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Final Supplement to
Final Environmental Impact Statements
DOE/EIS-0021,0029

Strategic Petroleum Reserve

Phase III Development
Texoma and Seaway Group Salt Domes
(West Hackberry and Bryan Mound Expansion, Big Hill Development)

Cameron Parish, Louisiana and Brazoria and Jefferson Counties, Texas

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STRATEGIC PETROLEUM RESERVE PHASE III DEVELOPMENT
TEXOMA AND SEAWAY GROUP SALT DOMES
(WEST HACKBERRY AND BRYAN MOUND EXPANSION, BIG HILL DEVELOPMENT)
CAMERON PARISH, LOUISIANA, AND BRAZORIA AND JEFFERSON COUNTIES, TEXAS

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ABSTRACT: This document supplements the Final Environmental Impact Statements (FEISs) for the Strategic Petroleum Reserve (SPR) Texoma and Seaway Groups of salt domes. Potential environmental impacts associated with construction and operation of crude oil storage and distribution facilities, which will increase quantities of crude oil stored in the Texoma and Seaway distribution systems, are assessed. This document addresses Phase III expansion of the SPR, which would increase the total SPR crude oil storage capacity from 538 to 750 million barrels (MMB) and SPR drawdown capability from 3.5 to 4.5 MMB per day. The preferred alternative would involve development of additional crude oil storage in Cameron Parish, Louisiana, and Brazoria County, Texas, and new storage in Jefferson County, Texas. This development would provide a total storage of 403 MMB for the Texoma Group, in which West Hackberry and Big Hill are located, and 220 MMB for the Seaway Group, in which Bryan Mound is located. The preferred alternative is expansion of Bryan Mound by 40 MMB and West Hackberry by 30 MMB and development of a new 140-MMB site at Big Hill salt dome in Jefferson County, Texas. Included in the proposal is the construction of a crude oil distribution system from Big Hill to existing terminal facilities, a raw water intake system from the Gulf Intracoastal Waterway to Big Hill, and a brine disposal system to the Gulf of Mexico. Alternatives considered include "no action," expansion of other SPR sites, and development of new sites at (1) other Gulf Coast salt domes, (2) salt domes off the coasts of Texas and Louisiana, (3) inland salt domes in northern Louisiana, Mississippi, and Alabama, and (4) conventional mines. The analysis of the Big Hill site also considers alternative crude oil terminals, pipeline routes, and brine disposal sites. Among the environmental impacts analyzed are potentially significant impacts on local surface water quality, floodplains and wetlands, air quality, endangered and threatened species, natural and scenic resources, archaeological, historical and cultural resources, socioeconomics, flora and fauna of the Gulf Coast area, and biota of the Gulf of Mexico. The supplement also discusses measures to mitigate adverse impacts.

SUMMARY

1.0 INTRODUCTION

This Final Supplement to the Final Environmental Impact Statements (FEISs) for the Strategic Petroleum Reserve (SPR) Seaway (DOE/EIS-0021) and Texoma (DOE/EIS-0029) Groups of Salt Domes is issued by the U.S. Department of Energy (DOE) to address environmental impacts of its proposal to expand existing SPR storage capacity by 212 million barrels (MMB). The SPR is a program being implemented by DOE for the purpose of providing the United States with sufficient petroleum reserves to minimize the effects of any future oil supply interruption. Congress declared, in the Energy Policy and Conservation Act of 1975, that the policy of the United States Government is to provide for the storage of up to one billion barrels of crude oil. The SPR Plan, as amended and approved by Congress, provides for expansion of the SPR from 500 to 1,000 MMB and includes an implementation plan for expansion of the reserve from 500 to 750 MMB.

The DOE has prepared several FEISs related to implementation of the SPR. A programmatic FEIS, published in 1976, addressed the development of a 500-MMB SPR program. The programmatic FEIS considered several different types of storage facilities; existing solution-mined cavities in salt formations, existing conventional mines, development of new solution-mined cavities in salt, existing and new surface tankage, and surplus tanker ships. A supplement to the programmatic FEIS, addressing the expansion of the reserve to one billion barrels, was published in January 1979.

To date, the SPR program has been organized into three major phases. Phase I consists of development of the initial 248 MMB in existing underground storage capacity available at five salt domes. These sites are West Hackberry, Louisiana (51 MMB); Bayou Choctaw, Louisiana (36 MMB); Weeks Island, Louisiana (75 MMB); Sulphur Mines, Louisiana (22 MMB); and Bryan Mound, Texas (60 MMB). A separate, site-specific FEIS has been published for each site. The sites are centered around three major interstate pipelines (Capline, Texoma, and Seaway) and their supporting terminals, which transport United States and foreign crude oil from the Gulf Coast region to inland areas of the United States.

Phase II of the SPR represents the current 290-MMB expansion of Bryan Mound, West Hackberry, and Bayou Choctaw. Phase II will increase SPR storage capacity to 538 MMB. FEISs addressing the Phase II expansion have been prepared by the DOE and made available to the public. These are the Seaway, Texoma, and Capline Group FEISs, which cover expansion of the Bryan Mound (120-MMB increase), West Hackberry (160-MMB increase), and Bayou Choctaw (10-MMB increase) sites, respectively. Other potential storage sites in the Gulf Coast region were addressed as alternatives in these three group FEISs.

Phase III of the SPR, which this Supplement addresses, represents expansion of SPR storage capacity by 212 MMB to achieve a 750-MMB reserve by 1989. This document is a supplement to the Seaway and Texoma Group FEISs.

2.0 DEVELOPMENT OF THE PROPOSED ACTION

The proposed Phase III plan is to increase the SPR crude oil storage capacity to 750 MMB by the addition of 212 MMB and to increase the average SPR drawdown rate by 1 MMB per day (MMB/d) from 3.5 to 4.5 MMB/d. To achieve the 212-MMB SPR Phase III requirement, the DOE proposes to construct storage facilities for 140 MMB at Big Hill salt dome in Jefferson County, Texas. Existing facilities at Bryan Mound (Freeport, Texas) would be expanded by 40 MMB and West Hackberry (Hackberry, Louisiana) by 30 MMB. There would also be 2 MMB in associated pipelines and storage tanks. This plan was developed through the evaluation of several alternatives.

2.1 EXPANSION OF EXISTING SPR SITES

Planning for Phase III focused on maximizing early oil fill as directed by Congress. Accordingly, first consideration was given to expanding the existing SPR sites beyond Phase II. In addition to the potential advantage of timely development, Phase III expansion of existing sites offers the economic advantage of cost savings through use of major onsite and offsite facilities previously constructed for Phase I and II (e.g., control facilities, centralized pumping facilities, crude oil distribution pipelines, raw water intake systems, and brine disposal systems).

Preliminary investigations determined that additional expansion of three of the five existing SPR sites (Sulphur Mines, Bayou Choctaw, and Weeks Island) would not be practicable. Sulphur Mines (Sulphur, Louisiana) is a small, irregularly shaped salt dome. It was selected in Phase I because of its 22 MMB of existing storage capacity and the ease of tying a crude oil pipeline into the West Hackberry distribution system. Expansion would be infeasible because there is limited salt available for new cavern development, high risk in drilling new caverns because of historical sulfur mining in the caprock, and limited capacity for brine disposal.

Bayou Choctaw (near Plaquemine, Louisiana) and Weeks Island (near New Iberia, Louisiana) are large enough to expand their storage capacities by more than 50 and 100 MMB, respectively. However, at each of these sites brine disposal would constitute a significant risk to the SPR program schedule. At Bayou Choctaw a brine disposal system of 28 injection wells designed to inject 960,000 barrels per day (bbl/d) was anticipated, but actual disposal operating experience was so adverse that only 12 wells were drilled. Problems encountered included formation plugging near the wellbore, excessive anhydrite buildup, sand inflow, and injection rates nearly half that expected. Extensive workover operations (acidizing) on each well were required almost daily. Brine disposal was also a limiting factor to further development at Weeks Island. A 50-mile-long pipeline to discharge brine into the Gulf of Mexico would be required to reach the minimum acceptable depth of 20 ft. Forty-eight miles would be in open-bay or offshore waters and would also necessitate crossing numerous pipelines in major producing oil fields.

Four criteria were established to determine options for expansion of Bryan Mound and West Hackberry (the two remaining sites):

- o Locating additional caverns, preferably within present property, or with limited additional land acquisition.
- o Maintaining total site brine disposal within hydraulic capacity of the existing brine disposal pipelines to the Gulf of Mexico.
- o Maintaining effective nominal leaching rates of 100,000 bbl/d per cavern.
- o Developing caverns and sites in the most timely and cost-effective manner.

At Bryan Mound the land within existing DOE property is sufficient to accommodate six Phase III 10-MMB caverns. At West Hackberry, less than 34 acres minimal land acquisition contiguous to the existing property could accommodate three additional 10-MMB caverns. Based on the first criterion, expansion of the two sites by 90 MMB is feasible.

Integrating the development of proposed Phase III caverns with Phase II evolved with the application of the second, third, and fourth criteria. The hydraulic capacity of the existing brine disposal pipeline at West Hackberry is 1,100,000 bbl/d, although the planned leaching rate for Phase II is 1,088,000 bbl/d. At Bryan Mound the hydraulic capacity is 1,100,000 bbl/d maximum (980,000 bbl/d average), although the current maximum permitted leaching rate is 680,000 bbl/d. The Environmental Protection Agency has granted an amended permit effective August 23, 1981, to increase the maximum permitted leach rate at Bryan Mound from 680,000 bbl/d to 1,100,000 bbl/d as a Phase II action to sustain an average accelerated leach rate of 980,000 bbl/d. Concurrently, the DOE has applied to the Texas Department of Water Resources for an amendment to its permit to appropriate a maximum of 367,000 acre-feet of state water from the Brazos River to provide for the increased volume of raw water required for leaching and displacement. Incorporating the hydraulic capacities of the pipelines and maintaining a 100,000-bbl/d leach rate per cavern, an efficient expansion configuration of 40 MMB at Bryan Mound and 30 MMB at West Hackberry would be obtained.

For management efficiency, cost effectiveness, and timely development, Phase II caverns at each site are now being developed in two sequential groups of six each at Bryan Mound and eight each at West Hackberry. All three potential Phase III caverns at West Hackberry could be developed simultaneously with Group II of the Phase II caverns within existing permit and hydraulic constraints. At Bryan Mound, given the permit modification from 680,000 to 980,000 bbl/d, up to four of the six potential Phase III caverns could be integrated with the Phase II leaching program. If the 680,000 bbl/d rate remains unchanged, integration of Phase III with Phase II leaching at Bryan Mound would require a proportional decrease in leaching rate in each cavern such that no net time saving would accrue relative to leaching Phases II and III in separate groups. Therefore, continuation of the 680,000-bbl/d rate would result in a 14-month delay in implementing Phase III compared with increasing the leach rate to 980,000 bbl/d.

2.2 DEVELOPMENT OF NEW STORAGE SITES

Based on the previous discussion, expansion of existing storage sites would produce an additional 70 MMB of storage capacity before 1989. Accomplishment of Phase III goals of 212 MMB of storage capacity and increased drawdown would require development of an additional 140 MMB of storage capacity. Numerous alternatives for creating this storage space were evaluated. The alternatives to Big Hill included evaluation of other Gulf Coast salt domes, offshore salt domes, inland salt domes, limestone and salt mines, surface tankage, surplus tankers, and storage to be provided by private industry on a turnkey basis.

Consideration of alternative new salt dome sites along the Gulf Coast was limited to salt domes previously considered in the Capline (Chacahoula, Iberia, and Napoleonville salt domes), Texoma (Big Hill, Black Bayou, and Vinton salt domes), and Seaway (Allen, Damon Mound, Nash, and West Columbia salt domes) FEISs. Development of more than one new site was discounted for Phase III development because of the ability to expand existing sites. All new sites, except for Big Hill, were rejected because of one or more of the following constraints: size (too small); adverse environmental impacts, especially in relation to potential acreage of wetland disturbance; prohibitive brine disposal pipeline costs; and unacceptable risk to SPR program objectives associated with reliance on underground injection of brine. In one case (at Allen dome), oil throughput capacity at the Seaway Terminal was a limiting factor in addition to the geotechnical determination of salt dome size and wetlands/floodplains problems.

Offshore dome development was rejected for Phase III because of the excessive time required for geotechnical and other technical and economic assessments (estimated to be 2 years) to establish feasibilities.

Development of inland domes was rejected because of the forced reliance upon underground injection of brine. There is no assurance, based on SPR experience with underground injection, that subsurface zones would accept the brine.

Storage of crude oil in three existing mines (Central Rock in Kentucky, Ironton in Ohio, and Kleer in Texas) was rejected because of the relatively small size of the mines, remoteness from a major oil distribution system, the capability of each to serve only one refinery, and high cost of pipeline construction to the individual refineries.

Storage of crude oil by private industry on a turnkey basis was rejected because of schedule constraints. This does not foreclose the development of sites selected for Phase III by the government through the use of a more limited turnkey approach.

2.3 NO ACTION

The no-action alternative was also evaluated. It would result in limiting SPR storage capacity to the 538 MMB available at the five current Phase I and II sites and associated tanks and pipelines. It would also be contrary to the Congressional mandate to expand the SPR capacity to 750 MMB as an intermediate step toward attaining the goal of a one-billion-barrel reserve. Failure to provide the mandated SPR capacity would directly impact the national capability to deal effectively with international oil supply issues.

2.4 DESCRIPTION OF THE PROPOSED ACTION

On the basis of the considerations presented above, the Big Hill site is proposed as the most practicable alternative available for developing a 140-MMB storage facility. The site, consisting of fourteen 10-MMB solution-mined caverns, would encompass about 250 acres. Major site facilities would consist of a raw water pond for fire protection; oil/brine separators; a lined brine pond for surge and settling of insolubles; blanket oil tanks; oil, brine, and water pumps; and a control house.

Development of a new SPR storage site would entail construction of a crude oil distribution pipeline to fill the caverns and for use in drawdown. The preferred pipeline route would go from Big Hill northeast to the Sun Terminal, a distance of 23 miles. This pipeline would increase the SPR's oil fill and drawdown capabilities by 280,000 and 935,000 bbl/d, respectively.

The proposed raw water intake structure would be located at an abandoned barge slip on the Gulf Intracoastal Waterway (ICW). A pipeline approximately 5.3 miles long would extend from the site southeasterly to the ICW along a route designed to avoid several freshwater marsh impoundments.

The proposed Big Hill brine pipeline would run approximately 12.7 miles southeasterly to a brine diffuser header located 3.5 miles offshore near the 30-ft depth contour. The brine pipeline would be laid adjacent to the raw water pipeline as far as the ICW. The 3.7-mile portion of the pipeline crossing the McFaddin National Wildlife Refuge would use existing pipeline rights-of-way (ROWs) where feasible. Modern mitigation techniques such as double ditching and revegetation could be applied to minimize impacts as needed.

Expansion of the Bryan Mound and West Hackberry sites would require minimal modifications to current facilities. At Bryan Mound all expansion would occur within existing DOE property. Expansion at West Hackberry could require the addition of between 4 and 34 acres. Fluid flow rates at West Hackberry would not be altered by the proposed action. At Bryan Mound, the proposed flow rates assume that the Phase II action will increase the leach rate from 680,000 to 980,000 bbl/d. One new oil brine separator is also planned for Phase II and III development at Bryan Mound. Expansion at these sites would not require alteration of existing raw water, brine, or crude oil pipelines.

2.5 ALTERNATIVES TO THE PROPOSED ACTION

No practicable alternative to the development of the 140-MMB Big Hill site is available if program schedules are to be met. Alternative crude oil pipelines to either the Oil Tanking of Texas, Inc., Terminal (OTTI) in Houston (60 miles) or the proposed Pelican Island Terminal (PIT) in Galveston (54 miles) could be constructed. These two pipelines are mutually exclusive, but either could be constructed in addition to or in lieu of the preferred line to Sun Terminal. At Big Hill, alternative brine disposal sites between 3.5 and 12.5 miles in the Gulf of Mexico were evaluated.

A 70-MMB Phase III expansion could be allocated differently between Bryan Mound and West Hackberry. Development of 60 MMB of storage at Bryan Mound and 10 MMB at West Hackberry, which would minimize the need to purchase additional lands at West Hackberry, would be possible. This action however, would preclude the advantage of complete integration of solution mining Phase III caverns with Phase II caverns at Bryan Mound, resulting in a 6-month delay in completion of Phase III site expansion compared with the preferred 40:30 alternative. The implications of continuing leaching at Bryan Mound at 680,000 bbl/d were assessed. Continued leaching at this rate would delay completion of Phase III site expansion by 14 months for the 40:30 case and 21 months for the 60:10 case and would increase program costs significantly.

2.6 IMPACTS OF THE PROPOSED ACTION AND REASONABLE ALTERNATIVES

The environmental impacts resulting from the Phase III expansion and development of the SPR are summarized below. Estimated nonmethane hydrocarbon (NMHC) emissions and predicted ozone levels during leach/fill for the proposed action and alternatives are based on worst-case assumptions for hydrocarbon dissolution rates and concentrations in brine within a cavern and corresponding emission rates. To date, there has been insufficient experience with leach/fill operations to verify the assumptions. DOE is now in the process of collecting field data at the existing SPR sites to evaluate the validity of the assumptions and model results. Appropriate mitigative measures would be taken to reduce emissions if necessary.

2.6.1 Big Hill Site

- Approximately 250 acres of prime farmland soils would be removed from potential agricultural production. Small mammals, birds, reptiles, and amphibians would be displaced or destroyed from this acreage. Increases in siltation from runoff into adjacent lands are anticipated. Approximately 1,400 cubic yards of sediment loss is expected to result from construction-related erosion. During construction and operation, insignificant spillage of brine, oil and grease, and toxic substances could occur.

- Air quality would deteriorate during construction and operations. The annual pollution emission rate of particulates would be less than 13,000 tons per year (tpy) during construction given standard construction practice. During leach/fill, NMHC emission rates could be as high as 163 tpy. At times these emissions could produce downwind concentrations of NMHC in excess of 160 $\mu g/m^3$ standard. In turn, under some meteorological conditions this could result in ozone concentrations in excess of the 0.12 parts-per-million (ppm) standard. During other operations, NMHC emissions would be substantially lower.

- Noise (sound pressure level) during construction and operation at 2,000 ft from the center of the site would be less than 55 dB(A).

- It is doubtful that any endangered species would be affected. The American alligator, which is threatened in the region, would be displaced into the surrounding area.

- All site facilities that could not withstand flooding would be above the 100-year floodplain elevation, and construction would not affect floodplains. The site is not in wetlands.

- The increase in traffic would be small. The demand for housing, schooling, and goods and services in surrounding towns would possibly increase.

2.6.2 Big Hill Pipeline Routes

- The crude oil distribution pipeline ROW to Sun Oil Terminal would traverse 18 miles of cropland/pasture, 2.5 miles of wetlands, 2 miles of developed land, and 0.5 mile of open water. Impacts of pipeline construction would be temporary, except for the permanent ROW (50 ft wide) on land, which would be kept cleared of woody vegetation.

- Air quality would be temporarily reduced during construction. After construction, each valve on the pipeline has been estimated to be capable of releasing NMHC at a rate of 0.108 pounds per day.

- About 145 acres of wetlands would be temporarily impacted by dredging and the resultant spoil deposition during construction of the raw water pipeline and the onshore portion of the brine disposal pipeline.

- Much of the proposed pipeline routes lies within floodplains. Construction would cause minimal impacts to drainage patterns. After backfilling, the pipeline corridors would not affect floodplains.

- o Although noise would be temporarily increased during construction, it would be negligible after the pipelines had been laid.

- o Dredging across water bodies would temporarily increase nutrient and biological oxygen demand load in the water column. Pollutants in the sediment, including low levels of PCBs, could be released into the water bodies.

- o Construction of the pipelines would temporarily force wildlife into surrounding areas. After construction, most inhabitants would return, except for those that depend on trees and shrubs that would be removed.

- o No endangered flora or fauna would be affected. The American alligator, a threatened species, would be temporarily displaced during the construction phase but would be expected to reenter the area after construction had been completed.

- o Traffic and usage of commodities in towns near construction areas would increase temporarily.

- o Construction of the 3.5-mile offshore portion of the brine disposal pipeline would result in the temporary suspension of sediments and destruction of sessile organisms in the path of the pipeline. Temporary spoil deposition adjacent to the pipe trench could snag or clog fishermen's nets, resulting in loss of fishing time and effort.

- o Brine disposal could cover an area of up to 2,600 acres with salinities in excess of 1 part per thousand (ppt) above ambient. Biological effects, if any, would be minimal.

2.6.3 Bryan Mound and West Hackberry Expansion

- o Expansion at Bryan Mound may destroy up to 5 to 10 acres of wetlands. This would result in a decrease in marsh vegetation and therefore an ensuing decrease in biological productivitiy. Few animals would be impacted because the four proposed 10-MMB caverns would be on existing DOE property and are subject to regular disturbance.

- o Expansion of Bryan Mound would occur within the 100-year floodplain elevation. Impacts to flood elevations by construction of wellpads and associated structures would be insignificant.

- o An increase in construction-related noise levels can be expected at each site during cavern construction, over and above normal operating noise levels.

- Air quality can be expected to deteriorate in proportion to the leaching of additional Phase III caverns. NMHC emissions during leach/fill could be as high as 121 tpy at Bryan Mound and 128 tpy at West Hackberry for the Phase III increment. At times these emissions could produce downwind concentrations of NMHC in excess of 160 $\mu g/m^3$ standard. In turn, under some meteorological conditions this could result in ozone concentrations in excess of the 0.12 parts-per-million (ppm) standard. During other operations, NMHC emissions would be substantially lower. Emissions from other operations would be substantially lower.

- No impacts are expected on any endangered or threatened species in the site areas.

- A minimal amount of pastureland (up to 34 acres of prime farmland) may be acquired for expansion at West Hackberry. Depending on specific cavern locations selected, up to 10 residences would be removed, resulting in displacement of up to 10 families.

- No wetlands would be affected by the proposed West Hackberry expansion, which is above the 100-year floodplain elevation.

- Expansion of either site should only negligibly increase demand on goods and services in the community.

2.7 IMPACTS OF ALTERNATIVE ACTIONS

One of the alternative actions available to the DOE is to change the number of new caverns developed at each of the existing sites. Six 10-MMB caverns could be developed at Bryan Mound and one 10-MMB cavern could be developed at West Hackberry to achieve 70-MMB capacity. Changes in impacts relative to the preferred 40:30-MMB expansion would be:

- Impacts to wetlands at Bryan Mound could be increased by half (i.e., by an additional 2 to 5 acres). There would be no offsetting wetlands avoidance at West Hackberry since none of the potential Phase III caverns are located in wetlands.

- Two more wellpads and associated structures would be located within the 100-year floodplain elevation.

- The integrated leach/fill plan would be altered, and the combined sites expansion time would increase by 6 months, significantly increasing program costs.

- Less than 4 acres of additional property would be required at West Hackberry, a possible savings of up to 30 acres.

During conceptual design studies, 2 alternative crude oil distribution routes were selected from 25 possibilities. Selection was based on the least damaging route (e.g., least wetland/open water acreage, avoidance of archaeological or historical sites, natural and scenic areas, biologically productive areas such as oyster reefs) and utilization of existing pipeline corridors to the greatest extent practicable. The two routes are a 60-mile pipeline route to OTTI in Deer Park, Texas, and a 54-mile pipeline route to the proposed PIT in Galveston, Texas. Impacts of these routes are:

- Both alternatives are longer than the route to Nederland, Texas. Big Hill to OTTI traverses 37 more miles, of which there is an increase of 24 miles of cropland, 0.5 mile of wetland, 11.5 miles of open water, and 3 miles of forested land. The route to PIT would be 31 miles longer, with additional impacts to 9 miles of cropland, 9.5 miles of wetlands, and 14.5 miles of open water. Impacts of pipeline construction would be temporary, except for the permanent ROW on land, which would be kept clear of woody vegetation.

An alternative Big Hill brine disposal pipeline route was evaluated to avoid crossing the McFaddin National Wildlife Refuge. This alternative route would cross the ICW at the same proposed point, but would follow the ICW to the southwest, then cross wetlands to the coast just west of McFaddin. Marsh of similar quality, which is valuable to fish and wildlife, would be involved, and the alternative route would disturb or destroy 23 more acres of wetlands than the direct route across the refuge. At the same time, the alternative route would increase other impacts, such as turbidity in water crossing areas, elimination of benthic habitat, and desorption of toxic chemicals, all in proportion to the difference in pipeline length.

Alternative brine diffuser sites more distant than the proposed site, 3.5 miles off shore, would involve proportionally greater destruction of sessile organisms in the dredged area. Additional associated construction impacts would be incurred, such as increased turbidity, increase in sediment settling, and a greater temporary hazard to commercial fishing as a result of the increased pipeline length. The practical limit for alternative sites is 12.5 miles off shore, beyond which additional concerns would include proximity to Heald and Sabine banks (choice benthic habitat harboring "hard bottom" fauna) and a higher ambient salinity ($\geq$33 ppt).

An alternative to the proposed Phase II 980,000-bbl/d leach rate at Bryan Mound is to maintain the current leach rate of 680,000 bbl/d. Impacts associated with this alternative include:

- Reduced NMHC emissions at Bryan Mound from an estimated 121 tpy to 86 tpy for leach/fill operations. These emissions could produce downwind concentrations in excess of the 160-$\mu g/m^3$ standard resulting in possible violations of the 0.12-ppm ozone standard.

- A delay of 14 months to complete the combined sites expansion for the 40:30 case and 21 months to complete the 60:10 case, with corresponding increases in program costs.

