser port, adults may be temporarily impacted. Egg and larval stages are most likely to be adversely affected if they are entrained in the plume.

Commercial fishing activities, particularly for white shrimp, would not be affected by the exposed diffuser ports because a "nonsnag" feature would be incorporated into their design. Sportfishing would be affected by brine disposal only in the immediate area around the diffuser but little fishing activity has been observed in this area.

3.3.5 Impact on Threatened or Endangered Species

It is not expected that threatened or endangered species listed for the northern Gulf of Mexico (Section 2.4.5) would be significantly affected by brine discharge. Although data on salinity and temperature tolerances of these creatures are sparse, these creatures are highly mobile and they should avoid any region of the plume they find undesirable. Those species swimming through the plume would experience only a temporary salinity-temperature stress and would move quickly to more favorable areas in the water column either above or to the side of the plume. Because of the short duration of this stress, recovery would commence soon after they encounter their preferred, ambient temperature-salinity regimes.

3.3.6 Impact on Unique or Important Habitats

Shipwrecks (Section 2.4.6) located within several miles of Sites A and B, with their associated fouling and nektonic reef communities, are considered to be unique and important habitats. Five wrecks are located within 6 miles of Site B and one wreck is about 8 miles north-west of Site A. There is little information on these specific wreck-reef communities, but they are probably both eurythermal and euryhaline since they inhabit shallow coastal shelf waters.

Analysis of the brine plume characteristics and the distance of
the shipwrecks from the diffusers suggests that the wreck-reef communi-
ties at Site B may be periodically entrained in the 0.5-ppt excess
isohaline. This periodic and small increase in salinity would not
be expected to severely impact euryhaline organisms in a region where
there are marked natural variations in salinity and temperature.

3.3.7 Conclusions

Based on the baseline biological data collected at Sites A and B
(Section 2) and the assessment of impacts of brine disposal (Section 3),
it appears that a discharge at Site B would have less potential for
impact on the biological community, mainly because of the greater abun-
dance of commercially important nekton observed at Site A.

The phytoplankton community attained minimum densities at Site
A during the fall and winter months and maximum densities at Site B
during the early spring months. Phytoplankton concentrations during
this sampling period are generally comparable to those found during
other studies undertaken in this region and the northwest Gulf area
(LOOP, 1975; USDI, 1978). These studies have shown that phytoplankton
densities are highest in the nearshore waters and decrease seaward.
This information suggests that less impact would occur to the phytoplank-
ton community as the offshore distance of the brine discharge increased.

The zooplankton community attained maximum densities during the
fall months at Site A and minimum densities during the winter and early
spring at Site B. Species composition is quite similar at both sites.
The fall maximum and spring minimum generally correspond with the natural
seasonal variations found for zooplankton densities west of the Mississippi
Delta. Since Sites A and B are in the same general area, it is not
expected that impacts on the plankton would vary significantly between
the two sites.

Benthic faunal diversity and density appear to be less at Site
A than at Site B, possibly due to the differences between the sites
in sediment characteristics and water quality. Although the sites
were sampled at different times of the year, this trend was still ap-
parent when samples from the two sites were compared for the same sea-
son--Site A during December 1977 and Site B during February 1978.

Furthermore, when Weeks Island Site A was compared to the proposed Chacahoula brine diffuser site (DOE/EIS-0024), a site which was sampled at the same time as Site A yet was close to and has characteristics similar to Site B, a similar conclusion could be reached--benthic diversity and density appear to be less at Site A. Based on these findings, it is estimated that possibly twice as many benthic organisms would be affected by brine disposal at Site B.

Comparison of nekton diversity and abundance at Weeks Island Site A with that of Site B and the proposed Chacahoula site during the same sampling periods reveals a greater diversity and abundance at Site A. This difference is more pronounced when specific species are considered. For example, at Site A, certain commercial species, particularly white shrimp, are present in greater numbers and over a longer period of time than at Site B. Thus, it is concluded that brine disposal at Site B would have less of a potential for adverse biological effects on nekton when compared to Site A.

APPENDIX A

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