- A decrease in the average size of the brine plume at Bryan Mound from an estimated average of 1,800 acres to 1,250 acres (based on salinities of 1 ppt or greater over ambient now experienced at Bryan Mound).

2.8 IMPACTS OF THE NO-ACTION ALTERNATIVE

If the decision is made not to expand the SPR by implementation of Phase III, the following impacts would result:

- The SPR would be limited to 538 MMB storage capacity and would not provide the United States with sufficient petroleum reserves to adequately minimize the effects of a future oil supply interruption.

- "No action" would be in direct violation of the Energy Policy and Conservation Act of 1975.

- Environmentally, the no-action alternative would limit SPR construction and operation impacts to those associated with Phase I and II activities. Bryan Mound and West Hackberry would remain as discussed in the Texoma and Seaway Group FEISs. Big Hill would remain with private owners. Land use, air quality, socioeconomic, species and habitats, archaeological, historical and cultural resources, and natural and scenic resources would be undisturbed by the SPR program.

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1.0 BACKGROUND

1.1 PROGRAM HISTORY

The Strategic Petroleum Reserve (SPR) is a program now being implemented by the U.S. Department of Energy (DOE). Creation of the SPR was mandated by Congress in Title I, Part B, of the Energy Policy and Conservation Act of 1975, P.L. 94-163, for the purpose of providing the United States with sufficient petroleum reserves to minimize the effects of any future oil supply interruption. In this Act, the Congress declared the policy of the United States Government to provide for storing up to one billion barrels of crude oil and petroleum products.

The policies for implementing the SPR program were expressed in the SPR Plan that was approved by Congress and became effective on April 18, 1977. In accordance with this plan, 500 million barrels (MMB) of oil would be in storage by December 1982. The SPR Plan was revised by Amendment 1 in June 1977, Amendment 2 in June 1978, and Amendment 3 in November 1979. The SPR Plan, as amended and approved by Congress, now provides for accelerated development of the SPR, expansion of the SPR from 500 to 1,000 MMB, and an implementation plan for expanding the reserve from 500 to 750 MMB. The first 750 MMB of the SPR is to be developed in underground storage.

A programmatic Final Environmental Impact Statement (FEIS) (FEA, 1976a), addressing the effects of a 500-MMB SPR program, was filed with the Council on Environmental Quality (CEQ) and made available to the public on December 16, 1976. This statement considers several different types of storage facilities: the use of existing solution-mined cavities in salt formations and conventional mines, the construction of new solution-mined cavities and conventional mines, the use of existing and construction of new conventional surface tankage, and the use of surplus tanker ships. The programmatic FEIS should be consulted for a description of each of these storage methods and the potential impacts that might result from its use. The programmatic FEIS also assesses cumulative impacts that could be expected from using various combinations of the different facility types. A supplement to the programmatic FEIS, addressing expansion of the reserve to 1 billion barrels, was published in January 1979 (DOE, 1979).

A six-criteria[1] screening process was used to identify nine sites as candidates for the initial phase of the SPR program. Five of these alternative sites were considered as possible Early Storage Reserve (ESR) sites to supply oil to refineries on the Gulf Coast, on the East Coast, and in the Caribbean. They include the Bayou Choctaw salt dome (Iberville Parish, Louisiana), the Cote Blanche salt mine (St. Mary

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[1]These criteria are existing storage capacity (or potential storage capacity for SPR), distribution accessibility, technical feasibility, potential environmental concerns, ease of acquisition, and cost. Section II.E.I of the programmatic FEIS describes in detail how the criteria were applied to about 300 salt domes and about 300 existing mines to select 32 candidate sites, including the nine candidate SPR sites.

Parish, Louisiana), the Weeks Island salt mine (Iberia Parish, Louisiana), the West Hackberry salt dome (Cameron Parish, Louisiana), and the Bryan Mound salt dome (Brazoria County, Texas).

FEISs on all five candidate sites (FEA, 1976b, 1977a, b, c, d) have been filed with the CEQ and have been made available to the public so that environmental impacts associated with possible use of these sites can be compared with one another. In addition, four final supplements (April, May, August, and December 1977) addressing design changes for all five candidate sites have been filed with CEQ. A sixth Gulf Coast site, the Sulphur Mines salt dome (Calcasieu Parish, Louisiana), was identified as a candidate site to provide additional existing storage capacity needed for the requirements of the accelerated storage schedule. The FEIS for Sulphur Mines was made available to the Environmental Protection Agency (EPA) in April 1978 (DOE, 1978a). Three other candidate sites, Central Rock Mine (Fayette County, Kentucky), Ironton Mine (Lawrence County, Ohio), and Kleer Mine (Van Zandt County, Texas), were considered. FEISs on these sites are also available (FEA, 1977e, f, g). To date, five storage sites (West Hackberry, Bayou Choctaw, Bryan Mound, Weeks Island, and Sulphur Mines) have been selected for use in the SPR.

To complete the 500-MMB program, three groups of candidate salt dome sites were considered as possible SPR storage sites. Most of the candidate sites are centered around three major interstate pipelines and their supporting terminals, which transport U.S. and foreign crude oil from the Gulf Coast region to the upper Midwest area refineries. Distribution centers include the Seaway Pipeline and Seaway Terminal (Freeport, Texas), the Texoma Pipeline and SUNOCO Terminal (Nederland, Texas), and the Capline Pipeline and Capline Terminal (St. James, Louisiana) (see Fig. 1-1).

The candidate sites of each group of salt domes would use the particular pipelines and terminals associated with that group for strategic distribution of SPR oil. A portion of the stored oil would be distributed through the pipeline to upper Midwest markets while the remainder would be distributed to local refineries and loaded onto tankers at the terminals for distribution to the East Coast and Caribbean refineries.

FEISs addressing the impacts of storing oil in the Seaway, Capline, and Texoma Groups of salt domes have been made available to the public. These documents are hereafter referred to as the Seaway Group FEIS (DOE, 1978b), the Capline Group FEIS (DOE, 1978d), and the Texoma Group FEIS (DOE, 1978e). Each of these groups includes one or more sites at which work is now underway to put oil in storage. This document supplements the FEISs for the Texoma Group and the Seaway Group of salt domes and has been prepared to address impacts that would be incurred because of an increase of 212 MMB in the quantity of oil stored in salt domes of these groups.

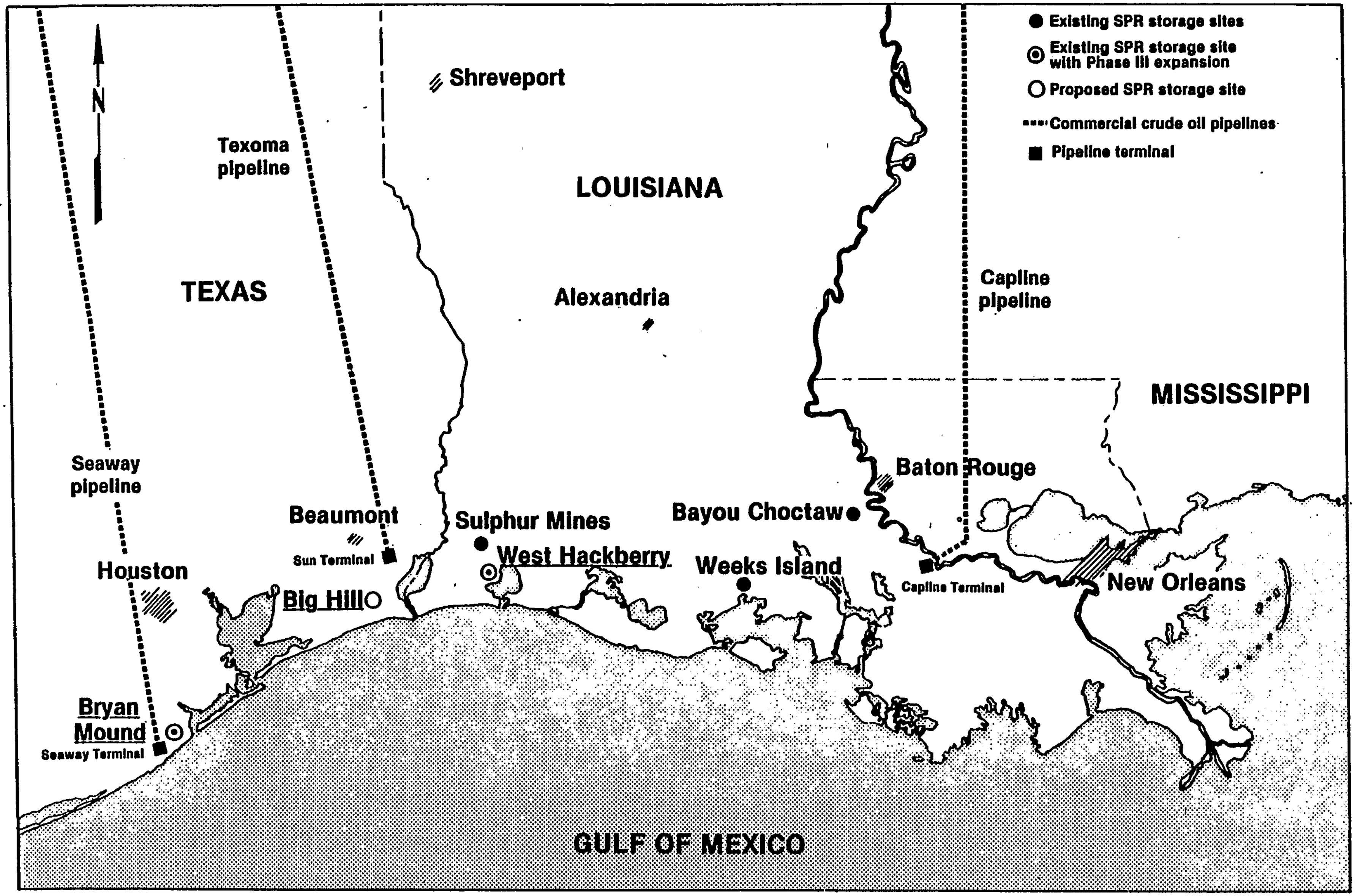


Figure 1-1. Existing and proposed SPR storage sites.

1.2 PROGRAM SCHEDULE REQUIREMENTS

The SPR program was formatted in January 1979 into four major phases. The development of the existing storage capacity at the five selected sites and one marine terminal, with total storage capacity of 248 MMB, was termed Phase I. Phase II is the current 290-MMB expansion of the Bryan Mound, West Hackberry, and Bayou Choctaw sites. Development and implementation of Phase III, addressed in this document, will increase the SPR storage capacity from 538 to 750 MMB. Decisions regarding the timing and method of achieving Phase IV, which would expand the reserve up to one billion barrels, have not been made.

The SPR program development schedule has been a major governmental policy issue. Considerable concern has been expressed by the Congress, the Executive Branch, and the private sector about the need to have protection as soon as possible against petroleum supply interruptions. The SPR Plan Amendment No. 2 expanded the reserve size to one billion barrels and contained plans for storing 750 MMB by the end of 1985 (DOE, 1978c). In November 1978, DOE solicited offers from private industries for the turnkey development of new sites on the basis that this approach might offer the earliest possible availability of storage capacity. The 1980 fiscal year (FY) budget, published in January 1979, projected completion of the 750-MMB system in 1986 (a one-year delay from the estimates in SPR Plan Amendment No. 2). However, in March 1979, oil purchases for the SPR were suspended because of tight world oil market conditions as a result of reduced Iranian production. The turnkey procurement was cancelled in August 1979 because changes in the world crude oil market made the oil-fill schedule and other assumptions of the turnkey effort less certain, and because the turnkey procurement did not offer any apparent advantages to offset the disadvantages of such an approach.

Widespread agreement about the urgency of developing the reserve as soon as practicable is evident:

- U.S. Congressional Budget Office (1980)

  > . . . the political stability of several key (oil) producing countries is increasingly uncertain, so that one or more oil supply interruptions in the next 20 years appear probable. The low cost of the oil reserve relative to the economic losses it could avert make the reserve a highly cost-effective Federal program for protecting against the risks of growing dependence on imported oil. Indeed, it is the only program that could offset the short-term economic effects of oil supply interruptions.
  >
  > The program's large benefits relative to costs, as well as [decreasing] U.S. dependence on imported oil, seem to bolster the arguments for acquiring the oil as rapidly as possible, subject to the constraints imposed by the Federal budget and the international oil market.

- U.S. Department of Energy (1980)

  Despite encouraging signs of reduced energy consumption and increased activity relating to energy production . . . the United States and other consuming nations are vulnerable to serious damage as the result of disruptions in the flow of imported oil and this vulnerability will continue through the 1980's.

  Stockpiles can add ready reserves to U.S. and world supplies during a disruption. They forestall panic and reduce the uncertainty that leads to inefficient purchasing, hoarding, and the invitation to price gouging. They might buy time for diplomatic and military planning during the early stages of a disruption. In fact, their very existence could deter or blunt the effectiveness of disruption threats. In principle, stategic stockpiles should be built-up rapidly in slack markets and drawn down rapidly during disruptions.

- U.S. Senate Committee on Energy and Natural Resources (1980)

  Recommendation 1 - The United States should build a 'domestic petroleum reserve' by filling the Strategic Petroleum Reserve as rapidly as possible and by encouraging private stockpiling of petroleum and petroleum products.

  Ample emergency oil stockpiles are the single most reliable and cost-effective means of deterring oil import interruptions and reducing this impact.

- Harvard Energy and Security Research Project (Alm et al., 1980)

  If the United States does not seize the initiative quickly by developing new storage capacity and filling the strategic reserve at a meaningful rate of at least 300,000 barrels per day, then we are likely to wonder after the next interruption why the United States was so blind to its own national security interests. Any potential discomfort that might be experienced now would seem small compared to the ordeal of a future large supply interruption with no protection.

- Federation of American Scientists (1980)

  We urge the Administration in general . . . to accelerate work on the next phase of storage space.

> . . . Rarely have so many portents of future disaster been so widely ignored in preparedness; the Strategic Petroleum Reserve is becoming a test of American common sense.

- National Petroleum Council (1981)

> The rapid development of the SPR is clearly in the national interest. With a firm commitment by the Federal Government and legislative action to reinforce this commitment, acceleration of the SPR program can be accomplished and the nation's vulnerability to a supply disruption reduced.

In 1980 Congress reaffirmed its commitment to fill the SPR. In the Energy Security Act of 1980, Congress mandated the resumption of SPR fill at a minimum rate of 100,000 barrels per day (bbl/d), beginning in FY 1981. SPR fill was resumed in September 1980 through an exchange of Naval Petroleum Reserve crude oil for oil delivered to the SPR. In taking final action on FY 1981 appropriations for the SPR in P.L. 96-514, Congress added the following provision:

> Provided, That the President shall immediately seek to undertake, and thereafter continue, crude oil acquisition, transportation, and injection activities at a level sufficient to assure that crude oil storage in the Strategic Petroleum Reserve will be increased to an average annual rate of at least 300,000 barrels per day or a sustained average annual daily rate of fill which would fully utilize appropriated funds: Provided further, That the requirement of the preceding provision shall be in addition to the provisions of Title VIII of the Energy Security Act and shall not affect such provisions of the Energy Security Act in any way.

The DOE is complying with this requirement through additional open market purchases.

Secretary of Energy, James B. Edwards, in testifying before the Committee on Energy and National Resources of the United States Senate on February 23, 1981, summarized the Executive Branch position on the SPR development timetable as follows:

> The Administration is committed to an effective Strategic Petroleum Reserve program. The Reagan budget will provide for development of 750 million barrels of government-owned storage by 1989, in a secure and reliable system capable of crude oil withdrawal of up to 4.5 million barrels per day.
>
> The Administration is taking an aggressive attitude toward filling the SPR as quickly as practicable. To accomplish this, the Administration will submit a FY 1981

supplemental request to offset the loss of entitlements under deregulation. Further, we are actively reviewing approaches which will accelerate the availability of storage capacity for the balance of the Reserve.

Fig. 1-2 shows the current SPR oil fill capability goals, as stated by the Secretary of Energy, in relation to the goals of SPR Plan Amendment 2 of June 1978. To achieve these fill goals, it is necessary that development of Phase III be integrated with Phase II. Therefore, the approved DOE plan for implementing Phase III calls for Phase III construction to begin in summer 1982 and leaching of the 212-MMB storage space to be completed by the end of 1988 in order to complete oil fill by October 1989. As is seen in Fig. 1-3, Phase I development would be complete before commencement of Phase III leaching operations. Leaching would be concurrent for Phases II and III for about 4 years, mid-1983 through spring 1987. Oil fill would be concurrent for Phases II and III for a period of less than 3 years, from mid-1984 through 1987. Failure to achieve these goals could have a serious adverse impact on the protection available to the United States against oil supply interruptions.

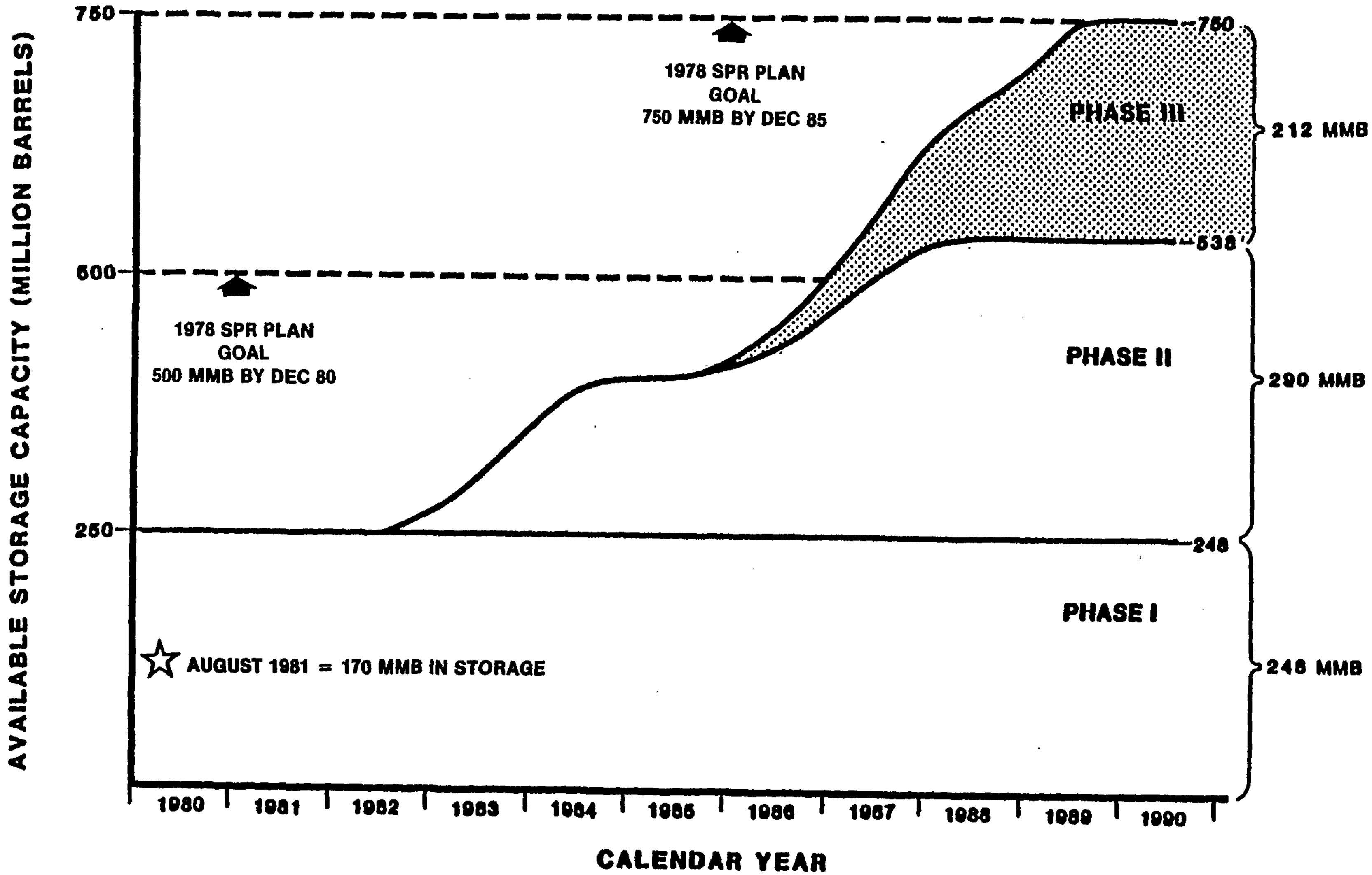
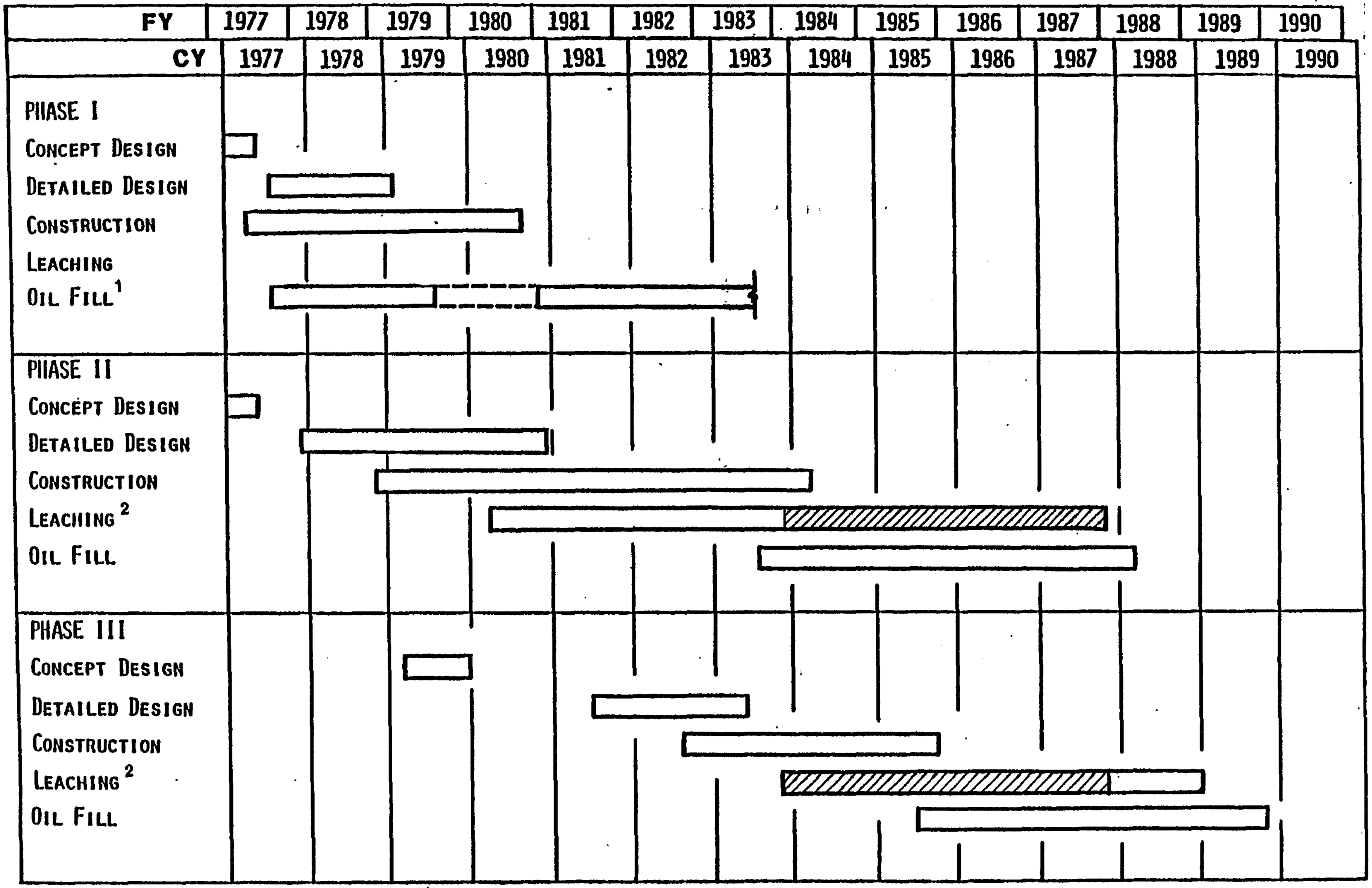


Figure 1-2. Cumulative oil fill capability goals.



[1] Start of oil fill is based on initial oil fill capacity; completion dates for Phase I & II oil fill are contingent upon allocation of fill between phases, available funding, and acquisition rates.

[2] Reflects accelerated leach rate of 980,000 bbl/d at Bryan Mound.

(hatched) Phase II/III integrated leach/fill.

Figure 1-3. Integrated milestone schedule, Phases I, II, & III.

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2.0 DESCRIPTION OF PROPOSED ACTION

2.1 PROPOSED ACTION

The proposed Phase III plan is to increase the Strategic Petroleum Reserve (SPR) crude oil storage capacity to 750 million barrels (MMB) by the addition of about 212 MMB and to increase the average SPR drawdown rate by about 1 MMB per day (MMB/d) from 3.5 to 4.5 MMB/d. Table 2-1 shows the storage capacities at the five current SPR sites and the proposed Phase III capacity to be added. The locations of proposed SPR Phase III storage and expansion sites are shown in Fig. 2-1.

Table 2-1. Current and proposed storage capacity at SPR sites (in MMB)

Storage site[1]	Phase I	Phase II	Phase III[2]	Total
Bayou Choctaw	36	10		46
Weeks Island	75			75
West Hackberry	51	160	30	241
Sulphur Mines	22			22
Bryan Mound	60	120	40	220
Big Hill			140	140
Tanks & pipelines	4	0	2	6
Total	248	290	212	750

[1]Existing and proposed.

[2]Preferred alternative.

The subsequent environmental analysis of the proposed action is based on the Final Environmental Impact Statements (FEISs) for the Seaway (Bryan Mound) and Texoma (West Hackberry and Big Hill) Groups of salt domes and includes recognition of the fact that the Phase II expansions described in the FEISs are being constructed (current Phase II expansions at Bryan Mound and West Hackberry). Overall effects on these groups, as well as site-specific effects, are evaluated.

2.2 PREFERRED ALTERNATIVE

The preferred means of achieving the 212-MMB SPR Phase III requirement is to construct storage facilities for 140 MMB at the Big Hill site and to expand facilities at Bryan Mound by 40 MMB and at West Hackberry by 30 MMB. There would also be 2 MMB in associated pipes and storage tanks. Development of the Big Hill site would include a 23-mile oil pipeline to the Sun Terminal at Nederland, Texas, and a brine disposal

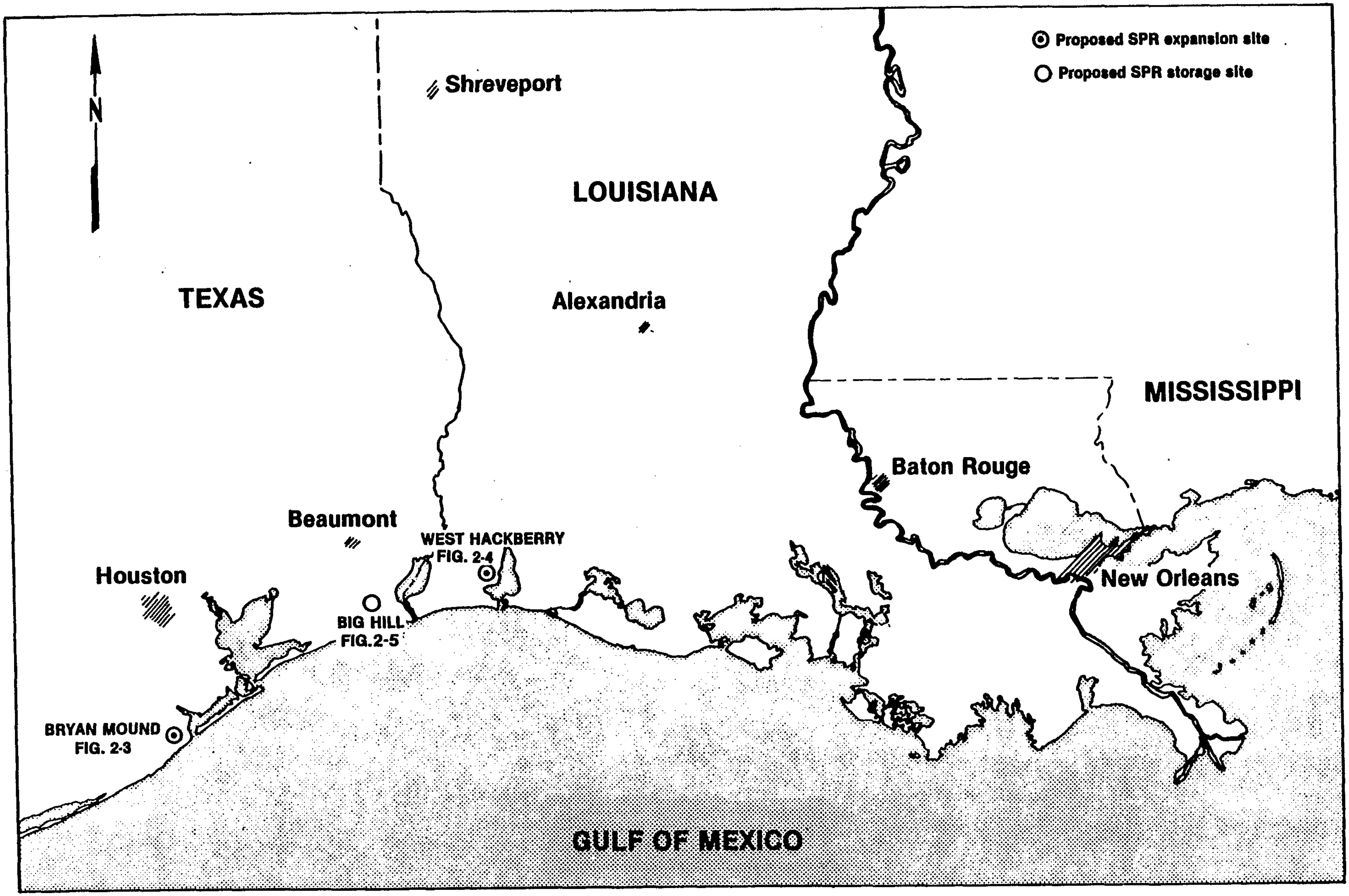


FIGURE 2-1. Proposed SPR Phase III sites.

line extending to a diffuser 3.5 miles off shore in the Gulf of Mexico. At Bryan Mound, an increase in the brine disposal rate from 680,000 to 980,000 barrels per day (bbl/d) average has recently been permitted by the Environmental Protection Agency (EPA) for Phase II leaching activities by using the existing brine pipeline to the Gulf of Mexico.

In its submission to the EPA requesting a permitted brine disposal increase rate from 680,000 bbl/d to 1.1 MMB/d at Bryan Mound, the Department of Energy (DOE) prepared and submitted supporting documentation to EPA taken from the environmental data and analysis summarized in Section 4.2.5.2. The analysis presented in this supplement is based on the 980,000-bbl/d preferred rate, which represents a reasonable worst-case analysis of the environmental impacts of this expansion.

2.2.1 Oil Storage Configuration: Big Hill (140 MMB), Bryan Mound (40 MMB), West Hackberry (30 MMB)

2.2.1.1 Expansion of Bryan Mound (40 MMB) and West Hackberry (30 MMB)

For Phase III, first consideration was given to expanding the existing SPR sites beyond Phase II. In addition to the potential advantage of timely development, Phase III expansion of existing sites offers the economic advantage of cost savings through use of major onsite and offsite facilities previously constructed for Phase I and II (e.g., control facilities, centralized pumping facilities, crude oil distribution pipelines, raw water intake systems, and brine disposal systems). The only new onsite facilities required would be the new caverns and their crude oil, raw water, and brine disposal system connections to the central pumping and control areas.

Preliminary consideration determined that additional expansion of three SPR sites (Bayou Choctaw, Sulphur Mines, and Weeks Island) is not practicable for reasons discussed in Sect. 2.3.1.2. Subsequently, four criteria were established to determine options for Phase III expansion of Bryan Mound and West Hackberry:

- Locating additional caverns, preferably within present property, or with limited additional land acquisition.
- Maintaining total site brine disposal within the hydraulic capacity of the existing brine disposal pipelines to the Gulf of Mexico.
- Maintaining effective nominal leaching rates of 100,000 bbl/d per cavern.
- Developing caverns and sites in the most timely and cost-effective manner; maximum oil fill by the end of 1986.

In accordance with the first criterion, there is sufficient land within the existing Bryan Mound property to accommodate six Phase III caverns of 10 MMB each. At West Hackberry, less than 4 acres of additional property would be required to accommodate one; a total of three new caverns could be accommodated with the acquisition of up to 34 acres, depending on the configuration selected. Based on the first criterion, therefore, expansion of the two sites by a combined 90 MMB is feasible.

For management efficiency, cost effectiveness, and timely development, Phase II caverns at each site are being developed in two sequential groups of six each at Bryan Mound and eight each at West Hackberry.

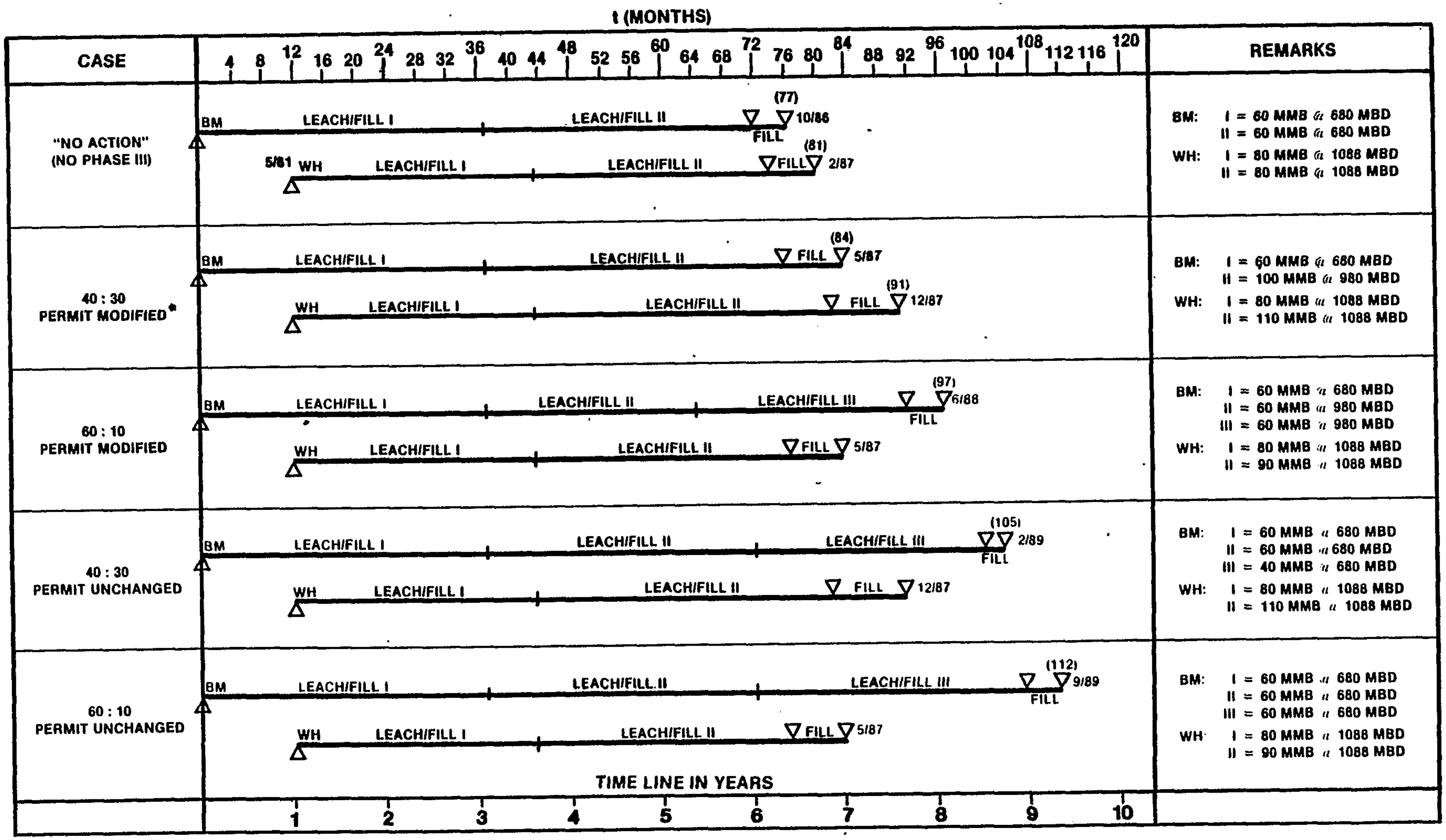
The concept of integrating Phase III cavern leaching with Phase II evolved from an application of the second, third, and fourth criteria. The hydraulic capacity of the existing brine disposal pipeline to the Gulf of Mexico at West Hackberry is 1,088,000 bbl/d, the planned leaching rate for Phase II at this site. At Bryan Mound, the hydraulic capacity of the brine disposal pipeline is 1.1 MMB/d maximum (980,000 bbl/d sustainable average), although the leaching rate for Phase II was limited until recently by permit to 680,000 bbl/d. Brine disposal and leaching rates could be increased to 980,000 bbl/d at Bryan Mound by installing additional pumps on the brine disposal pipeline. Application of criterion three (i.e., a leaching rate of 100,000 bbl/d per cavern) would allow leaching of eleven caverns at West Hackberry and ten caverns at Bryan Mound to be undertaken simultaneously. Therefore, given the modification to the Bryan Mound permit to allow an average leaching rate of 980,000 bbl/d, it would be possible to integrate up to four of the six potential Phase III expansion caverns at Bryan Mound with the second group of six caverns of the Phase II leaching program; a maximum of three Phase III expansion caverns at West Hackberry could be integrated into the second group of eight caverns of the Phase II leaching program within existing permit and hydraulic constraints. Thus, based on land acquisition and leaching considerations, the most efficient configuration for Phase III expansion of existing sites is to expand Bryan Mound by 40 MMB and West Hackberry by 30 MMB. This is termed the 40:30 alternative.

Integrating Phase III caverns at Bryan Mound with the Phase II leaching program is predicated upon increasing leaching from 680,000 to 980,000 bbl/d. Continuation of the 680,000-bbl/d leaching rate at Bryan Mound would result in any Phase III expansion being done as a separate, third leaching group. Although it would be possible to integrate Phase III and II for the 680,000-bbl/d leach rate case by reducing brine production from each cavern proportionally, this would not be done because each cavern would develop at a proportionally slower rate, and no time saving would be realized. Complexity of management would increase substantially, and use of the system would be inefficient.

As was described above, the existing SPR property boundary at Bryan Mound would accommodate six additional 10-MMB caverns. Acquisition of less than 4 acres would accommodate one additional 10-MMB cavern at West Hackberry. Thus, based on land acquisition considerations alone, an alternative configuration for Phase III expansion at existing sites is to expand Bryan Mound by 60 MMB and West Hackberry by 10 MMB. The main disadvantage of this alternative, however, is that a separate, third leaching group at Bryan Mound would result, whether or not the leaching rate is increased. That is, the 60:10 alternative would preclude integrating leaching Phase III with Phase II caverns at Bryan Mound, with or without a permit modification, for reasons similar to the case of the 40:30 alternative without permit modification described above. Integration would require proportionally lower brine production from each cavern and result in no net time saving, while increasing complexity and lowering efficiency.

A schematic comparison of development schedules for the 40:30 and 60:10 alternative, with and without an increase in leaching rate at Bryan Mound, is shown in Fig. 2-2. These are compared with the present development schedule for Phase II expansion at the respective sites, which represents the "no action" case. The schematic takes into account the fact that leaching effectively began at West Hackberry 12 months after Bryan Mound. In all cases, development of the first group of caverns is the same. For visual clarity, final fill of this group (Group I), which occurs concurrently with the start of leaching of the second group, is not shown in the figure. Final fill, after completion of leach/fill of the second group of caverns, will require 5 months at Bryan Mound and 7 months at West Hackberry. (For a discussion of the leaching, leach/fill, and final fill stages of cavern development, see Appendix C.2.) The leach rate and total storage volume for each group of caverns for each site is listed by alternative under the "Remarks" column of Fig. 2-2. (Cavern groups are indicated by Roman numerals.) As currently authorized, Phase II of the SPR will be complete upon completion of final fill of the second cavern group at West Hackberry in February 1987, 4 months after Bryan Mound has been completely filled.

The advantage of increasing the Bryan Mound leach rate, and thereby integrating Phase III with Phase II, is evident in comparing the schedules for the 40:30 alternative, permit modified versus permit unchanged (Fig. 2-2). West Hackberry is unaffected and is completed in either case in two groups, first with 80 MMB and second with 110 MMB in December 1987. At Bryan Mound, permit modification allows development in a group of 60 MMB, followed by a group of 100 MMB (the increase in leach rate is assumed to begin with commencement of leaching the second group, as indicated under "Remarks" in Fig. 2-2). However, if leaching continues at Bryan Mound at 680,000 bbl/d, Phase II and III development would occur consecutively in groups of 60, 60, and 40 MMB, and development of the last 100 MMB would require 21 months more than for the increased leach rate, integrated case. This would represent a 45 percent increase in time to develop the last 100 MMB at Bryan Mound, from 47 to 68 months. Expressed another way, accelerated, integrated leaching at Bryan Mound for the 40:30 alternative would result in the availability of 40 MMB of storage space 21 months earlier than with a leaching rate of 680,000 bbl/d. This is critical either for the case of



* PERMIT REFERS TO LEACHING RATE AT BRYAN MOUND

Figure 2-2. Comparison of efficiency between integrated and separate Phase II and III leaching programs.

short-term excess supply in the world oil market resulting in temporarily stable or lower prices or for the case of excess demand resulting in rapid price escalation. Taking West Hackberry into account, the net delay to implementation of Phase III would be 14 months, from December 1987 to February 1989.

For the case of the 60:10 alternative with Bryan Mound permit modification, three cavern groups of 60 MMB each would result at Bryan Mound (Fig. 2-2) as discussed earlier. Group I will be completed in 37 months; with an increase in leach rate at the start of Group II, Groups II and III each would require an additional 27.5 months for leaching and leach/fill, followed by 5 months for final fill of Group II, for a total Phase II and Phase III development time of 97 months. By reducing the number of West Hackberry Phase III expansion caverns from three to one, West Hackberry would be completed 7 months sooner for the 60:10 alternative than for the 40:30 alternative. Overall, however, for the 60:10 alternative, implementation of Phase III expansion would be delayed by 6 months relative to the 40:30 alternative because of the time extension to complete a larger Bryan Mound facility.

If the Bryan Mound discharge rate is unchanged, Groups II and II of the 60:10 alternative would take 32 percent longer to leach (37 months versus 28 months each) and would result in a 21-month delay relative to the 40:30 alternative overall in implementing Phase III expansion.

In conclusion, with or without Bryan Mound permit modification, the 40:30 alternative would result in more timely implementation of Phase III expansion than the 60:10 alternative and is, therefore, preferred. For the 40:30 alternative, integration of Phase III leaching with Phase II occurs only with an increase in the leach rate from 680,000 bbl/d to 980,000 bbl/d.

The preferred schedule for leaching Group II of Phase II and Phase III (Fig. 2-2) is based on the recently permitted increased maximum disposal rate at Bryan Mound of 680,000 bbl/d to 1.1 MMB/d. Concurrently, with the increased brine disposal rate permitted by EPA, DOE has applied to the Texas Department of Water Resources (TDWR) for an amendment to its current permit to appropriate state water from the Brazos River. Based on application No. 3987A, DOE is seeking an amendment to Permit No. 3681, pursuant to Sect. 11.122, Texas Water Code, and TWDB Rules 156.04.10.001-.002 to increase the total amount of state water authorized for leaching and displacement from 204,400 to 367,000 acre-feet. The schedule assumes operations at West Hackberry within existing permits.

In support of the applications for amended Bryan Mound permits, an evaluation of data of existing leaching and brine disposal operations was prepared by the National Oceanic and Atmospheric Administration (NOAA, 1981) and submitted to EPA pursuant to 40 CFR Part 125.122 (Federal Register, October 3, 1980) under Ocean Discharge Criteria, Section 403 (C) of the Clean Water Act. The existing permit is based on judgments of *a priori* assumptions, one of which was that impacts to the biota would be significant within the zone where salinity would be increased above ambient by 3 parts per thousand (ppt) or more. Preliminary analysis of intensive monitoring data indicates no detectable impacts to date, even within salinity zones of 3 ppt or more above ambient surrounding the diffuser area (see Sect. 4.2.5.2). If the amendment to the permit were granted, the brine plume would increase incrementally from an estimated 1,250 to 1,800 acres. The quality of the discharged brine will not change. Diffuser port exit velocities would remain within permit levels, discharge water quality criteria would not be exceeded, and biological impacts, if any, are expected to be within existing permit requirements. Therefore, increasing the average leach rate to 980,000 bbl/d at Bryan Mound should have no significant adverse impacts to the marine environment. Design modifications to the brine diffuser, other than opening all 56 diffuser ports, are not necessary. The increased raw water requirements are within the existing capacity of the raw water intake structure on the Brazos River, and no significant impacts on aquatic biota should result.

At Bryan Mound, an additional oil/brine separator of 300,000-bbl/d capacity would be constructed. An oil-in-brine model study (Appendix C.2) indicates that air quality degradation could exceed the standard for a major source, >100 tons per year (tpy), only during the leach/fill period of construction. Estimated hydrocarbon emission rates of 121 tpy could be expected at Bryan Mound during leach/fill. Worst-case estimated hydrocarbon emissions at West Hackberry and Big Hill could be 127 and 163 tpy, respectively.

The risk of brine spill occurrence would be slightly lower with an increase in flow rate to 980,000 bbl/d average, since risk estimates are based on pipeline size and duration of operation (increased flow = decreased duration). The amount of brine spilled could increase slightly.

Phase III expansion of Bryan Mound and West Hackberry would not change the sites' Phase II oil fill rates (180,000 and 175,000 bbl/d, respectively) or Phase II oil drawdown capability (1,054,000 bbl/d and 1.4 MMB/d, respectively). However, the duration of these operations would increase in relation to the additional storage volume created at each site, and consequently, oil spill risk would increase slightly.

The description of the Phase II expansion of Bryan Mound in the Seaway Group FEIS envisioned a 100-MMB expansion of the 63-MMB Phase I site. The current conceptual layout of the expanded Phase III site, with a total capacity of 220 MMB (60 MMB, Phase I; 120 MMB, Phase II; 40 MMB, Phase III), is shown in Fig. 2-3. This drawing includes six candidate expansion caverns (Nos. 113 to 118), located across the southern portion of the site, inside the present boundary. Caverns 113 through 116 would be developed for this 40-MMB expansion. Selection of cavern locations was based on geotechnical and environmental considerations, physical features, and proximity to existing SPR wells and equipment. Ongoing design evaluations could alter the exact locations of the well pads within the site.

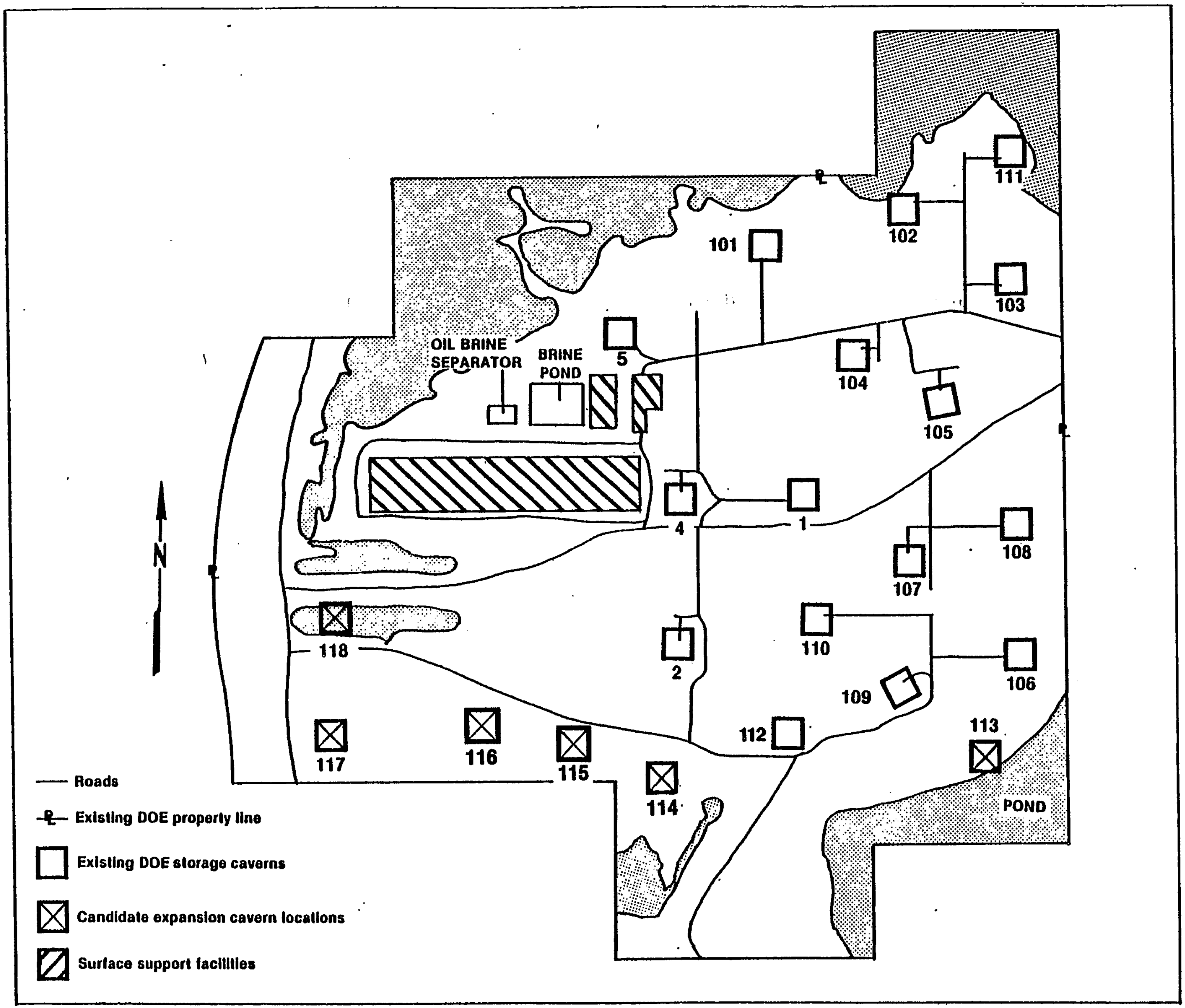


Figure 2-3. Bryan Mound storage site - proposed expansion.

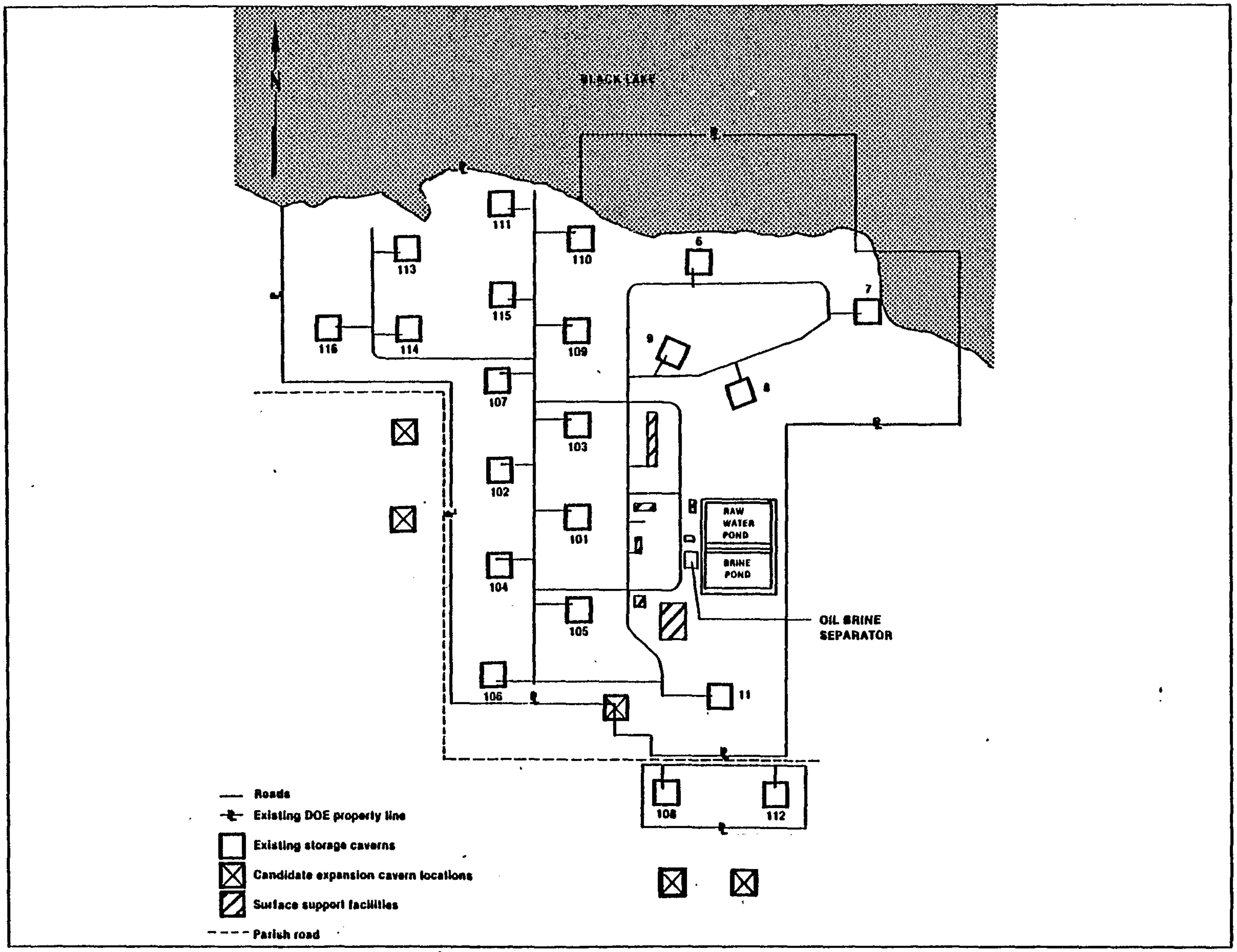


Figure 2-4. West Hackberry storage site - proposed expansion.

The description of the Phase II expansion of West Hackberry in the Texoma Group FEIS envisioned a 150-MMB expansion of the 60-MMB Phase I site. The candidate cavern locations of the expanded Phase III site, with a total capacity of 241 MMB (51 MMB, Phase I; 160 MMB, Phase II; 30 MMB, Phase III), are shown in Fig. 2-4. This drawing includes 5 candidate expansion cavern locations. As with the Bryan Mound site, cavern locations were determined through geotechnical and environmental considerations, physical features, and proximity to existing SPR wells and equipment. Detailed design studies could require modifications to the conceptual layout.

Additional land would be required at West Hackberry. Several alternative configurations are under consideration. Additional land requirements range from 4 to 34 acres, depending on the configuration selected.

2.2.1.2 New Site at Big Hill (140 MMB)

The preceding section presented the considerations involved in the conclusion that the practicable limit for expanding existing SPR sites, consistent with the timing objectives of Phase III, is 70 MMB. To accomplish the Phase III goals of increasing oil storage capacity by 212 MMB and increasing SPR drawdown capability by about 1 MMB/d requires, in addition to the 70-MMB expansion, the development of a new site with 140-MMB capacity.

Construction and operation of a 100-MMB site at Big Hill was evaluated in the Texoma Group FEIS as an alternative to the current Phase II expansion of West Hackberry. A subsequent conceptual design has expanded the site's proposed capacity to 140 MMB, while requiring slightly less surface area by altering parameters of cavern dimensions and configuration. These are shown in Table 2-2, which also compares other aspects of increased raw water and brine flow rates of the current proposed design to the design evaluated in the Texoma Group FEIS.

Also shown in Table 2-2 is a potential reduction in the size of the brine pond (from 120,000 bbl to possibly only 50,000 bbl) in the conceptual design compared with the Texoma Group FEIS. A final sizing of the brine pond would be determined during detailed design. If the brine pond capacity were 50,000 bbl and if leaching were increased from 687,000 bbl/d to 1.4 MMB/d, the brine residence time in the pond would be reduced by 80 percent from 4.3 to 0.86 h. An underground brine disposal well system, which would require additional settling time for suspended particulates in the pond, is not being used. Consequently, the reduction of brine residence time in the pond would not affect hydrocarbon emissions because evaporation of hydrocarbons dissolved in the brine occurs rapidly in the oil/brine separators.

The current proposed site layout is shown in Fig. 2-5. The precise location of the layout on the dome will be determined by ongoing geotechnical investigations and real estate factors. Recent investigations indicate a possible overhang in the southern extremity of the dome. More detailed investigations may validate the requirement for a more central location. This decision would cause no significant variation in environmental aspects of site construction and operation.

Table 2-2. Big Hill storage site characteristics

Item	Texoma Group FEIS	Conceptual design
Cavern		
Capacity	100 MMB	140 MMB
Number	8 @ 10 MMB 4 @ 5 MMB	14 @ 10 MMB
Height	1,000 ft	2,000 ft
Spacing	800 ft on center	750 ft on center
Land area	230 acres, 10 acres for facilities	~250 acres, 18 acres for facilities
Roads on site	1.5 miles	2.7 miles
Injection pumps		
Oil	4 @ 700 HP[1]	6 @ 1,750 HP
Raw water	10 @ 1,150 HP	12 @ 1,750 HP
Raw water system		
Pipeline to ICW	36-in. diameter	46-in. diameter
Permanent easement	31 acres	31 acres
Pumps at intake	4 @ 700 HP	8 @ 1,500 HP 2 @ 200 HP
Water intake velocity	0.5 ft/s	0.5 ft/s
Fish protection system	Not described	Fine mesh traveling screen
Raw water treatment	Not described	Chlorine injection
Raw water pond and tank	120,000-bbl pond 3,000-bbl tank	26,000-bbl pond for fire protection
Operations data		
Rate during leaching	687,000 bbl/d	1.4 MMB/d
Rate during drawdown	700,000 bbl/d	935,000 bbl/d

Table 2-2. (continued)

Item	Texoma Group FEIS	Conceptual design
Duration of leaching	38 months	39 months
Total volume for leaching	782 MMB	1,200 MMB
Brine disposal system		
Pipeline	36-in. diameter	42-in. diameter
Lined brine pond	120,000 bbl	50,000 - 120,000 bbl
Pumps	6 @ 500 HP	8 @ 1,500 HP
Permanent easement	55 acres	55 acres
Oil brine separator	15 mg/L (max) 10 mg/L (av)	15 mg/L (max) 10 mg/L (av)
Operations data		
Rate during leaching	672,000 bbl/d	1.4 MMB/d
Rate during refill	117,000 bbl/d	280,000 bbl/d
Oil distribution		
Pipeline	27 miles, 42-in. diameter	23 miles, 36-in. diameter
Tankage		
Surge	20,000 bbl	None
Blanket oil	3,000 bbl	10,000 bbl
Slop oil	None	1 @ 3,000 gal 1 @ 6,000 gal
Permanent easement	144 acres	142 acres
Operation data		
Rate during drawdown	667,000 bbl/d	935,000 bbl/d
Rate during fill/refill	117,000 bbl/d	140,000 to 280,000 bbl/d

Table 2-2. (continued)

Item	Texoma Group FEIS	Conceptual design
Roads offsite		
Fee	Not described	2 miles
Easement	Not described	5.7 miles

[1]HP = Horsepower.

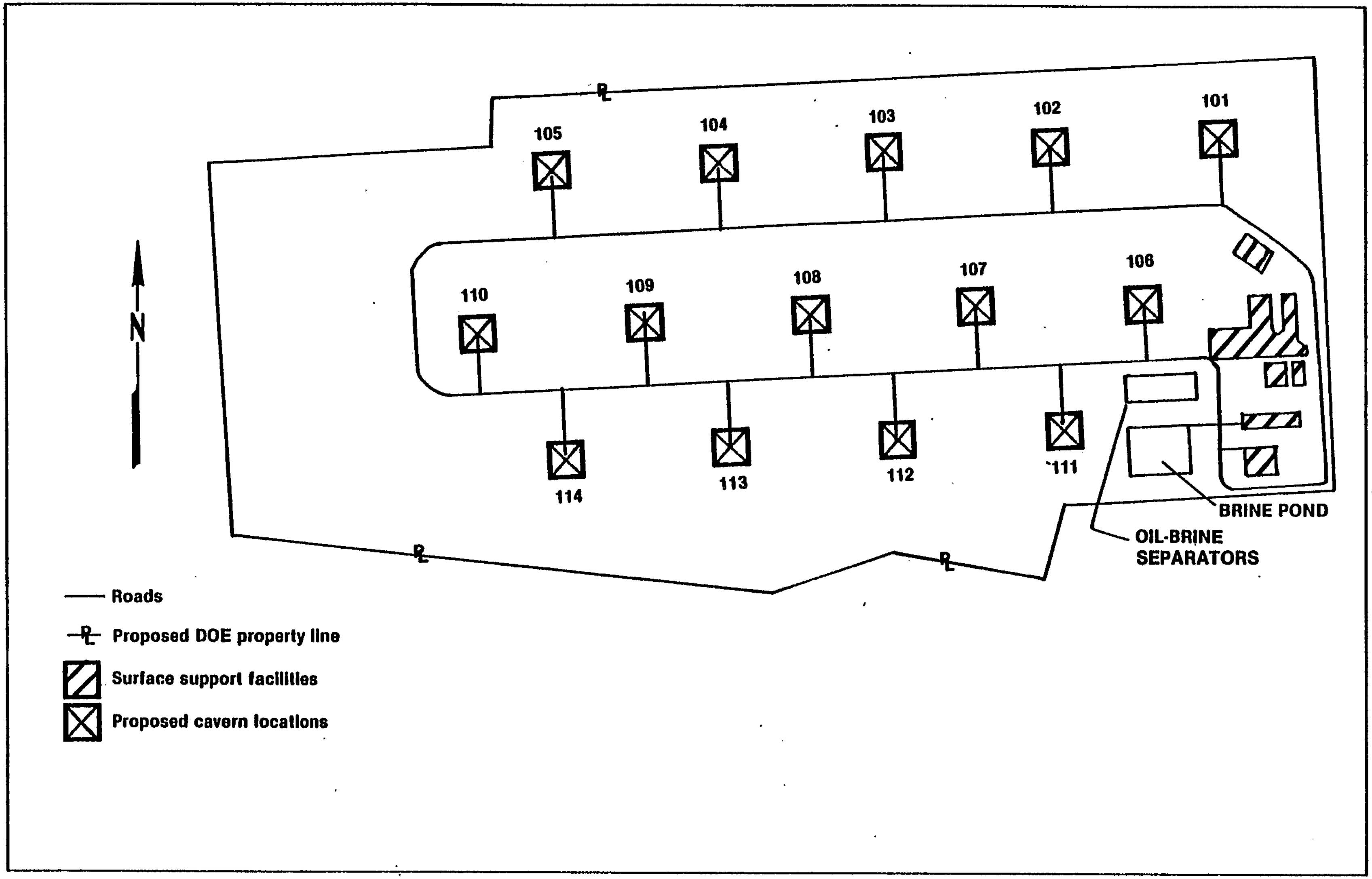


Figure 2-5. Proposed Big Hill storage site.

2.2.2 Preferred Systems

This section describes the preferred oil distribution and brine disposal systems for Phase III development at Big Hill. Alternative Big Hill oil distribution and brine disposal systems are described in Sect. 2.3.3.

2.2.2.1 Crude Oil Distribution: Big Hill to Sun Terminal

The preferred and alternative oil pipeline routes are shown in Fig. 2-6. The preferred route is the shortest, from Big Hill to the Sun Terminal at Nederland, Texas, 23 miles to the northeast. This route differs only slightly from the route in the Texoma FEIS (Sect. 3.3.4.5) and involves fewer water crossings and wetlands. This route is included in the environmental evaluation in subsequent sections.

As discussed in Sect. 2.2.1.1, Phase III expansion of Bryan Mound and West Hackberry would not affect SPR oil fill or drawdown rate capabilities. Phase III development of a new site at Big Hill, however, is designed to increase SPR oil fill rate by up to 280,000 bbl/d and drawdown rate capability by 935,000 bbl/d. If the three Texoma Group sites distribute oil to Sun Terminal simultaneously at design drawdown rates, the throughput requirements would be 2,335,000 bbl/d (1.3 MMB/d from West Hackberry, 100,000 bbl/d from Sulphur Mines, and 935,000 bbl/d from Big Hill). After Sulphur Mines is drawn down, flow rates from West Hackberry would increase to 1.4 MMB/d. The terminal is designed to distribute 420,000 bbl/d through the Texoma pipeline, 413,000 bbl/d through local deliveries, and 412,000 bbl/d via pipelines now under construction, making a total of 1,245,000 bbl/d. Current ship and barge loading capacity ranges between 763,000 and 1,165,000 bbl/d, assuming a 60 percent berth utilization. Some of this capacity is generally used for transporting refined petroleum products and may be unavailable for SPR needs. The Sun Terminal now has permits for constructing one new berth, which would have a capacity of 201,000 bbl/d. Assuming that full use of the pipeline capacity can be made during a foreign oil supply disruption, the requirement for dock throughput (1.1 MMB/d) would be within the range of capacity at Sun Terminal.

2.2.2.2 Big Hill Raw Water and Brine Disposal

The proposed raw water intake structure would be located on an abandoned barge slip at mile 305 of the ICW. The structure would consist of a concrete box containing bar racks, traveling screens, fish protection devices, raw water pumps, and screen wash pumps. The design would ensure a maximum velocity at the traveling screens of 0.5 ft/s. A 46-in. pipeline would connect the intake structure with the site about 5.3 miles to the north. Electric power for pumps and motors would be supplied through cables buried in the pipeline right-of-way (ROW). Detailed discussions of raw water intake structures and their ecological impacts are presented in the Texoma and Seaway Group FEISs.

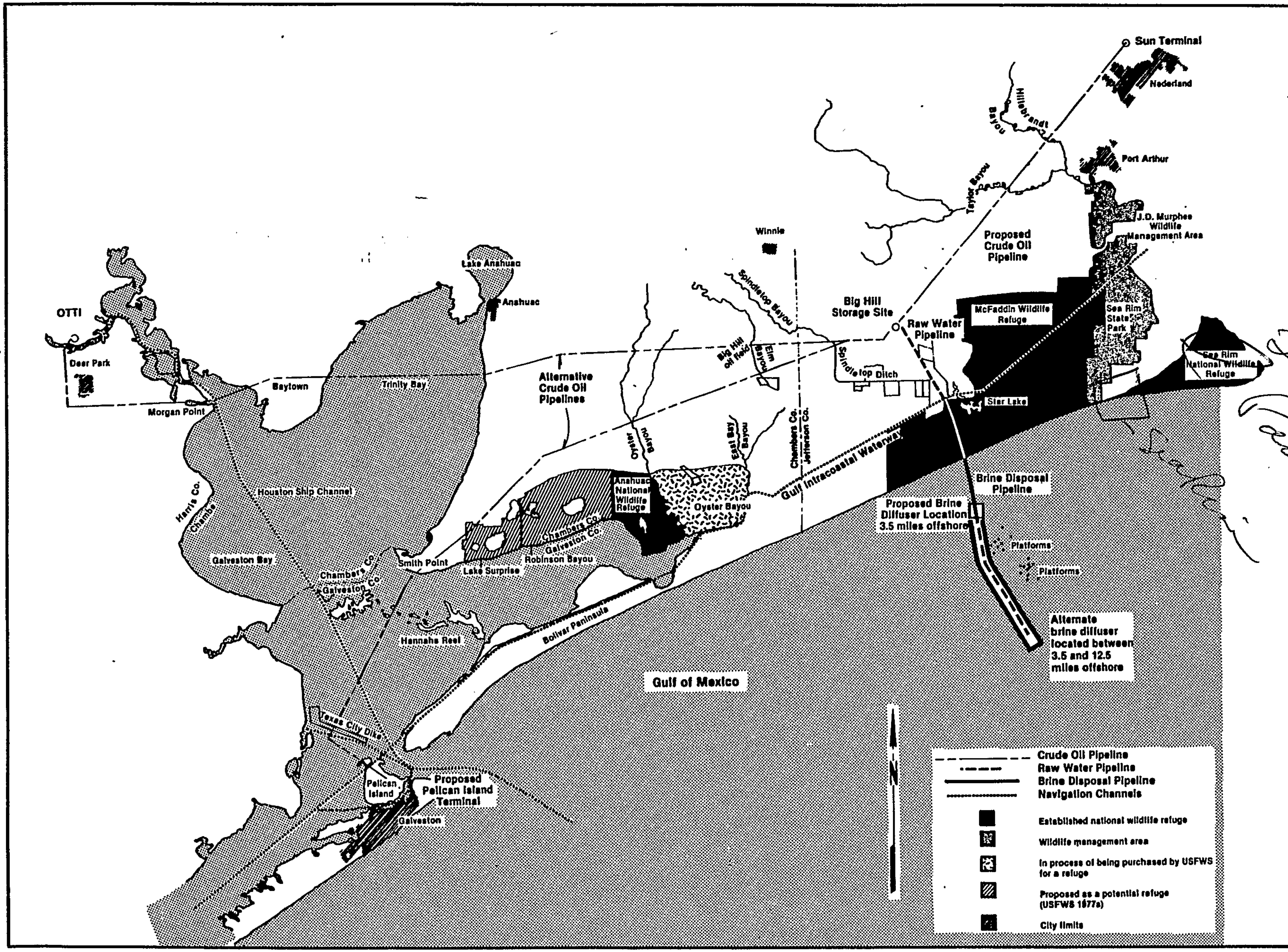


Figure 2-6. Preferred and alternate pipelines associated with the Big Hill 140-MMB crude oil storage facility.

The proposed 42-in. brine disposal pipeline would run southeasterly 12.7 miles to a diffuser located 3.5 miles offshore near the 30-ft depth contour (Fig. 2-6). On shore, the 9.2-mile-long pipeline would be coated with concrete to achieve a negative buoyancy. Throughout its length, the pipeline would be buried with a minimum of 3 ft of cover. The brine and raw water pipelines would use one ROW between the site and ICW. The proposed brine diffuser site would be located near latitude 29° 34' North and longitude 94° 09' West (see Fig. 2-6).

The diffuser header would be buried, with the top of the header about 6 ft below the Gulf floor. The diffuser header would consist of 74 3-in.-diameter diffuser ports, located 60 ft apart at centers (Fig. 2-7). Total diffuser length would be 4,380 ft. To prevent entanglement of fishing nets, 3-in.-diameter rubber discharge hoses would extend from the diffuser port to a point 5 ft above the Gulf floor. A diffuser guard would be installed on each diffuser port before backfilling (Fig. 2-7). Brine effluent velocity would be 25 ft/s, with a discharge rate of 91 ft^3/s. To maximize dispersion, the diffuser would lie perpendicular to the coast to take advantage of the predominant longshore currents.

2.3 OTHER ALTERNATIVES

In planning for Phase III, the complete range of alternatives considered for earlier program actions was reviewed. Some storage media, such as moored tankers and aboveground tanks, were rejected for reasons such as excessive costs, unacceptable environmental impacts, and excessive time for development. These issues are documented in earlier program reports and FEISs (DOE, 1981). Other alternatives considered in Phase III planning, described in this section, include alternative storage sites, alternative systems to the preferred storage configuration, and the "no action" alternative (i.e., limiting the SPR to 538-MMB capacity at the completion of Phase II).

2.3.1 Alternative Oil Storage Sites and Configurations

2.3.1.1 Big Hill (140 MMB), Bryan Mound (60 MMB), West Hackberry (10 MMB)

The economic advantages of Phase III expansion of Bryan Mound and West Hackberry and the efficiencies of integrated Phase II/Phase III cavern development were discussed in Sect. 2.2.1.1.

As an alternative to the 40:30 allocation between Bryan Mound and West Hackberry of the preferred approach (Sect. 2.2.1.1), the 70-MMB Phase III expansion could be achieved by allocating 60 MMB to Bryan Mound and 10 MMB to West Hackberry. This configuration would result in the minimum land acquisition for Phase III, less than 4 acres at West Hackberry. Development of 60 MMB at Bryan Mound in Phase III could be integrated with the second group of Phase II caverns by reducing the average leaching rate for each and, consequently, increasing the duration of leaching for each cavern proportionately. However, this would result in no net time saving or other advantage relative to development as a separate group following the completion of Phase II. Both of these approaches would extend the duration for development of

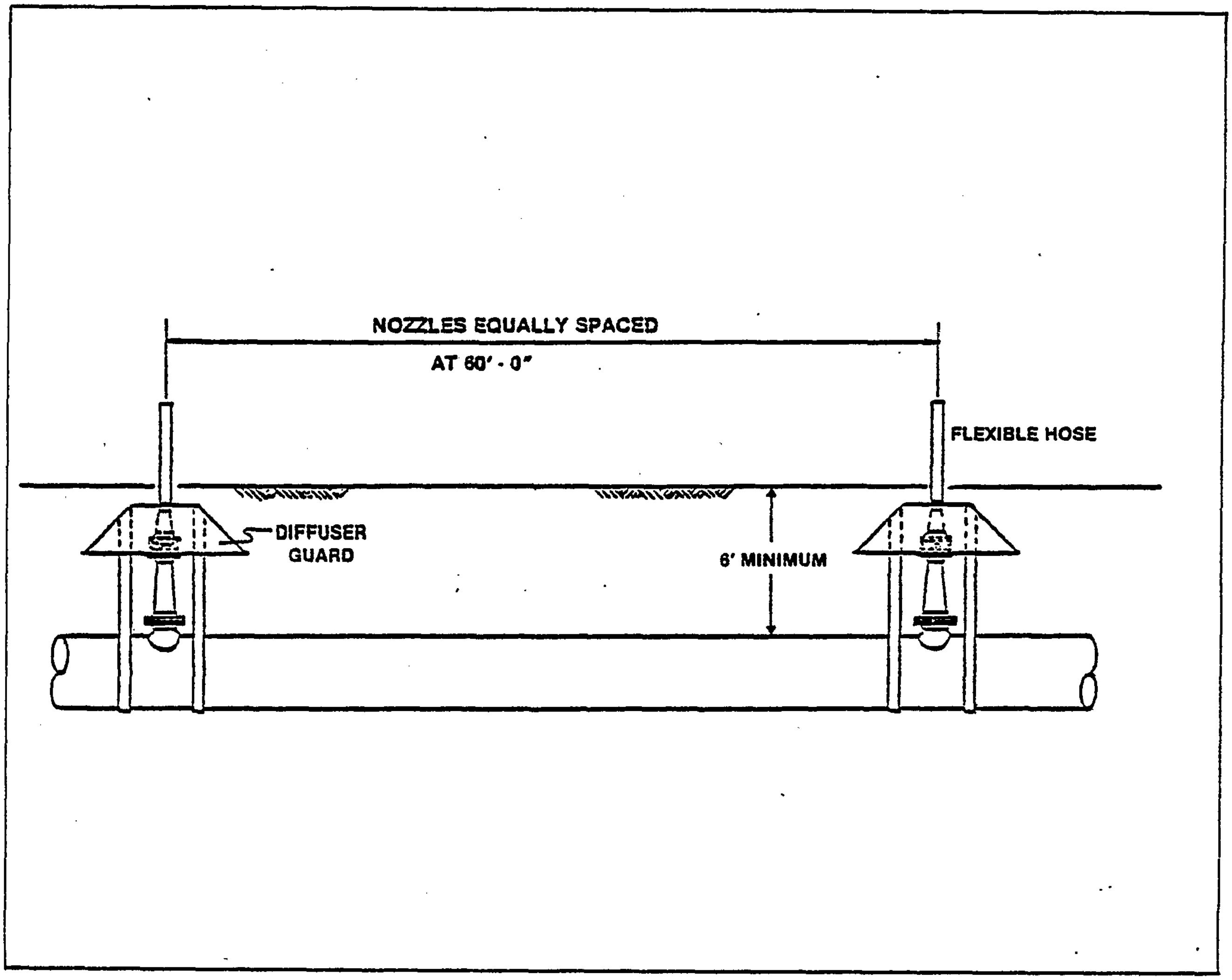


Figure 2-7. **Diffuser header showing typical diffuser nozzle and diffuser guard.**

the 70-MMB expansion at the existing SPR sites and increase costs. Development of this alternative would require an additional 6 months (see Fig. 2-2) and increase costs, approximately $30 million over the preferred configuration.

2.3.1.2 Expansion of Other SPR Sites

In the evaluation of expanding existing SPR sites, Bayou Choctaw, Sulphur Mines, and Weeks Island were considered, as well as Bryan Mound and West Hackberry. None of these sites is a reasonable alternative to Bryan Mound or West Hackberry for expansion.

Sulphur Mines (DOE, 1978a) is a small, irregularly circular salt dome with an irregular top and very steep sides. It was selected for SPR Phase I because of the availability of 22 MMB of existing storage space and the relative ease of tying into the West Hackberry oil distribution line. The salt available for expansion is very limited; 103 acres of salt are located within the -2,000-ft contour, and 0.259 cubic mile of salt is located above the -10,500-ft contour. The site also poses high risk in drilling new caverns because of extensive historical sulfur mining in the dome's caprock. Finally, the capacity to dispose of brine by underground injection is limited. The existing brine disposal system consists of four injection wells, which were designed for a nominal capacity of 1,000 gal/min (34,000 bbl/d) each. There has not been sufficient oil fill experience at the site to evaluate performance of the injection wells there, but a brine injection experience superior to that at Bayou Choctaw or West Hackberry would not be expected (see Appendix H). Problems encountered include excessive anhydrite buildup, formation plugging near the well bore, sand inflow, daily acidizing treatments, and resultant downtime. These all result in program delay and increased cost.

There is sufficient salt at Bayou Choctaw to expand the site by 50 MMB beyond Phase II. Originally, a brine disposal system of up to 28 wells designed to inject 960,000 bbl/d was anticipated at Bayou Choctaw (FEA, 1976). However, disposal operating experience during initial Phase I development was so adverse that only 12 wells were built. These 12 wells are projected to sustain a combined rate of 115,000 bbl/d. Increasing the brine disposal rate to accommodate new cavern development in accordance with Phase III schedules would not be reasonable (see Appendix H).

Weeks Island has sufficient salt for expansion by more than 100 MMB. However, this site also presents major brine disposal problems in spite of its location on the edge of Vermilion Bay. Because of the number of environmentally sensitive areas involved and the distance off shore to the minimum acceptable depth for a Gulf of Mexico brine diffuser, a very large pipeline (greater than 42-in.-diameter) of more than 50 miles would be required, 48 miles of which would be off shore (DOE, 1978c). Crossing major producing oil fields, which could not be avoided, would cause additional major construction problems. Because of the remoteness of the diffuser from the site and from available onshore support bases for offshore services, operation and maintenance of the diffuser would be difficult.

2.3.1.3 Other Gulf Coast Salt Dome Storage Sites

As discussed in Sects. 2.2.1.1, 2.3.1.1, and 2.3.1.2, expansion of existing SPR sites beyond Phase II, in a manner consistent with Phase III objectives and criteria, is limited to a combined volume of 70 MMB at Bryan Mound and West Hackberry. To acquire 210 MMB in Phase III, development of 140 MMB of storage at a new site or sites would be required. Consideration of alternative new sites along the Gulf Coast was limited to salt domes previously considered in the Capline, Texoma, and Seaway FEISs. Development of more than one new site has been discounted for Phase III development since there would be additional impacts to land use, natural and scenic resources, air quality, species and habitats, and socioeconomics. There are individual salt domes with the desired potential capacity available for storage.

Candidate storage sites evaluated in the Capline Group FEIS included Napoleonville salt dome in Assumption Parish, Louisiana; Chacahoula dome in Lafourche Parish, Louisiana, and Iberia dome in Iberia Parish, Louisiana. The locations of these domes are shown in Fig. 2-8. The Iberia dome is small, with a projected capacity of only 50 MMB. Development would require underground injection of brine and the construction of a 39-mile oil pipeline crossing the Atchafalaya Basin to connect with the Weeks Island-St. James pipeline near Napoleonville. The Chacahoula dome, although large enough to accommodate up to 200 MMB of storage, was considered to be environmentally undesirable because of the impact on wetlands at the storage site and the associated oil and brine disposal pipelines. In addition, the cost of the brine pipeline would be high because of the distance off shore (23 miles), at Point-au-Fer, required to reach a suitable diffuser site. The Napoleonville dome could accommodate 150 MMB of storage and was the proposed development for expansion of the Capline Group. (This site is now considered impracticable because of the unavoidable impact on wetlands and the need to inject brine or to construct an extensive pipeline to the Gulf of Mexico.) None of the candidate sites in the Capline Group will be considered further.

Candidate storage sites evaluated in the Texoma Group FEIS included Black Bayou salt dome in Cameron Parish, Louisiana; Vinton dome in Calcasieu Parish, Louisiana; and Big Hill dome in Jefferson County, Texas. The locations of these domes are shown in Fig. 2-8. One site, or a combination of these new sites, was proposed as an alternative to the SPR Phase II expansion of the West Hackberry site. The Black Bayou dome could accommodate 150 MMB of storage, a more than sufficient capacity, in combination with feasible expansions of the Phase II Bryan Mound and West Hackberry sites. This site lies entirely in a wetland area, however, and is considered to be environmentally undesirable. The Vinton dome would accommodate only 50 MMB and would be considered only in order to decrease the required capacity at another site. Cost considerations and the necessity to dispose of brine by underground injection preclude the development of the Vinton site, if the Phase III storage goal can be reached by using other candidate sites. The Big Hill dome could accommodate the needed storage. As described in the Texoma Group FEIS, Big Hill was assessed as a 100-MMB site. After publication of the Texoma Group FEIS, a conceptual design study was

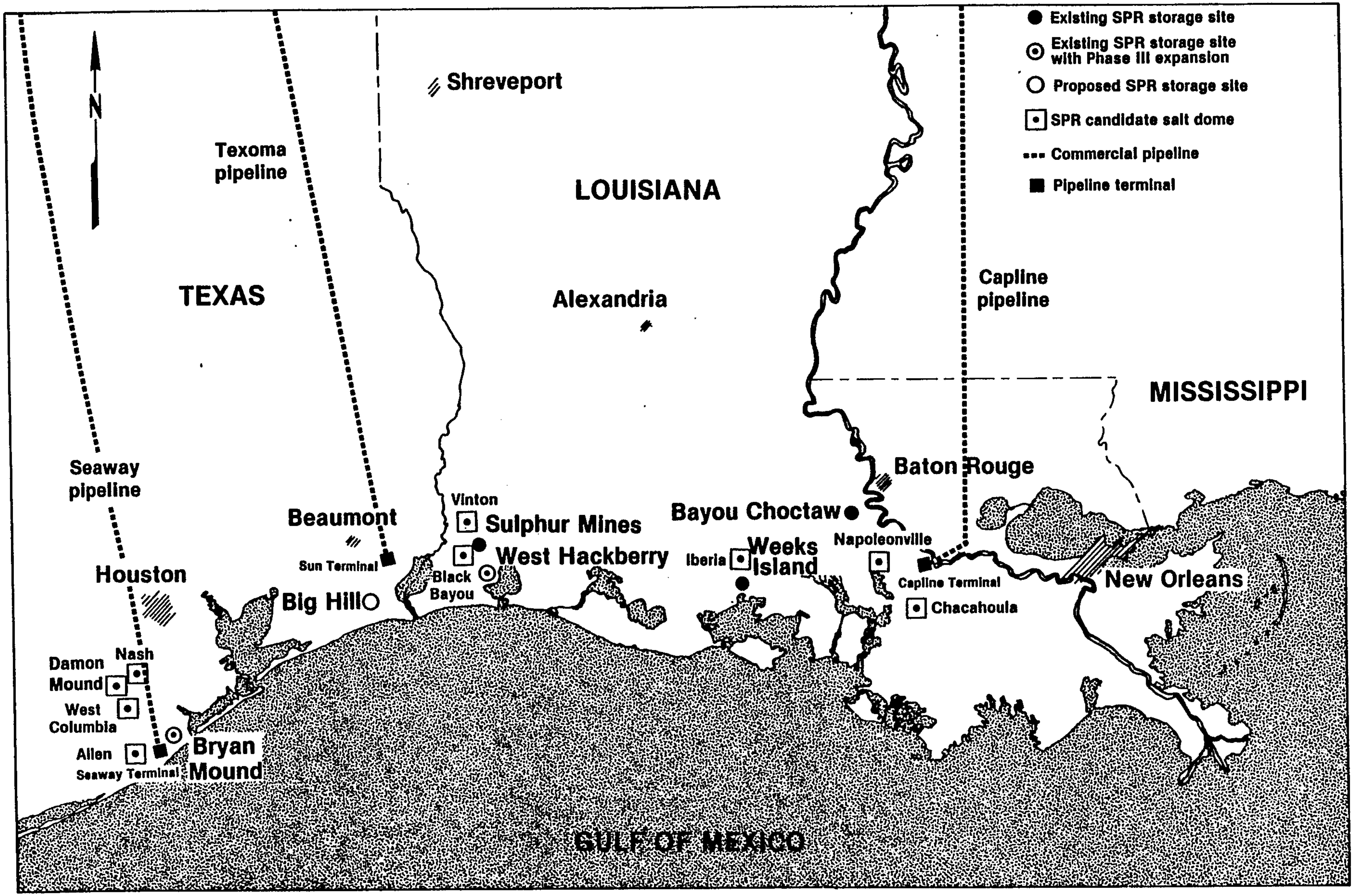


Figure 2-8. Seaway, Texoma, and Capline group salt domes.

conducted for a 140-MMB storage facility, which changed cavern dimensions and configuration, as is seen in Table 2-2. Big Hill salt dome has the major advantages of having a minimal effect on wetlands and ease of brine disposal to the Gulf, and as previously discussed in this section, it represents the major element of the preferred alternative for Phase III development. It is the only new site within the Texoma Group that will be considered further in subsequent sections.

Candidate storage sites evaluated in the Seaway Group FEIS included Nash salt dome in Fort Bend County, Texas; and Allen, Damon Mound, and West Columbia domes in Brazoria County, Texas. The locations of these domes are shown in Fig. 2-8. These sites were proposed as alternatives to the Bryan Mound site expansion that is part of SPR Phase II. Each of the sites was assessed at 100 MMB of storage, and the development of each was considered to be feasible without unacceptable adverse impacts on wetlands. However, the three inland domes, Nash, Damon Mound, and West Columbia, are no longer considered practicable because of their reliance on underground injection for brine disposal (see Appendix H).

Allen dome is within 7 miles of the coastline, making offshore brine disposal feasible. The site is not considered a reasonable alternative to Big Hill for Phase III objectives, primarily because of the crude oil distribution capabilities of the Seaway Terminal. Drawdown rates, combined with those at Bryan Mound, would overload the throughput capacity of the terminal and would require additional development of port and terminal facilities.

A 1976 feasibility study (Crutcher, Rolf, Cummings, Inc., 1976) indicated the suitability of developing 35 MMB of storage at Allen dome. Development of the site at 100 MMB, or a greater amount, would require a substantial subsurface testing program to augment limited existing data for confirming the salt dome boundary. A thorough testing program would take several years. Part of the dome lies under the San Bernard River and would be unavailable for development. The remainder lies within the floodplain and would not be developed unless there was no practicable alternative.

2.3.1.4 <u>Offshore Domes</u>

Three salt domes off shore from the present SPR locations in Louisiana and Texas have been identified as candidate SPR storage sites. The locations of these domes are shown in Fig. 2-9, and their basic characteristics are provided in Table 2-3.

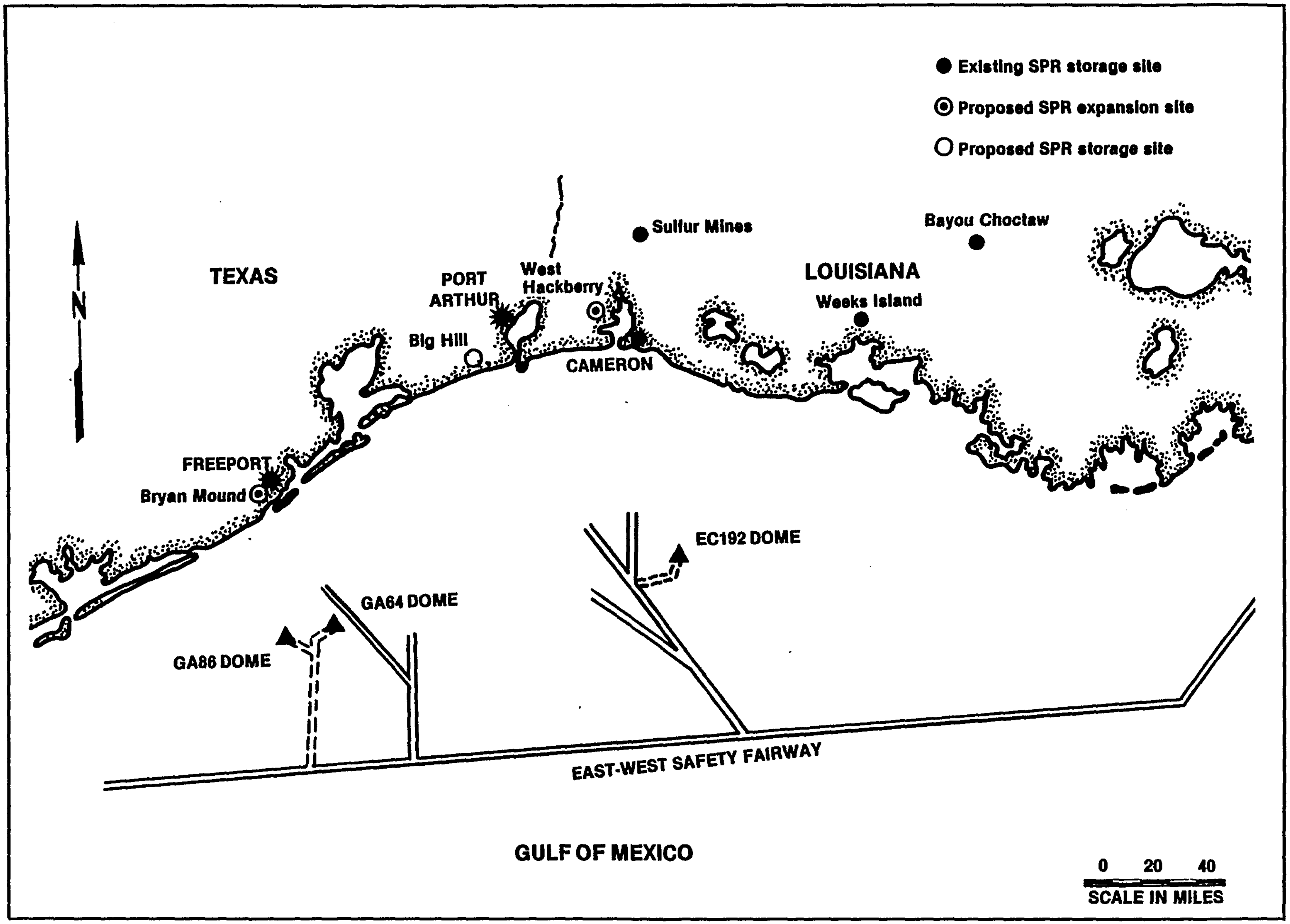


Figure 2-9. Offshore salt domes - candidate sites.

Table 2-3. Characteristics of proposed offshore dome SPR sites

Dome	Proposed capacity (MMB)	Water depth (ft)	Depth from sea floor to salt (ft)	Distance offshore (miles)
Galveston Block A-86	200	115	600	40
Galveston Block A-64	200	122	455	45
East Cameron Block 192	200	85	1000	60

Up to 24 storage caverns, each having a nominal capacity of 10 MMB, could be developed in each dome. Cavern leaching would be accomplished by using seawater, and brine would be discharged at selected locations in the vicinity of each dome. Surface facilities to accomplish leaching, leach/fill, drawdown, and refill would include offshore platforms for pumping and control equipment, crew living quarters, and ship mooring and anchorage facilities. Fairways leading to designated shipping lanes would be identified. Onshore support bases near Freeport, Port Arthur, and Cameron could service the offshore operations.

This concept offers certain environmental, logistic, and strategic advantages over onshore concepts. However, the offshore option poses a series of technical difficulties and a sequence of management complexities significantly different from those encountered to date. More time is required for geotechnical investigations, technical assessments, and economic analyses to better establish feasibility. Confirmation of the salt dome boundary is significantly more involved than on shore, as is establishing the feasibility of a major self-contained power generation system. The power requirement for conventional offshore producing platforms does not approach that of the necessary system of pumps for leaching. Consequently, it is conservatively estimated that selection of offshore domes would result in a 2-year delay in implementing Phase III. Although offshore domes are still considered to be a viable alternative for the future and investigations and analyses will continue, they will not be evaluated further in this document.

2.3.1.5 Inland Domes

The large group of salt domes in northern Louisiana, Mississippi, and Alabama has been extensively evaluated for SPR development potential (Dames and Moore, 1979; Science Applications, Inc., 1979). Seven domes were selected for further study from the 42 candidates examined. These domes are Gilbert in Franklin Parish, Louisiana; Bruinsburg in Claiborne County, Mississippi; Leedo in Jefferson County, Mississippi; Byrd, Cypress Creek, and Richton in Perry County, Mississippi; and McIntosh in

Washington County, Alabama. Byrd and McIntosh domes are considered capable of accommodating about one-half of the SPR Phase III requirement, while each of the other five domes is capable of storing the entire Phase III amount.

Of the various crude oil handling concepts for the Gilbert, Bruinsburg, and Leedo sites, the alternative considered most practicable was to connect the sites by pipeline to deepdraft port facilities at Baton Rouge, Louisiana. Raw water required for leaching and drawdown could be obtained from the Mississippi River and would represent a negligible fraction of total flow, even during minimum flow periods. Port facilities for the remaining domes could be constructed at Mobile, Alabama, or Pascagoula, Mississippi. Raw water sources include the Leaf River in Mississippi and the Tombigbee River in Alabama.

Use of these inland domes presents several serious problems resulting from the impracticality of the available method of brine disposal and the paucity of adequate geologic information required to select and develop viable candidate inland domes.

The only available method of brine disposal is underground injection. Disposal to the Gulf is not practicable because pipelines of up to 120 miles would be required. The impracticality of underground injection at the scale of leaching operations is documented in Appendix H. First, before site selections could be made, a geotechnical program of several test wells would be necessary to confirm the nature, extent, and thickness of reservoir sands and the existence of aquicludes to prevent contamination of freshwater supplies. The lack of existing geotechnical data stems from the relatively small amount of oil and gas exploration around inland domes. Compared with Gulf Coast salt domes, where the likelihood of oil and gas traps is much greater because of larger structural disturbances, such as folding and faulting, the extent of exploration is significantly less. Second, additional delays in the SPR program would result from development of an underground injection system. To accommodate the brine disposal parameters proposed for Big Hill, 1.4 MMB/d for almost 4 years, an injection well field of 112 wells located on 980 acres of land would be required (see Appendix H). Considering the substantial number of wells, the probability of land accessibility problems, and shortages of drilling rigs and crews, a lengthy construction period would probably be required.

Disregarding inordinate costs and delays in developing the required brine injection systems, the decisive difficulty with inland domes is that there is no assurance that the subsurface disposal zones would accept brine at the required rate and volume for the required period. Therefore, use of inland domes constitutes an unacceptable risk to SPR objectives and will not receive further consideration in this document.

2.3.1.6 Mines

An alternative concept for a portion of the SPR Phase III requirement is storage of crude oil in existing mines. Three mines that were being considered are Central Rock limestone mine in Kentucky, Ironton limestone mine in Ohio, and Kleer salt mine in Texas. Their characteristics are summarized in Table 2-4.

Table 2-4. Characteristics of proposed inland mine SPR sites

Mine	Available capacity (MMB)	Type of mine	Oil pipeline terminal	Length of offsite oil pipeline (miles)
Central Rock	14	Limestone (active)	Tates Creek Terminal	13.5
Ironton	21	Limestone (abandoned)	Catlettsburg Terminal	13.1
Kleer	30	Salt (active)	Winnsboro Terminal	42

The primary advantage of conventional dry mines stems from the use of submersible pumps which pump oil out as opposed to the fluid displacement system of leached caverns. Consequently, no raw water is required, and no brine is produced. Because water is not introduced to remove the oil, there is no cavern growth; thus, conventional dry mines are not constrained to a given number of fill/drawdown cycles. The space above the oil within the mine would be occupied by an inert gas.

Kleer Mine is in a region of domestic oil production, where local pipelines would not be available for distribution. Oil would have to be distributed via a 38-mile pipeline to the Texoma pipeline at Winnsboro, Texas, which would be carrying SPR crude oil from Sun Terminal during drawdown. For only 30-MMB capacity, a pipeline of this length and the necessary additional storage tankage are not practical.

Ironton and Central Rock Mines could supply one, possibly two, refineries belonging to one oil company. Both Ironton and Central Rock Mines would require a 13-mile pipeline constructed through solid rock terrain. Neither is practical for 21 and 14 MMB, respectively. Further, both mines would require additional tankage, and Ironton Mine would require a water treatment plant for mine seepage water before discharge into the Ohio River. The relatively small capacity of these mines, their remoteness (which requires long pipelines relative to their capacity), their capability to supply principally one refinery, the anticipated higher costs associated with pipeline construction in solid rock, and the need for a water treatment plant at Ironton Mine preclude further consideration for SPR Phase III storage.

2.3.1.7 Turnkey

During 1978 DOE developed a plan for acquiring additional SPR storage capacity for Phase III by requesting offers from private industry for the turnkey development of new sites because this approach would result in the earliest possible availability of storage capacity. The turnkey approach would have minimized direct DOE involvement and required the offerors to direct all aspects of the development of the sites proposed by them, including environmental compliance, site design and construction, and initial fill. Noncompetitive negotiations were initiated with owners and operators of three sites with existing storage capacity, and a competitive procurement action for additional site development was begun in November 1978.

Subsequently, changes in the world crude market made the oil fill schedule and other assumptions of this turnkey effort less certain. To maintain flexibility in the development of the remaining necessary SPR facilities, DOE concluded that it was inappropriate to continue these procurement actions. The solicitation was cancelled in August 1979, and the noncompetitive negotiations were discontinued.

Schedule constraints and the need for flexibility preclude the use of a similar turnkey procurement for the selection and development of new storage sites. This does not foreclose the development of sites selected for Phase III by the government through the use of a more limited turnkey approach.

2.3.2 No-Action Alternative

The no-action alternative would result in limiting SPR storage capacity to the 538 MMB available at the five current Phase I and II sites and associated tanks and pipelines. This would be contrary to the Congressional mandate to expand the SPR capacity to 750 MMB as an intermediate step toward the goal of a one-billion-barrel reserve (Sect. 1.1).

Failure to provide the mandated SPR capacity would directly impact the national capability to deal effectively with international oil supply issues. An embargo or other supply interruption dramatically reducing the availability of imported crude oil would have an increased impact on the petroleum industry, the economy, and national security. A large reserve is also a good deterrent against threats of an oil embargo. The urgent need for the reserve and its overall importance to the nation is discussed in Sect. 1.2.

Environmentally, the no-action alternative would limit SPR construction and operation impacts to those described in the FEISs listed in Sect. 1.3. The West Hackberry and Bryan Mound sites would remain as discussed in the Texoma and Seaway Group FEISs respectively. Under this scenario the Big Hill site would remain with private owners. It could continue to be used as agricultural pastureland, be further developed as a liquid petroleum gas (LPG) storage site by the private sector, or subdivided and developed for some purpose such as real estate speculation. A brief summary of the resource commitments which would not be made under the no-action alternative is presented in Table 8-1 (see Sect. 8.0). The environmental impacts of an inadequate oil reserve cannot be accurately determined because of the large number of variables involved.

2.3.3 Alternative Systems for Preferred Alternative

This section addresses alternatives to the preferred crude oil distribution and brine disposal systems for Big Hill that were described in Sect. 2.2.2. Existing Phase II systems at Bryan Mound and West Hackberry for oil distribution and brine disposal are unaffected by Phase III development; however, alternative brine disposal rates and Phase III configurations are addressed in this section.

2.3.3.1 Alternative Crude Oil Distribution

In addition to the preferred alternative of an oil pipeline from Big Hill to Sun Terminal, two alternative oil distribution pipelines from Big Hill to the Galveston Bay area, shown in Fig. 2-6, have been evaluated. These pipelines would connect the Big Hill site with either the Oil Tanking of Texas, Inc., Terminal (OTTI) located on the Houston Ship Channel (60 miles) or the planned Pelican Island Terminal (54 miles) described in the U.S. Army Corps of Engineers FEIS for port expansion at Galveston Island (USACE, 1979). Either pipeline could be constructed in addition to, or in lieu of, the pipeline to Sun Terminal. These two routes have been selected from a large number of possible options based on numerous criteria, including total length, related land use patterns, ecologically sensitive areas (wetlands, oyster reefs, etc.), locations of known historical and archaeological sites, major and minor crossings (water, railroad, highway, etc.), utility of existing ROWs, and construction techniques required.

A crude oil, distribution capacity of 620,000 bbl/d to local customers and a 818,000-bbl/d dock capacity is now available at OTTI. Plans for expansion of OTTI (not a part of SPR) include increasing local distribution to 1,150,000 bbl/d and constructing two new 201,000-bbl/d loading docks, for which permits have been obtained. This facility could easily handle the Big Hill SPR crude oil, reducing risk associated with utilization of Sun Terminal at or near capacity levels.

The proposed Pelican Island facility is discussed in detail by the U.S. Army Corps of Engineers (1979). If constructed, the terminal would have a local distribution capacity in excess of 1.1 MMB/d and could handle the Big Hill SPR oil in the event of a major foreign supply interruption. This option is less desirable than the pipeline to OTTI because of the tentative nature of the proposed Pelican Island development.

For either the OTTI or Pelican Island alternative, the intent would be to maximize flexibility between supplying local refineries and transshipping to Caribbean and East Coast refineries.

2.3.3.2 Alternative Raw Water and Brine Disposal Pipeline Routes

The raw water and brine disposal pipeline routes shown in Fig. 2-6 were developed through an evaluation of environmental considerations, constructability, and the desire to use one ROW for both pipelines between the Big Hill site and the Gulf Intracoastal Waterway (ICW). The proposed raw water intake structure would be located at mile 305 of the ICW on an abandoned barge slip. This would preclude the need to dredge an inlet for siting the intake structure away from the ICW, as described in the Texoma Group FEIS Sect. A.7.4.1.3. The proposed route to the ICW also avoids crossing Spindletop Ditch and the associated freshwater impoundments shown in Fig. 2-6. The major concern associated with this route is the presence of high-quality wetlands and the McFaddin Wildlife Refuge south of the ICW. Wetlands of high quality are distributed somewhat homogeneously between Sabine Lake and Galveston Bay (USFWS, 1977). Existing and proposed wildlife refuges are abundant in the region (see Fig. 2-6).

Avoiding the McFaddin Wildlife Refuge and other management areas would require routing the pipeline to the south. This could be accomplished by numerous means. The raw water and brine line could remain as proposed between Big Hill and the ICW. At the ICW the brine line could parallel the ICW southwestward, and once beyond the refuge boundary, the line would cross to the Gulf of Mexico. A second option would involve the use of separate ROWs for the raw water and brine pipelines. The brine line would follow a separate route, across Spindletop Ditch and the freshwater management areas (see Fig. 2-6) to a position beyond the refuge boundary before crossing to the Gulf. A third possibility would involve moving both the raw water and brine lines and raw water intake structure to some point beyond the southern boundary of the refuge. This would maintain the concept of using a single ROW for the two pipelines. Major problems associated with all these options include increased costs, increased pipeline length, increased types of habitats affected, and increased amount of high-quality wetlands impacted. Because of these concerns, these options were not considered practicable.

2.3.3.3 Alternative Brine Disposal Site

The practical limit in distance off shore for alternative sites is 12.5 miles in 40 ft of water. There are no significant topographic differences in the flat bottom throughout the corridor from 3.5 to 12.5 miles (Fig. 2-6). Physical dispersion of the brine plume should not differ significantly throughout the corridor. Beyond 12.5 miles potential concerns would include proximity to the Sabine and Heald banks, which are choice benthic habitat harboring "hard bottom" fauna.

Sites further off shore become more marine than a near-shore site because of less influence from river runoff; consequently, biotic communities should be less tolerant to fluctuations in environmental parameters (Wolschlag, 1976). Benthic communities at the 40 ft contour site would be expected to be richer and more diverse than at the 30 ft contour site because of the greater stability of salinity and temperature regimes offshore and because of the difference in bottom substrates. Bottom sediments near the 40-ft contour are patchy and include sandy mud, muddy sand, shelly sand and outcrops of Beaumont clay. Near shore, the sediments are a veneer of fine silt and clay overlying stiff Beaumont clay.

It may be postulated that, within the corridor, biotic communities at the preferred site (30-ft contour) are better suited to withstand the effects of brine discharge than communities further offshore because those at the 30-ft contour are adapted to an environment of greater fluctuation in salinity and other environmental parameters.

An identical brine diffuser would be built at any selected disposal site (Sect. 2.2.2.2); however, extension of the brine pipeline to 12.5 miles off shore would require an increase in pipeline diameter from 42 to 48 in. to accommodate frictional head loss.

Brine disposal at Big Hill by underground injection is not a practical alternative, as discussed in Appendix H.

2.3.3.4 Alternative Brine Disposal Rate

If no change in the Bryan Mound brine disposal rate of 680,000 bbl/d is assumed, the leaching duration of Group II and Group III would increase by 21 months. The four Phase III caverns would still be leached simultaneously with the second group of caverns. This operation would be held within existing brine disposal permit constraints by reducing the average leaching rate for each cavern and, consequently, increasing the duration of leaching each cavern. As inferred from previous discussions, no significant differences in adverse environmental impacts should result relative to integrated leaching, except for air quality. Leach/fill at a brine disposal rate of 680,000 bbl/d could result in nonmethane hydrocarbon emissions of 86 tpy.

2.4 SUMMARY OF IMPACTS ASSOCIATED WITH THE REASONABLE ALTERNATIVES

The goal of Phase III expansion of the SPR would be to increase program storage capacity by 212 MMB. Various storage scenarios were examined to determine feasibility, practicality, and timeliness. The preferred alternative for achieving the 212-MMB increase in storage includes the creation of one new 140-MMB storage facility at Big Hill, Texas, and the expansion of the existing Bryan Mound and West Hackberry sites by a total of 70 MMB. In planning the 70-MMB capacity, two scenarios were developed. The proposed option would involve expanding Bryan Mound by 40 MMB and West Hackberry by 30 MMB. An alternative would involve expanding Bryan Mound by 60 MMB and West Hackberry by 10 MMB.

The most significant environmental impacts would occur at the Big Hill site and the associated offsite facilities. Impacts projected to occur in the Big Hill project area, as well as at the existing SPR expansion sites (detailed in Sects. 4.0 and 6.0), are summarized in Table 2-5.

Table 2-5. Summary of potential impacts resulting from proposed and alternative actions

Development Option	Site or Route Affected	Potential Impacts to Resources
I. Development of new storage facility for 140 MMB A. Onsite facilities	Big Hill, Jefferson County, Texas	--Removal of 250 acres of prime farmland soil from potential production --Alteration of natural drainage pattern; sediment and other contaminants may enter nearby bodies of water during construction --Increase in particulate emissions during construction and hydrocarbon emissions during leach/fill operations --Removal of prairie grassland habitat --Localized increases in noise and traffic --Possible stress to community goods and services with influx of workers
B. Offsite facilities 1. Raw water pipeline and intake structure; onshore brine disposal pipeline	Big Hill site to ICW and Big Hill site to Gulf of Mexico	--9.2-mile ROW (total); 5.3-mile ROW from site to ICW and 3.9-mile ROW from ICW to Gulf of Mexico --Water quality perturbations (i.e., from dredging) during construction --Habitat destruction of wetlands; increased activity and noise may disturb resident fauna --Withdrawal of water from ICW for leaching and displacement predicted to cause only slight alteration in the ICW's flow velocity and salinity. Only very minor entrainment and impingement impacts anticipated
2. Offshore brine disposal pipeline and diffuser	Gulf of Mexico, both routes and locations	--Habitat destruction and water quality perturbations during construction --Water quality perturbations during leaching and refill associated with the chemical properties of the brine. Area of impact estimated to be 2,575 acres
	Different routes and locations --Out to 3.5 miles	--21 acres affected by construction operations --During leaching and displacement, dimensions of brine plume = 2,575 acres
	--Out to 12.5 miles	--Up to 76 acres affected by construction operations --During leaching and displacement, dimensions of brine plume = 2,575 acres
3. Crude oil distribution pipeline	All routes	--Impacts to both terrestrial and aquatic habitats --Water quality perturbations (turbidity) during construction --Localized increases in noise and traffic during construction
	Different routes --Preferred route, Big Hill to Sun Terminal	--23-mile ROW 18 miles cropland pasture 2.5 miles wetland 0.5 mile open water 2 miles industrial/residential
	--Alternative route, Big Hill to OTTI	--60-mile ROW 42 miles cropland pasture 3 miles wetland 12 miles open water 3 miles forested land
	--Alternative route, Big Hill to Pelican Island	--54-mile ROW 27 miles cropland pasture 12 miles wetland 15 miles open water

Table 2-5 (continued)

Development Option	Site or Route Affected	Potential Impacts to Resources
B. Offsite facilities (continued) 4. Tanker facilities	All locations	--Increase in hydrocarbon emissions --Oil spill risk
	Different locations --Preferred facility, Sun Terminal	--Annual pollutant emission rate for hydrocarbons = 2,426 tpy --Probability of a major oil spill = 0.02 during withdrawal and = 0.04 during refill
	--Alternative facilities, OTTI or Pelican Island	--Annual polluant emission rate for hydrocarbons = 1,372 tpy --Probability of a major oil spill = 0.02 during withdrawal and = 0.04 during refill
II. Expansion of storage facilities at existing SPR sites	West Hackberry, Cameron Parish, Louisiana; Bryan Mound, Brazoria County, Texas	
A. Storage of 30 MMB at West Hackberry and 40 MMB at Bryan Mound		--Purchase and development of up to 26.5 acres of additional prime farmland at West Hackberry; 10 residences potentially affected. Expansion at Bryan Mound would occur within existing facility boundaries; up to 15 acres of wetlands possibly affected
B. Storage of 10 MMB at West Hackberry		--Expansion at Bryan Mound would occur within existing facility boundaries; significantly fewer impacts envisioned to occur at West Hackberry with 10-MMB storage option; less than 4 acres of land acquisition; while additional impacts resulting at Bryan Mound from 60-MMB storage option considered minor --Extension of schedule by 6 months
III. Modification of flow rates at existing SPR site	Bryan Mound, Brazoria County, Texas	
A. Preferred flow rate, 980,000 bbl/d		--Estimated brine plume ~1,800 acres --Worst-case hydrocarbon emissions of ~121 tpy
B. Alternative flow rate, 680,000 bbl/d		--Estimated brine plume ~1,250 acres --Worst-case hydrocarbon emissions of ~86 tpy

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3.0 AFFECTED ENVIRONMENT

The purpose of this section is to supplement the detailed description of the environment, as presented in the Texoma and Seaway Group Final Environmental Impact Statements (FEISs), and to focus on the specific areas that would be affected by the Phase III SPR expansion, as presented in Sect. 2.0.

3.1 REGIONAL ENVIRONMENT (OVERVIEW)

The region that would be affected by the proposed action extends from the Mississippi River to the Rio Grande and is commonly described as the western part of the Gulf Coast Physiographic Province or northwest Gulf of Mexico. Off shore, the outer limits of the region may be defined as the shelf break or the ∿650 ft (200 m) depth contour. Major physical processes associated with the region are presented in Fig. 3-1. Numerous researchers have described the northern Gulf Coast region as a large, integrated, ecological complex (Hedgpeth, 1957). Major ecological subsystems of the northwest Gulf are the Mississippi Delta Ecosystem, the Chenier Plain Ecosystem, and the Strand Plain Ecosystem.

The area of proposed SPR Phase III construction is located within the western portion of the Chenier Plain of southwest Louisiana and east Texas, the eastern region of the Strand Plain of Texas, and the transition zone between these two physiographic provinces (see Fig. 3-1). Gosselink et al. (1979) have described the Chenier Plain in detail. The term "chenier" refers to a continuous ridge of beach material built up on marshy deposits which characterizes this region. Off shore of the Chenier Plain, the Continental Shelf is at its widest, and on shore much of the land area is covered by intermediate and brackish marshes, where primary productivity may exceed 2000 g/m^2 per year (Chabreck and Linscombe, 1978). Freshwater marshes are common in waterfowl management areas and in areas located north of the Intracoastal Waterway (ICW). Major estuaries of the western Chenier Plain are associated with the Calcasieu, Sabine, and East Bay drainage basins. The East Bay-Galveston Bay system represents the transition zone into the barrier-island-dominated Strand Plain estuaries. The region near the Bryan Mound site is unique in that the Brazos River is building the only active delta along the coast of Texas (Coastal Environments, Inc., 1977). Southwest of Galveston, the Continental Shelf narrows and steepens.

Sediments of the coastal plain are derived from deposits of the Quaternary period, with only Beaumont clay (Pleistocene) and deposits of Recent epoch exposed at the surface. Near-shore sediments are generally mixed, with outcrops of Beaumont clay prominent. Because of abundant sediment deposition in this region (in excess of 50,000 ft in places), the earth's crust has down-warped, forming the Gulf Coast geosyncline. The great weight of these sediments, along with uneven spatial distribution of deposition, is believed by many investigators to have initiated the lateral, then vertical, migration of Triassic and/or Jurassic salt into the large domes that characterize the region today.

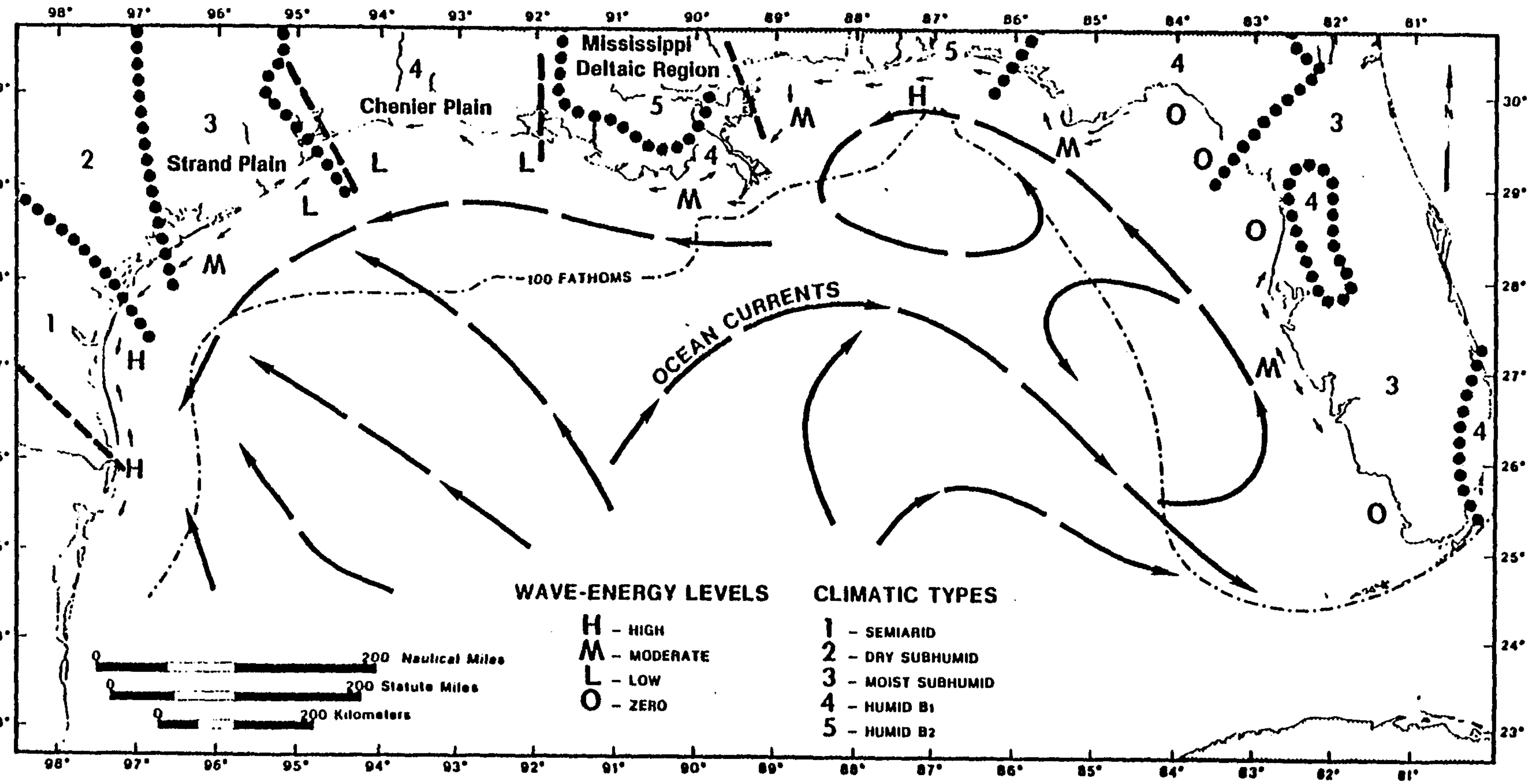

Figure 3-1. Some major process parameters of the northern Gulf of Mexico. Source: Kwon 1969, Coastal Environments, Inc. (1977).

These salt domes are typically cylindrical in shape, 1 to 5 miles in diameter, and are found at depths from less than a hundred feet to several thousand feet below the earth's surface. When near the surface, the domes produce a localized uplift, thereby giving rise to a circular mound that may reach up to 170 ft in height and cover several acres. These mounds are typically the highest points in the region.

Many of the domes have been mined for chemical feedstock brine or petrochemical storage facilities. The Bryan Mound, West Hackberry, and Big Hill domes examined in this supplement have all been solution-mined by industry. Additional caverns are currently being leached for petroleum storage at the Bryan Mound site, and preparations for leaching are occurring at the West Hackberry site under Phase II of the SPR program.

The hydrological regime of the northwest Gulf of Mexico is defined by two major transitional features. These are the longshore westward reduction in the volume of freshwater inflow and the onshore-offshore transition from fresh and estuarine to marine environments. Hedgpeth (1953) states that the average annual salinity increases from about 4 parts per thousand (ppt) at Eugene Island, Louisiana, to 23 ppt off Galveston, Texas, to 34 ppt at Port Isabel, Texas. The timing and magnitude of the Mississippi-Atchafalaya River discharge represents the single dominant factor of this longshore trend and directly influences the timing of spring increases in productivity through nutrient contributions. Near-shore currents run generally westward, with summer reversal becoming more prominent to the west. Sharp density stratification is typical near-shore, especially during periods of high river discharge.

In the coastal waters there is a seaward increase in mean salinity, while variability in hydrologic parameters, like temperature and salinity, decreases. Two major depth-related biological communities have been historically described, each named for one of the dominant penaeid shrimp species. The members of the near-shore white shrimp community generally are more euryhaline (tolerant to wide salinity variations) and more estuarine-dependent than members of the brown shrimp community located further off shore (Chittenden and McEachran, 1976). Accumulating evidence indicates that, at least for penaeid shrimp, hydrologic factors (temperature, nutrients, and salinity) in the estuaries at critical periods during the year determine inshore and offshore shrimp productivity. The outer edge of the brown shrimp community generally coincides with the offshore limits of the Gulf Coast Physiographic Province.

Climate and air quality of the region are dramatically influenced by the waters of the Gulf of Mexico. The movement of maritime air from the Gulf moderates extremes of summer heat and winter cold. Severe weather is usually associated with heavy thunderstorms and tropical cyclones. Periods of atmospheric stagnation are minimal because of the prevailing Gulf Coast winds with an annual total hour inversion frequency of 25 percent (Hasler, 1961).

Available air quality data for the northwest Gulf Coast indicate that the National Ambient Air Quality Standards (NAAQS) for ozone, nonmethane hydrocarbons (NMHC), and suspended particulates are exceeded at several locations. Except for the ozone standard, which is now 0.12 parts per million (ppm) for a 1-h averaging time and lead which has been set at 1.5 $\mu g/m^3$, all of the Federal air quality standards are the same as those presented in the Texoma Group FEIS, Sect. C.3.1.3.3. In this region, ozone concentrations generally range from 0.02 to 0.04 ppm. The 1-h ozone standard is most frequently exceeded in the greater Houston area, with monitors at Houston Southeast/Seabrook recording 150 violations in 1979. NMHC levels average 0.1 to 1.0 ppm for all hours and 0.2 to 1.2 ppm between 6 and 9 a.m. As with the ozone concentrations, excessive quantities of NMHC occur most frequently in the greater Houston area. In 1979 as many as 203 exceedances were reported at a Harris County monitoring station (Texas Air Control Board, personal communication, November 1980). Those regions showing high NMHC and ozone concentrations are generally associated with the large petrochemical industries and urban areas along the Gulf Coast, but measurements by the Texas Air Control Board have shown that ozone and NMHC levels may occasionally exceed the NAAQS in rural and offshore areas as well (Seaway Group FEIS, Sect. B.2.3.3). No exceedances of the sulfur dioxide, carbon monoxide, or nitrogen dioxide standards have been reported [U.S. Army Corps of Engineers (USACE), 1979].

Regional centers of economic activity are Lake Charles, Beaumont, Port Arthur, Brazosport, and Houston metropolitan complexes. The Houston area ranks as the third-most active port in the country. The petroleum industry involves exploration, production, refining, and transportation of natural gas, oil, and other petrochemical products. Texas is one of six states in the nation with substantial rice farming. As well as rice, regional agriculture involves such items as sugarcane, cotton, and cattle production. The commercial fishery consists primarily of white and brown shrimp and menhaden. The shrimp fishery is the most valuable fishery, and the menhaden is the largest fishery (by weight) in the United States (NOAA, 1979).

3.2 SITE-SPECIFIC ENVIRONMENT

This section deals with the site-specific environments associated with activities described in Sect. 2.0. Previous SPR environmental impact statements that have been prepared for earlier SPR construction will be referenced in support of this document to prevent unnecessary repetition.

3.2.1 Big Hill Storage Facility (140 MMB)

Design for the proposed Big Hill complex, with its raw water intake and brine disposal systems, is discussed in Sect. 2.0.

3.2.1.1 Land Features

Site Facilities

The Big Hill site, as proposed, would cover about 250 acres of land located about 22 miles southwest of Port Arthur and 70 miles east of Houston (Texoma Group FEIS, Sect. B.3.4.1.1). The Big Hill dome is a piercement structure which had previously been developed for storage of liquid petroleum gas (LPG). Two caverns with capacities of 326,000 and 314,000 bbl exist on the north rim of the dome. The caprock over the dome is 1,200 to 1,300 ft thick and is composed of porous sandstone overlying dolomitic limestone, gypsum, and anhydrite. Potential mineral resources in the vicinity of the dome include oil and gas, salt, and brine production. The site rises to an elevation of 35 ft above sea level and is typical of agricultural land in the region. No wetlands occur within the immediate vicinity of the site. However, less than a mile south of the dome is the northern boundary of fresh to intermediate marsh, which grades into brackish and saline marsh towards the Gulf Coast (Texoma Group FEIS, Sect. 3.3.4.1). The extensive wetlands south of the site are located in what Gosselink et al. (1979) describe as the Sabine Basin. There are approximately 352,000 acres of wetlands including open and impounded marshes in the Sabine Basin.

The Big Hill salt dome is overlain by the soil type, Hockley silty loam (Crout et al., 1965). This soil type is considered to be a prime farmland soil in its native state and is somewhat rare in Jefferson County, occurring chiefly in higher reaches of the coastal prairie. Of Jefferson County's 597,345 acres, only 5,009 acres, or 0.8 percent, are classified as prime farmland soils in their native state. As high as 62.1 percent of the county's soils are potentially prime farmland soils, but would require drainage to be farmed successfully (Soil Conservation Service, 1980). Although the soil at the proposed site would be suitable for the cultivation of such crops as feed sorghum and corn (Crout et al., 1965), this area serves as pastureland and has been largely developed for oil production.

Beyond the dome's boundaries, the more poorly drained soils, such as Beaumont clay, are cultivated for rice production. Rice is Jefferson County's only crop of commercial importance (Crout et al., 1965), and the acreage currently used for rice farming has not changed significantly in the past 40 years (Table 3-1).

Raw Water and Brine Disposal Systems

Land features of the raw water system would consist of a pipeline right-of-way (ROW), extending 5.3 miles from the site to the raw water intake structure located on an abandoned barge slip on the ICW. The 150-ft construction ROW would extend in a southeast direction across about 1.3 miles of prairie pasture and 4 miles of wetlands (Texoma Group FEIS, Sect. 3.3.4.5). The brine disposal system pipeline, as proposed, would follow the raw water pipeline ROW to the ICW, pass under the waterway, and extend in a southeasterly direction to the coastline (see Fig. 2-6). Gosselink et al. (1979) describe the wetlands north of the ICW in this area as primarily fresh-brackish marsh. Brackish and intermediate marsh occur south of the ICW to Texas Highway 87. A section of small barrier dunes and beach predominates from the highway to the Gulf. The land crossed by the brine disposal line south of the ICW falls within the newly created McFaddin National Wildlife Refuge (see Fig. 2-6), which provides wintering habitat for migratory waterfowl [U.S. Fish and Wildlife Service (USFWS), 1977b].

Table 3-1. Rice production in Chambers and Jefferson Counties, Texas[1]

Crop parameter	Jefferson County 1942	Jefferson County 1979	Chambers County 1942	Chambers County 1979
Acres planted	62,000	65,300	40,000	55,300
Acres harvested	60,000	65,200	38,300	55,200
Yield (average), lb/acre	4,340	3,304	4,170	3,766
Production (total harvested), 10^6 lb	260.4	215.4	159.7	207.9

[1]Information provided by Texas Crop Reporting Agency, personal communication, December 1980.

3.2.1.2 Water Environment

Surface waters located between the Big Hill site and the Gulf of Mexico include Spindletop Ditch, Spindletop Marsh, the ICW, Salt Bayou, Salt Bayou Marsh, Star Lake, and Clam Lake (Texoma Group FEIS, Sect. B.3.4.2.1). They range from freshwater to brackish in nature, depending on meteorological conditions and the degree of man-made control. Subsurface waters in this area consist of those in the Chicot aquifer. Groundwater for agricultural, municipal, and industrial uses is withdrawn at three major locations: the Beaumont-Port Arthur area and Winnie and Baytown in Chambers County (Texoma Group FEIS, Sect. B.2.2.2).

Big Hill Site

The Big Hill site is located 35 ft above sea level. It represents the highest elevation in the region and directly influences local hydrological patterns. The only water bodies in the vicinity of the site are two small freshwater ponds, about 10 to 20 acres in size, located at the northern and eastern edges of the dome. Surface drainage is generally to the south and east toward existing wetlands (Texoma Group FEIS, Sect. B.3.4.2.1).

Raw Water and Brine Diffuser Systems

The raw water intake structure and brine diffuser pipeline would interact directly with the ICW at approximately mile 305 in an abandoned barge slip. Water quality information for the waterway, presented in Table 3-2, is indicative of the extreme water quality variability commonly found in coastal areas. None of these values exceed any applicable state standards. Water use classification of the ICW (noncontact recreation and propagation of fish and shellfish), applicable state water quality standards, and Federal water quality criteria have been discussed in the Texoma Group FEIS (Sects. D.2 and D.3). Off shore, the brine diffuser locations [3.5 miles (proposed) or out to 12.5 miles (alternative)] are within the hydrodynamic regime of the near-shore Gulf of Mexico. Water depths are about 30 and 40 ft, respectively, for the two sites. A detailed discussion of the offshore environment is presented in Sect. 3.2.1.5 and Appendix F.

3.2.1.3 Climate and Air Quality

Climatological factors are important on a regional basis because they interact dynamically with water and water movement in the coastal zone. The Big Hill site lies within a humid, marine-dominated region. Prevailing winds are onshore from the Gulf of Mexico, except for interruptions due to mid-latitude disturbances and passing frontal systems (USACE, 1979). The closest meteorological station to the Big Hill site is the Jefferson County Airport, about 22 miles to the northeast.

Annual precipitation averages 44 in./year between the Sabine and East Bay basins, with water surplus occurring from December through April and deficits occurring from May through July. Extreme fluctuations in water level may be associated with tropical disturbances in the Gulf. The probability that tropical storms will cross the Chenier Plain in any given year is 0.5 percent (Gosselink et al., 1979).

Table 3-2. Water quality data for the ICW near the location of Big Hill water intake structure (Jefferson County, Texas)

1. CONVENTIONAL PARAMETERS	Intake Waters a.	Intake Waters b.
Conductivity, Micromhos/cm @ 25°C	1,900	17,000
Nitrate Nitrogen as NO_3 (mg/l)	None detected less than 0.1	0.17
Total Chloride as Cl (mg/l)	556	6,800
Total Sulfate as SO_4 (mg/l)	94	876
Oil and Grease (by IR) (mg/l)	0.2 ppm	--
2. METALS (mg/l)		
Total Arsenic as As	0.036	<0.02
Total Barium as Ba	None detected less than 0.1	<0.05
Total Cadmium as Cd	None detected less than 0.01	<0.02
Total Calcium as Ca	13	--
Total Copper as Cu	None detected less than 0.01	0.04
Total Chromium as Cr	None detected less than 0.01	<0.02
Total Iron as Fe	3	0.150
Total Lead as Pb	None detected less than 0.5	0.1
Total Manganese as Mn	0.1	0.09
Total Magnesium as Mg	37	--
Total Mercury as Hg	None detected less than 0.0004	<0.0005
Total Nickel as Ni	None detected less than 0.1	0.1
Total Potassium as K	15.8	--
Total Sodium as Na	301	--
Total Zinc as Zn	0.05	0.12

a. Sampling done by PB-KBB Inc., on June 14, 1979 - In ICW at location of proposed raw water intake. Analysis performed by Shilstone Engineering Testing Laboratory, New Orleans, Louisiana.

b. From Appendix D of Final EIS - Texoma Group Salt Domes, Table D.6-4, p. D.6-5

Although no site-specific data currently exist, the present ambient air quality conditions at Big Hill are related to regionally high levels of NMHC and photochemical oxidants (measured as ozone) (see Sect. 3.1). Regional air quality data are summarized in Table 3-3. These data indicate that monitored concentrations of ozone are often in excess of the appropriate standard. The exact monitoring site locations are associated with specific source emissions that would not be present at the rural Big Hill site. Discussions with the Texas Air Control Board (Chief Air Quality Information Officer) indicated background NMHC concentrations can be best approximated (as a worst case) by using monitored values from the Houston Southeast/Seabrook site which is located about 50 miles southwest of Big Hill. Of the existing monitoring sites available, this one appeared most representative of topographic and industrial conditions found near Big Hill.

3.2.1.4 Ambient Sound Levels

Background noise levels around the Big Hill facilities are estimated to average 48 dB, with values generally ranging from 35 to 75 dB (Texoma Group FEIS, Sect. 4.6.4). Principal sources now present at the Big Hill site include periodic vehicle noise and sounds related to existing petroleum-based activities. At the raw water intake structure, transportation activities related to barge traffic on the ICW are the primary sources of above-ambient sound levels. Traffic along Highway 87 and the surf zone may add significantly to background sound levels at the intersection of the brine disposal line and Gulf Coast (see Fig. 2-6).

3.2.1.5 Species and Habitats

Big Hill Site

Existing habitats in the vicinity of the proposed 250-acre complex are related primarily to agricultural usage, although the U.S. Geological Survey (USGS) (1973) described much of the dome surface as industrial-urban because of the presence of existing petroleum-related development. Two ponds are present on the eastern edge of the site along with a stand of live oak trees. Agricultural lands surrounding the Big Hill site consist primarily of pasture and croplands, which may be rotated from year to year depending on owner preference.

Flora and fauna common to Chenier Plain upland habitats are discussed in detail in the Texoma Group FEIS, Sects. B.2.5.2.4, B.3.4.5.3, and K.7. This area consists largely of prairie grasslands which have been converted to pastureland. The vegetation is dominated by tall grasses such as bluestem, Indiangrass, Johnson grass, switchgrass, and prairie wildgrass, as well as improved pasture grasses and legumes. Dominant species of mammals include rabbits and rodents as well as domestic livestock, which graze on the prairie grasses. Birds in the area include several species of upland game birds and numerous sparrows and blackbirds. Nearby prairie grasslands which have been cultivated for rice crops are popular feeding grounds for geese and ducks in winter months. Some reduction in prairie grassland habitats converted for agricultural purposes has been noted in the Sabine Basin (Gosselink et al., 1979). Much of this change is attributed to changing patterns in urbanization.

Table 3-3. Texas Air Control Board continuous air quality monitoring stations (all values in ppm)

MONITOR LOCATION:	JEFFERSON CO. A.P.		BEAUMONT/LA MAR UNIVERSITY	WEST ORANGE	ALDINE/HARRIS CO.	HOUSTON EAST	TEXAS CITY	CLUTE/ FREEPORT	HOUSTON SOUTHEAST/ SEABROOK
PERIOD OF RECORD:	(Jan. to mid April 1979	(Sept. to Dec.) 1979	(Jan. to Dec.) 1979	(Jan. to June) 1979	(Jan. to Dec.) 1979	(Jan. to Dec.) 1979	(Jan. to Dec.) 1979	(Jan. to Dec.) 1979	(Jan. to Dec.) 1979
O_3/									
High 1 h avg.	.19 ppm	.14 ppm	.19 ppm	.20 ppm	.24 ppm	.24 ppm	.23 ppm	.22 ppm	.23 ppm
Mean	.04 ppm	.03 ppm	.02 ppm	.04 ppm	.03 ppm	.02 ppm	.03 ppm	.03 ppm	.04 ppm
# h > .12 ppm	18 h	5 h	20 h	22 h	128 h	67 h	48 h	76 h	150 h
NO_x/									
High 1 h avg.	.11		.15	.19	.73	.95	.17		.19
Mean	.03		.02	.01	.04	.07	.02		.02
NO_2/									
High 1 h avg.	.06		.05	.06	.26	.35	.11		.10
Mean	.01		.01	.01	.02	.03	.01		.01
NO/									
High 1 h avg.	.09		.12	.22	.65	.89	.11		.14
Mean	.01		.01	.02	.03	.04	0		.01
CO/									
High 1 h avg.				7.7	11.7	8.6	3.9	7.1	12.4
Mean				.20	0.6	0.7	0.2	0.3	0.2
NMHC/									
High 1 h avg.				2.0	7.0	7.0	8.2	6.2	4.4
Mean				0.1	0.5	1.0	0.5	0.5	0.3
6-9 am High 1 h avg.				1.5	3.2	3.8	3.1	5.2	3.9
6-9 am Mean				0.2	0.6	1.2	0.5	0.6	0.3
6-9 am # hrs >24 pphm				24	190	203	128	99	109
WS/									
High (mph)	33		19	25	25	39	29	27	28
Average	12		5	7	6	9	8	8	8
Temp/									
High (°F)	82		93	95	93	94	92	98	92
Average	56		70	67	65	64	67	70	66

SO_2/	JEFFERSON CO. A.P.	BEAUMONT/LA MAR UNIVERSITY (Jan. to Oct.) 1979	BEAUMONT/LA MAR UNIVERSITY (Oct. to Dec.) 1979	ALDINE/HARRIS CO. (Jan. to Oct.) 1979	ALDINE/HARRIS CO. (Oct. to Dec.) 1979	HOUSTON EAST Mar. to Oct.) 1979	HOUSTON EAST (Jan. to Feb., (Nov. to Dec.) 1979	TEXAS CITY (Jan. to Oct. 19) 1979	TEXAS CITY (Oct. 20 to Dec.) 1979
High 1 h avg.	.18	GC* .20	PF* .42	GC* .04	PF* .15	GC* .13	PF* .20	*GC .13	PF* .19
Mean	.00	.02	.02	0	0	0	.01	0	.01

*GC = Gas chromatography; PF = pulse fluorescence

NMHC standard of 160 $\mu g/m^3$ = 0.24 ppm

Raw Water and Brine Diffuser Systems

The raw water and brine diffuser pipelines would cross primarily wetlands and open-water habitats, in addition to some pastureland. North of the ICW the combined ROW will traverse about 4 miles of fresh-brackish marsh habitat. South of the ICW the brine line would cross about 3.5 miles of brackish and intermediate marsh. Common plant species and net primary production for the different marsh types are compared in Table 3-4 (Gosselink et al., 1979).

Insects are considered major consumers of net primary production in all wetland habitats (Gosselink et al., 1979). Their importance increases in freshwater marshes as the diversity of crustaceans decreases in response to lower salinities. Brackish and intermediate marsh habitats play an important role as nursery areas for shrimp, menhaden, croaker, and other estuarine-dependent taxa that comprise the bulk of Gulf Coast fisheries. A functional overview of a typical wetland system is presented in Fig. 3-2. Primary production, fixed as plant material, is the energy available for the rest of the food web and is directly linked to secondary production of fish, waterfowl, furbearers, and other renewable resources.

The point at which the brine disposal pipeline crosses the ICW is a brackish open-water habitat maintained periodically by the USACE at a controlling depth of 12 ft. Most primary production in the open waters results from phytoplankton of the coccoid blue-green and green algae types. Zooplankton communities are generally dominated by calanoid copepods and larval stages of other invertebrates such as polychaetes, oyster, crabs, shrimp, and barnacles. Many of these taxa, as discussed by Poirrier (1979), could present biofouling problems at the raw water intake structure.

Benthic communities in the ICW, having evolved in the presence of extreme fluctuations of salinity, turbidity, temperature, and dissolved oxygen, are typical of physically stressed estuarine environments. Fish and macrocrustaceans common to the ICW include members of the drum, anchovy, and shrimp families. Detailed descriptions of these communities are presented in the Texoma Group FEIS, Sect. B.2.5.2.4 and Appendix K. Site-specific data taken near the proposed intake structure generally indicate sparsely populated faunal communities.

Brine Disposal Sites (3.5- to 12.5-Mile Alternatives)

The Big Hill offshore sampling program was part of a comprehensive Texoma Group FEIS baseline physical, geochemical, and biological monitoring effort conducted from September 1977 through October 1978 (Comiskey et al., 1979). Monthly sampling occurred at five sites, three of which were potential brine discharge sites, in southwest Louisiana and southeast Texas (Fig. 3-3). Sampling at the Big Hill and Big Hill Control (BHC) sites continued for 14 months (13 collections) while the West Hackberry group sites (West Hackberry, West Hackberry Control, and Black Bayou) were sampled from September 1977 to May 1978 (8 collections). These five sites, which spanned a distance of about 55 miles of the Gulf Coast, encompass a wide range of sediment characteristics. The discussion of results at the Big Hill site can best be understood in the context of the other sites.

Table 3-4. Estimated net primary production per square meter for marsh habitats [total net primary production is calculated as the Σ_1^n (percent coverage times net primary production) for n species]

Salt marsh

Species	Net primary production (g/m²/year)	Coverage[1] (%)	Contribution to habitat net primary production (g/m²/year)
Saltgrass	2,900[2]	44.23	1,283
Smooth cord-grass	2,200[2]	12.31	270
Saltmeadow cordgrass	4,200[2]	3.08	129
Blackrush	3,300[2]	2.31	76
Alligatorweed	3,140[3]	1.15	36
Bulltongue	2,300[2]	1.15	26
Other[5]	---	15.92	451
Open area	---	19.85	---
Total net primary production			2,271

Intermediate marsh

Species	Net primary production (g/m²/year)	Coverage[2] (%)	Contribution to total net primary production (g/m²/year)
Saltmeadow cordgrass	4,200[2]	29.92	1,257
Bulltongue	2,300[2]	3.17	73
Common reed	2,400[2]	3.14	75
Alligatorweed	3,140[3]	2.72	85
Other[5]	---	34.90	1,335
Open area	---	26.35	---
Total net primary production			2,825

Brackish marsh

Species	Net primary production (g/m²/year)	Coverage[1] (%)	Contribution to total net primary production (g/m²/year)
Saltmeadow cordgrass	4,200[2]	36.70	1,541
Widgeon-grass	5,840[3]	4.67	273
Saltgrass	2,900[2]	9.88	287
Other[5]	---	15.81	655
Open area	---	32.77	---
Total net primary production			2,756

Fresh marsh

Species	Net primary production (g/m²/year)	Coverage[1] (%)	Contribution to total net primary production (g/m²/year)
Bulltongue	2,300[2]	17.90	412
Alligator-weed	3,140[3]	4.19	131
Saltmeadow cordgrass	4,200[2]	7.21	302
Blackrush	3,300[2]	1.31	43
Other	---	---	1,344
Open	---	23.08	---
Total net primary production			2,232

[1]Chabreck, 1972.

[2]Gosselink et al., 1977.

[3]Boyd, 1969.

[4]Nixon and Oviatt, 1973.

[5]Productivity assumed to be equal to the average for other species in the habitat.

Source: Gosselink et al. (1979)

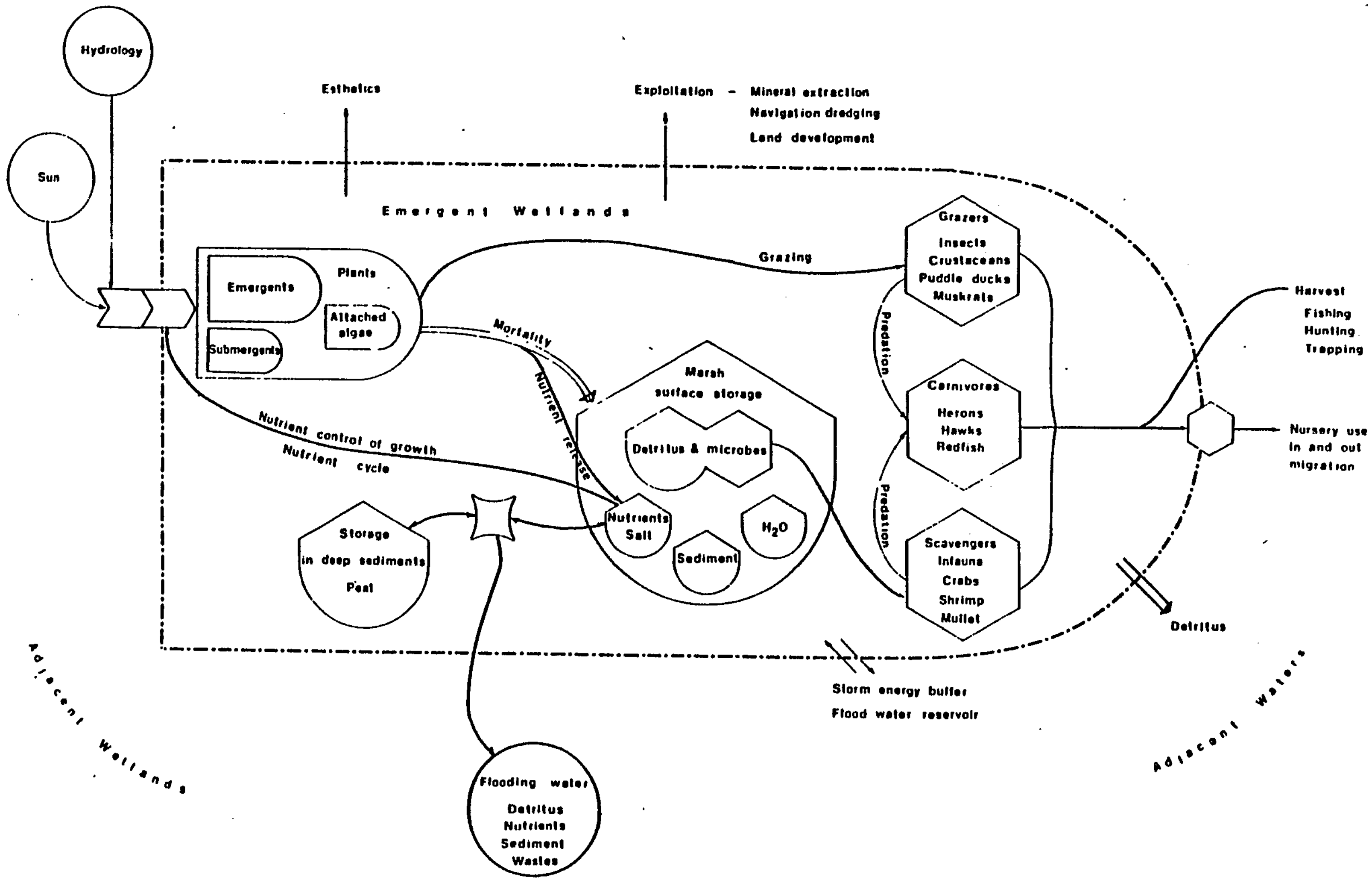

Figure 3-2. A model of a typical wetland system, showing major components and processes. Source: Gosselink et al. (1979).

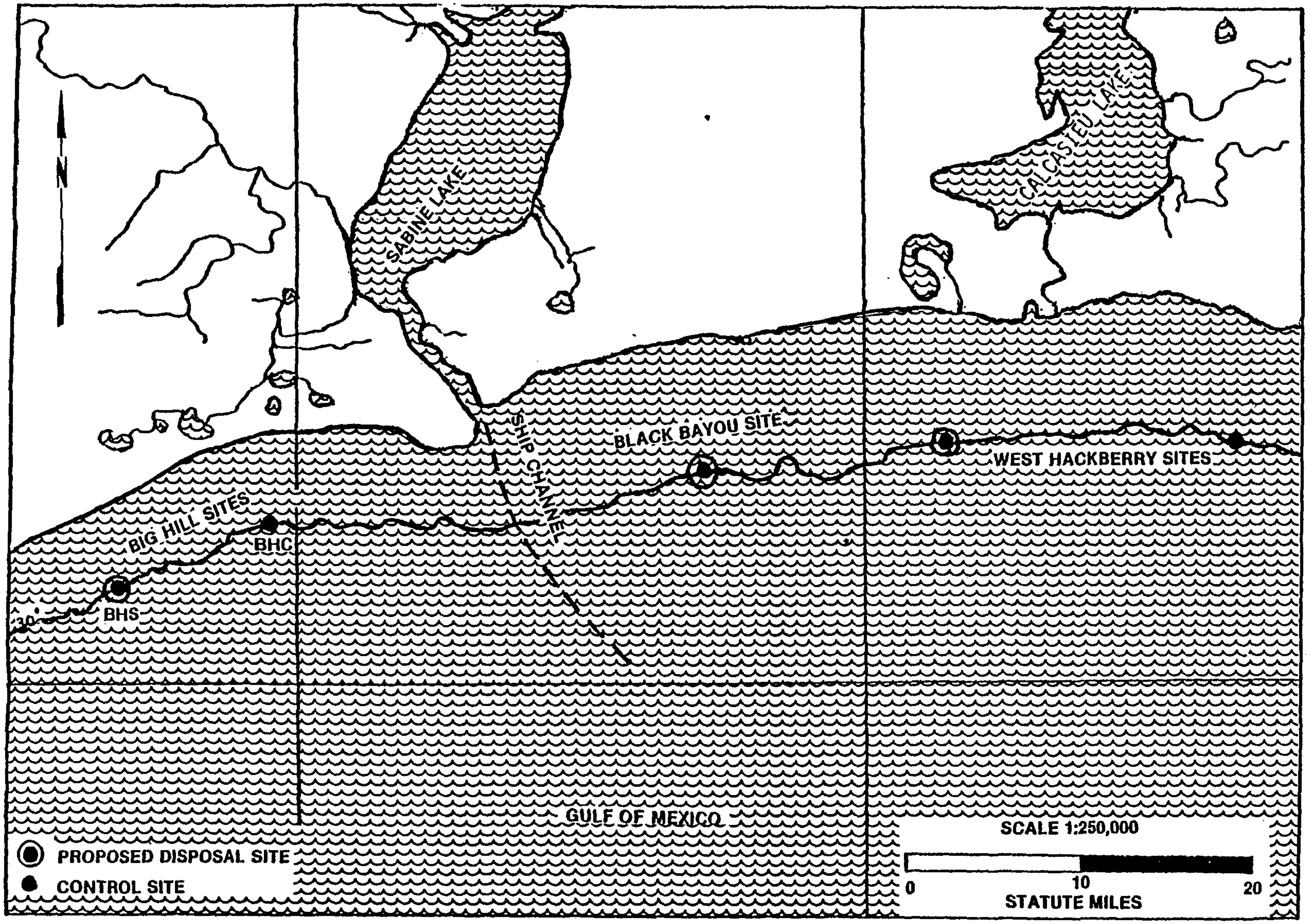

Figure 3-3. Location of Texoma biological study sites.

The bottom topography in the Big Hill study area consists of a steep near-shore zone that stretches from the beach off shore about 5 miles to the 35-ft contour line (Fig. 3-4). At this contour the bottom configuration changes to a large, flat plateau that extends about 15 to 20 miles further toward the Heald and Sabine Bank areas, which are separated by a relatively shallow submarine valley, about 11 miles wide.

The sampling stations at the Big Hill site are shown in Fig. 3-5. Coordinates for these stations and a sampling schedule for the whole program are presented in Appendix F, Tables F-1 and F-2, respectively. The sampling program was designed to optimize economic considerations and maximize statistical validity. As such, not all sites had the same number of stations and not all stations were sampled on each cruise. Two current meter stations were also used.

Results of the Texoma sampling program are summarized below. More detailed results for currents, winds, hydrologic and water quality parameters, phytoplankton, zooplankton, benthic macrofauna, and nekton, as well as sediment characterization, are presented in Appendix F.

Currents appeared to be mainly wind-driven, with net transport to the west during most seasons. However, during sampling period 3 (May 15 to July 12), this direction was reversed, with near-bottom currents strongest to the east. A near-surface current meter deployed at BHC at the start of sampling period 3 showed net longshore near-surface transport to the west, opposite that shown by a near-bottom current meter. During sampling period 4 (July 12 to September 13), mean longshore near-bottom currents were oriented in different directions for the Big Hill Secondary (BHS) and BHC sites. The near-surface current meter at the BHC site recorded onshore directed currents in excess of 3.3 ft/s during the passage of a large tropical depression in August 1978.

The longshore current component dominates near-shore circulation. Generally, the transshelf currents appear as minor deflections of the much more pronounced currents parallel to the local isobaths. There was an occasional episode during which the two current components were of similar magnitude, but this was usually the result of a decrease in longshore currents rather than any substantial increase in transshelf currents.

In general, the Big Hill 3.5-mile offshore site is typical of neritic waters with a variable hydrologic regime resulting from the interaction of terrestrial runoff and estuarine water with open Gulf water. Salinity was negatively related to river discharge, whereas land-derived nutrients (phosphate, nitrate, silicate) were positively related to regional and local discharge. Dissolved oxygen was strongly and negatively related to temperature, whereas salinity concentrations were strongly and positively related to sulfate. The Big Hill site did not show trends as distinct as those seen at the West Hackberry site for salinity/nutrient relationships due to the further distance of the Big Hill site from an estuarine water source.

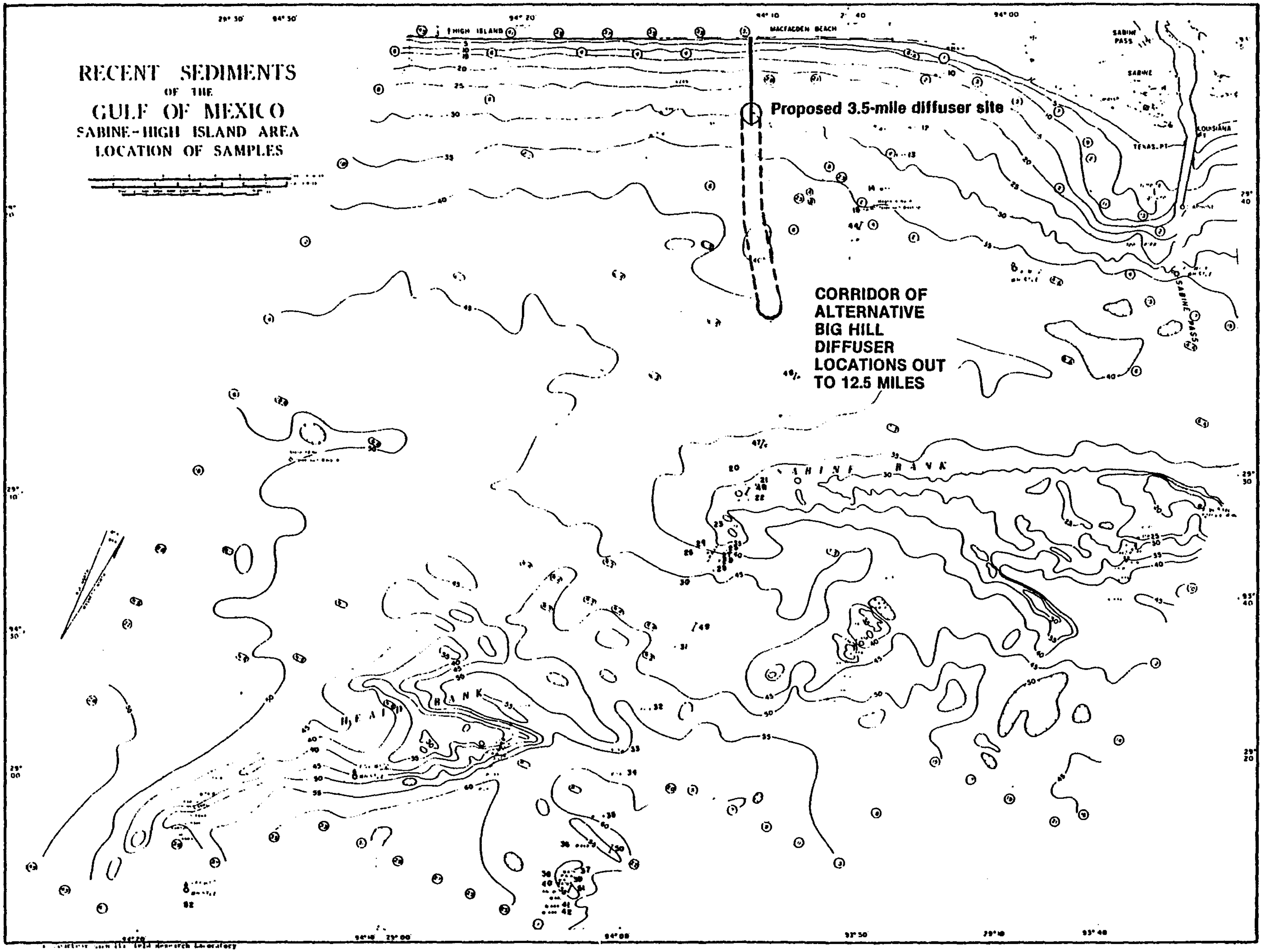

Figure 3-4. Bottom topography in the vicinity of the possible Big Hill diffuser sites.
Source: Hu[illegible]gs (1955).

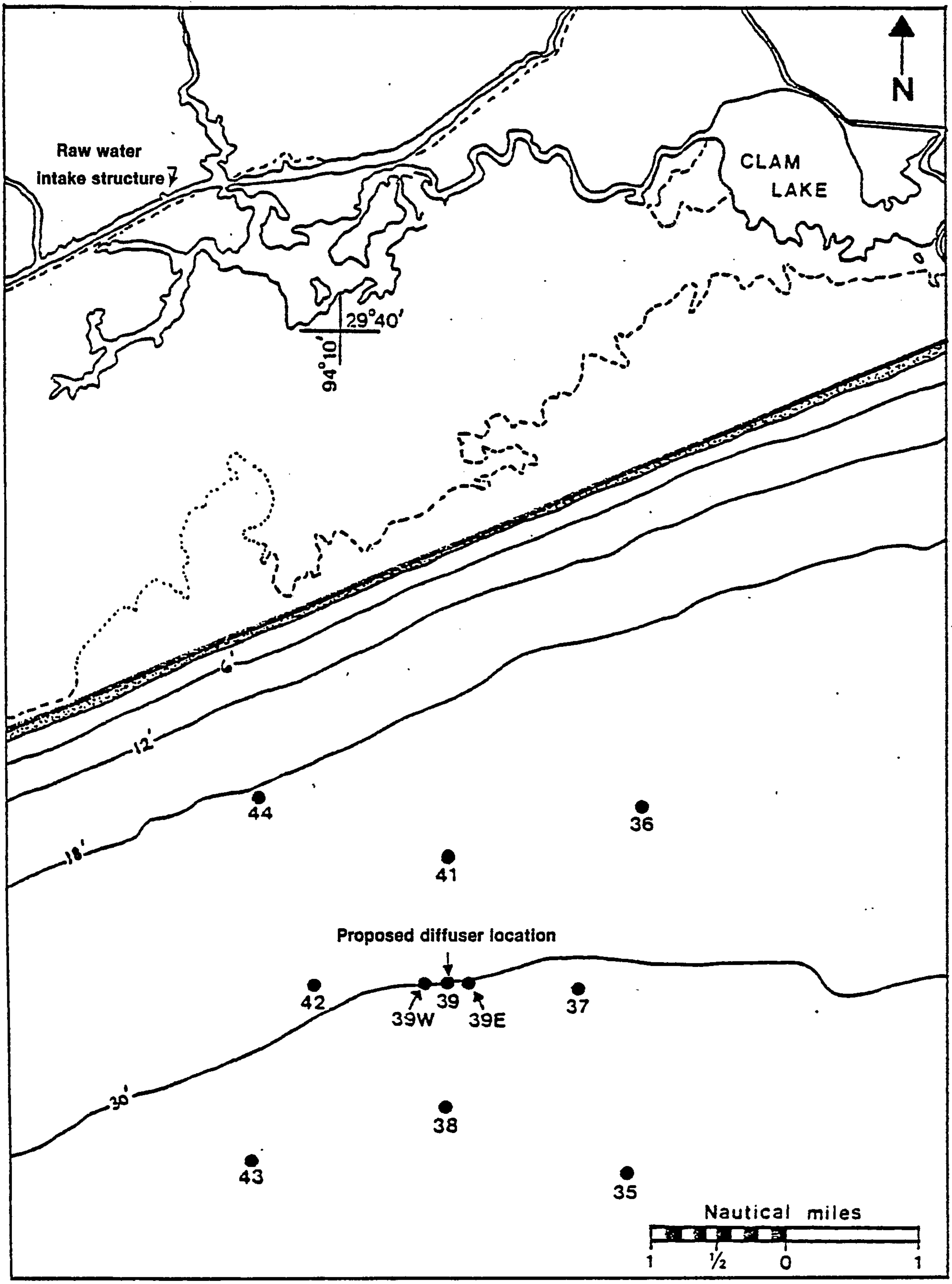

Figure 3-5. Sampling stations at the proposed 3.5-mile Big Hill brine disposal site.

A distinct dissolved oxygen minimum was recorded in June 1978. This is probably attributable to decay of phytoplankton-derived, organic detritus in addition to well developed density stratification and increasing temperatures. The only group to be affected by this dissolved oxygen minimum was the nekton, which apparently moved out of the zone of low dissolved oxygen concentrations, as evidenced by the low catches in the trawl sample. However, by the next collection, the nekton had returned.

Phytoplankton standing crops showed two peaks coincident with the peaks in freshwater discharge and high nutrient concentrations. Zooplankton standing crops were highest in the mid-spring to late-summer period and appeared to respond to increased availability of phytoplankton-derived detritus. Fish eggs, larvae and penaeid larvae, and postlarvae were most prevalent in the plankton in the summer. As with the phytoplankton, zooplankton abundance was dominated by seasonal effects, with spatial effects minimal. For both groups, the late-spring through summer samples were very similar in community composition.

Sediments at the Big Hill site have the highest means for most indicators of decreasing grain size, except for percent silt. No station at Big Hill had more than 10 percent sand-sized particles. Based on grain-size differences, the Big Hill site was more homogeneous than the West Hackberry site. The Big Hill sediments had the highest organic content of all the Texoma sites, but much of this was probably refractory (resistant to biodegradation). Seasonally, the highest percent clay occurred during the winter-early spring as a result of erosion of the overlying silt layer. The Big Hill site appears to be situated on an outcrop of Beaumont clay.

The benthos distribution is believed to be closely related to sediment particle size distribution. Most species showed a negative correlation to the fine-textured bottom sediments at Big Hill as compared with those Texoma sites with more coarsely textured substrates. Only Petricola pholadiformis (pelecypod) and Sabellides oculata (polychaete) showed a strong preference for the Big Hill site. Standing crops at Big Hill were the lowest of the five Texoma sites and lower than most historical studies in the area which utilized similar field and laboratory methodologies.

Based on the results of the Texoma sampling (Appendix F), along with the literature reviews of shrimp and menhaden ecology (Appendix G) and historical studies in the Big Hill area (Appendix F), the following comparisons and generalities can be made.

1. The topography of the study area is a gradual sloping shelf interrupted about 20 to 25 miles off shore by the presence of isolated patches of shell and by several large shell ridges (Sabine and Heald Bank). Because these banks are oriented longshore and are separated by a distinct gap, they should have little effect on circulation in the area. The shell banks, which are usually surrounded by sandy bottom, are choice benthic habitats and may harbor "hard bottom" fauna. The clay bottom at the 3.5-mile site

is one of the poorest substrates for benthos in the Gulf. The sediments in the corridor out to a 12.5 mile site may be only slightly more favorable to benthos, with both sites maintaining a more poorly populated community as compared with sand or shell substrates.

2. Bottom currents, which are important for maintaining circulation, are expected to be less responsive to wind effects at sites deeper than 30 ft.

3. Variations in ambient salinity are more likely near shore because of the proximity to freshwater sources. As one proceeds off shore, salinities rise to oceanic levels ($\geq$33 ppt). In the baseline Texoma studies, no salinities greater than 30 ppt were measured in the vicinity of the proposed 3.5-mile diffuser site. Salinity variance, especially that for near-surface waters, greatly decreases in an offshore direction.

4. Most of the demersal species found at the 30-ft contour are estuarine-dependent at some stage in their life cycle. These forms represent the most eurytolerant members of the fish fauna of coastal Louisiana and Texas. Euryhaline organisms are generally tolerant to both high and low salinities. Species composition gradually changes going off shore, with stenohaline marine forms replacing the euryhaline members of the more inshore community.

5. Brown shrimp, Penaeus aztecus, do not generally spawn in areas as close to shore as the 3.5-mile diffuser site, but may spawn at a 12.5-mile site. Postlarval and young shrimp may pass through the 3.5-mile site on their migrations to and from the estuaries.

6. Adult shrimp populations at both the 30- and 40-ft depths consist primarily of white shrimp. Few individuals of spawning size were collected at the 3.5-mile site, although postlarvae and juveniles were present throughout much of the year. Studies have shown that white shrimp larvae and postlarvae are able to withstand higher temperatures and salinity fluctuations than brown shrimp larvae. Bioassay results indicate that toxic effects from salt dome brine on eggs, larvae, and postlarvae of shrimp begin at approximately 38 to 40 ppt with minimum exposures of 24 h. Control salinities for these experiments which correspond to ambient conditions in the Gulf ranged from 30 to 33 ppt.

7. All literature reviewed indicated that penaeid shrimp and Gulf menhaden are euryhaline, with all stages of the life cycles easily able to tolerate the increases in salinity from brine disposal.

8. The shrimp populations and also those of many finfishes in the Big Hill area are heavily exploited, perhaps receiving the heaviest pressure of any fishery in the world. Catch success is based on a single year class. During most years, due to fishing pressure, less than maximum population densities exist.

9. The great fecundity of female shrimp allows successful recruitment despite the high degree of exploitation by man. It also allows quick recovery from a bad year. This is typical of estuarine-dependent organisms, adapted to environments which are variable. No studies have defined spawner-recruitment relationships for commercial shrimp. This factor allows the penaeid populations to rebound quickly from a poor production year. However, since the supply of postlarval shrimp entering the estuaries has not been shown to be closely related to shrimp production, the shrimp populations will not necessarily rebound if conditions in the estuary are not conducive to shrimp production.

10. Most recent studies from a number of shrimp fisheries have confirmed that it is factors inside the estuaries (especially temperature and salinity) that determine the success or failure of the shrimp year class. Studies that have attempted to use postlarval catch near the estuaries as an indication of subsequent adult production have generally proven highly inaccurate. On the other hand, juvenile abundance in the estuaries has been closely linked to subsequent offshore production. In this regard, Sabine Lake, the only estuarine habitat in the immediate (<20 miles) vicinity of the Big Hill sites is no longer an important nursery for shrimp production. Upstream impoundment of the Sabine River has changed the seasonal flow regime, and it no longer is as conducive to shrimp production.

Threatened and Endangered Species

Big Hill development would occur within the possible ranges of some endangered, threatened, and protected species. Information on these organisms which is specific to the components of the Big Hill complex is not available. Through consultation with the USFWS, it was determined that the taxa presented in Table 3-5 were of primary concern (letter communication between W. E. Klett, USFWS Area Manager to N. D. Gray, DOE/SPR, October 28, 1980; see Appendix D).

All of the on-land preferred actions discussed in this document occur within the historic range of the red wolf. Carley (cited in USACE, 1979) states that probably fewer than 50 pure red wolves now remain in the wild. Habitat destruction, predator control, disease, and hybridization with coyote appear to be the greatest threats to the remaining population.

The entire upper Texas coast is considered feeding habitat for migrating bald eagles and peregrine falcons. Several brown pelicans are known to reside on the grounds of Sea-Arama Marineworld in Galveston and may fly over and possibly feed in and around the region (USACE, 1979).

The American alligator is now considered threatened in southeast Texas coastal counties. It is possible for the alligator to inhabit virtually any predominantly freshwater habitat within the area. Several have been observed in the wetlands between the Big Hill site and the ICW, and these populations are on the increase. A limited hunting season has been established by the Louisiana Department of Wildlife and Fisheries in the state.

Table 3-5. **Threatened and endangered species in Jefferson County, Texas**

LISTED SPECIES

Red Wolf (Canis rufus) - Limited in Texas to Orange and Jefferson Counties south of I-10. Probably will soon be extinct in its final range in Texas.

Brown Pelican (Pelecanus occidentalis) - Brown pelicans may be found in adjacent Chambers County. A small resident flock is found along the Central Coast. Migratory flocks from the Gulf Coast of Mexico frequently enter Texas waters.

Peregrine Falcon (Falco peregrinus tundrius) - May occur statewide during spring and fall migration. Concentrate along Gulf Coast, especially North and South Padre Island.

Bald Eagle (Haliaeetus leucocephalus) - May occur statewide as a wintering species around large bodies of water. The major concentrations generally occur from November to March.

Alligator (Alligator mississippiensis) - May be found anywhere along the Texas coast in rivers, swamps, marshes, lakes, and estuaries.

PROPOSED SPECIES

NONE

CRITICAL HABITAT

NONE

Source: USFWS, 1980 (see Appendix D).

Marine mammals such as sperm whale (Physeter catodon), finback whale, (Balaenoptera physalus), blue whale (Balaenoptera musculus), and black right whale (Balaena glacialis) are considered accidental in near-shore regions and rare off shore in this region of the Gulf of Mexico. Sea turtles such as the loggerhead, green, leatherback, hawksbill, and ridley have been reported along the Texas coast. However, in recent years they have become extremely rare. A single female ridley was observed nesting in south Texas in 1979. Other species that could potentially occur within the project area are discussed in Appendix E.

3.2.1.6 Natural and Scenic Resources

Site Facilities

The area around Big Hill salt dome is a rural coastal Texas agricultural setting. Although natural and scenic resources are less evident in the actual site area, an extensive system of coastal wetlands, which serve as important waterfowl wintering areas, id found in areas adjacent to the site and extend from Sabine Lake to East Bay. Nearby wildlife refuge and management areas are described in the Texoma Group FEIS, Sect. B.2.6. Since publication of the FEIS, the USFWS has established McFaddin National Wildlife Refuge immediately to the south and east of the Big Hill salt dome (USFWS, 1977b). The McFaddin Marsh is ranked 4th of 25 "key" areas along the Gulf Coast of Texas with high value for waterfowl (USFWS, 1977a). The McFaddin Refuge is about 54,500 acres in size, and its major purpose is to provide wintering habitat for migratory waterfowl (USFWS, 1977b). Habitats within the refuge consist of 40,800 acres of wetland, 800 acres of open water, and 12,900 acres of upland. State authorities recognize the area for its high natural productivity and importance in overall coastal ecosystem functioning. These factors are discussed in detail in Gosselink et al. (1979) and Texoma Group FEIS, Sects. B.2.5.1 and B.2.5.2.4.

Raw Water and Brine Disposal Systems

The area that would be traversed by the common corridor of the raw water supply pipeline and the brine disposal pipeline from the Big Hill site to the ICW is primarily marshland. Hunting, fishing, and birdwatching are popular recreational activities because these wetland areas provide wintering grounds for ducks and geese, year-round habitat for furbearers, and nursery areas for many aquatic animal species. Beyond the ICW, the brine disposal pipeline would cross McFaddin National Wildlife Refuge enroute to the Gulf of Mexico (Fig. 2-6). Near the coast, the pipeline would cross a small section of sand dunes and beach. These resources are continuous from Sabine Lake to Galveston Bay and, as such, would be traversed by any pipeline route from the Big Hill site to the Gulf of Mexico (see Sect. 4.2.1.1).

3.2.1.7 Archaeological, Historical, and Cultural Resources

Archaeological, historical, and cultural resources in the vicinity of the Big Hill salt dome have been described in the Texoma Group FEIS, Sects. 3.3.4.7 and B.3.4.7. A cultural resources survey randomly sampled the dome area (Thomas et al., 1977). Although no sites were found, additional studies would be conducted before and during construction activities. The proposed brine discharge pipeline corridor was also surveyed in the cultural resources study, which concluded that it is unlikely that historical sites will be located near the impact area.

Based on the National Register of Historic Places (Federal Register, February, 1979; March, 1980; February, 1981), there are no properties listed or proposed that would be affected by construction at Big Hill. The closest site in Jefferson County is the Lucas Gusher, Spindletop oil field about 3 miles south of Beaumont.

3.2.1.8 Socioeconomics

The Big Hill site is located in a rural portion of Jefferson County, southwest of the Beaumont-Port Arthur-Orange industrial triangle. Over 99 percent of the county population lives in the northern part of the county away from the coast. The periphery of the greater Houston, Texas City, and Galveston areas is about 50 miles from Big Hill. Population estimates for the metropolitan areas within commuting distance of the site are presented in Table 3-6. The slight decrease in the population of Jefferson County between 1970 and 1980 may reflect (1) census undercounts, (2) small changes in employment trends, or (3) population shifts to bordering counties. Goods, services, and housing are readily available in Jefferson County cities (Southeast Texas Regional Planning Commission, personal communication, November 1980).

Only very small unincorporated communities are located within a 15-mile radius of the Big Hill salt dome. Of these, Winnie in Chambers County is the largest (see Table 3-6). The closest residence is over a mile from the proposed site facilities. Goods, services, and housing are not readily available. In these small communities, many people reside in mobile homes (Chambers County Courthouse, Southeast Texas Regional Planning Commission, personal communication, November 1980).

Land use patterns around the site consist primarily of farming, cattle grazing, and industrial development, especially petroleum production. Transportation networks through the area consist of highways, unpaved roads, railroads, the ICW, pipelines, and several landing strips for small planes. Vehicle counts for the major access roads to the Big Hill site, Interstate 10, and Texas Highways 124, 73, and 65 are presented in Table 3-7.

The overall economy of the area around Big Hill is based on agriculture and production of oil and gas. Rice, the most common crop in the area, ranks third in value among Texas crops. Since discovery of the Spindletop oil field in 1901, oil has been a major source of revenue in Jefferson County.

The total number of people in nonagricultural wage and salary employment was estimated in September 1980 at 145,550 for Jefferson, Orange, and Hardin Counties combined. Of this labor force, 10,200 people (or 7.0 percent) were involved in construction-related employment (Texas Employment Commission, personal communication, November 1980). It is

Table 3-6. Population estimates for the geographic area around Big Hill salt dome, Jefferson County, Texas

Location	1970	Other	1980 (projected)
TEXAS			
Jefferson County			
County (total)	246,402		242,601
Beaumont	117,548		114,895
Port Arthur	57,339		59,087
Groves	18,067		16,684
Nederland	16,810		16,575
Port Neches	10,894		13,648
La Belle[2]	3,453		4,571
Fanette[2] Hamshire[2]			<2,000
Chambers County			
County (total)	12,184	16,286 (1978)	16,962
Anahuac	1,881	2,340 (1978)	
Montbelieu	1,144	1,529 (1978)	
Winnie[2]			2,365
Stowell[2]			1,429
Sea Breeze[2] Figridge[2]			<900
Orange County			
County (total)	71,170		81,822
Orange	24,457		23,010
Vidor	9,738		11,125
Bridge City			7,549
West Orange	4,820		4,449
Pinehurst	2,198		2,672
Harris County			
County (total)	1,741,912	2,364,400 (1978)	2,578,225
Houston	1,235,992	1,693,206 (1978)	
Pasadena	89,277	105,209 (1978)	
Baytown	43,980	48,114 (1978)	
Deer Park	12,773	21,214 (1978)	
Galveston County			
County (total)	169,612	202,767 (1978)	207,565
Galveston	61,809	71,861 (1978)	
Texas City	38,908	41,692 (1978)	
Lamarque	16,131	16,279 (1978)	
League City	10,818	13,261 (1978)	
Crystal Beach	2,425	~ 5,000 (1978)	

(Column heading "Population estimate[1]" spans 1970, Other, 1980 (projected).)

Table 3-6 (continued)

Location	Population estimate[1]		
	1970	Other	1980 (projected)
LOUISIANA			
Calcasieu Parish			
Parish (total)	145,415	161,473 (1979)	
Lake Charles	77,998	80,684 (1979)	
Sulphur	14,959	19,366 (1979)	
Westlake	4,082	4,375 (1979)	
Vinton	3,545	3,739 (1979)	
Cameron Parish			
Parish (total)[3]		10,021 (1979)	

[1]Information provided by personal communication (November 1980) with Southeast Texas Regional Planning Commission, Houston-Galveston Area Council, Chambers County Courthouse, Imperial Calcasieu Regional Planning and Development Commission, and Louisiana Department of State.

[2]Unincorporated.

[3]All towns within parish are unincorporated.

Table 3-7. Estimated vehicle counts on highways near Big Hill salt dome, Jefferson County, Texas[1]

Highway	Year of count	Point at which count taken	Vehicle count (cars/day)
Interstate 10	1976	Winnie	16,960
		Wallaceville	18,060
		Cedar Bayou	19,920
	1978	Beaumont	
		Fannett Area	20,890
		Near US-90	84,450
		East; near 11th Street	61,890
		Vidor	
		Near Highway 105	43,050
		Orange	
		Near LA border	17,840
		Near Highway 87	22,270
Highway 73	1978	Port Arthur	
		Near Highway 214	14,630
		Towards Winnie	
		Near Taylor Bayou	6,160
		At LaBelle Road	3,550
Highway 124	1976	Hamshire	2,160
		Winnie	
		Near Highway 65	5,340
		Stowell	2,580
Highway 65	1976	Stowell	1,280
		Anahuac	1,180

[1]Information provided by personal communication (November 1980) with Texas Highway Department, Beaumont Office.

also possible that skilled labor from Houston, Galveston, and Lake Charles may be available for construction operations at the Big Hill complex.

Offshore Shrimp and Menhaden Fisheries Economics

Gulf Coast shrimp landing data are published by the National Oceanic and Atmospheric Administration/National Marine Fisheries Service (NOAA/NMFS) for the entire Gulf of Mexico by statistical area (Fig. 3-6) and by 5-fathom depth intervals. Both monthly and annual catch are given for brown, pink, white, others (including sea bobs), and total catch, as well as total dollar value. Also presented are the number of trips and total days fished for each area and depth interval stratum. Recruitment values can be determined from inshore catch. For each species, catch data are also presented by size class.

Because the Big Hill sites are located almost directly on the dividing line between statistical areas 17 and 18, Tables 3-8 and 3-9 present the 1977 (NOAA, 1979) annual summary data for both areas, which collectively extend from the east of Calcasieu River to just west of Galveston Bay. Table 3-8 presents data for all important species, while Table 3-9 presents size class composition data for P. aztecus and P. setiferus, respectively.

The potential Big Hill diffuser sites would be located at depths of 30 and 40 ft, requiring the examination of potential brine disposal impacts for the three innermost depth zones (0 to 15 fathoms). The annual catch data for statistical areas 17 and 18 for three depth intervals (0 to 5 fathoms, 6 to 10 fathoms, and 11 to 15 fathoms) and also for the combined 0- to 10-fathom intervals are presented in Tables 3-10 and 3-11. The area within each depth interval (which allows catch per unit area to be calculated) is also provided in these tables. The total shrimp catch (all species) for the entire statistical area in waters less than 10 fathoms was $9,202,935 and $9,250,723 for statistical areas 17 and 18, respectively. Although the total pounds of the catch from the 0- to 5- and 6- to 10-fathom intervals were similar in statistical area 17, the dollar value of the 6- to 10-fathom interval is about $1 million higher due to the higher market value of the larger offshore shrimp. For statistical area 18, both the total dollar value and total pounds are over twice as high for the 6- to 10-fathom depth interval as compared to the 0- to 5-fathom interval (which is small in area due to the lack of large open bays). As Table 3-11 shows, the white shrimp (P. setiferus) catch tends to be greatest in waters less than 10 fathoms deep, whereas the brown shrimp (P. aztecus) catch tends to be more numerous in the 6- to 15-fathom depths. These trends are consistent with the generally understood ecological requirements of the two species and the concept of an inner white shrimp community and an offshore brown shrimp community (Hildebrand, 1954; Chittenden and McEachran, 1976). Pink shrimp catch is virtually nonexistent in the two statistical areas, and the substantial catch of "others" in the 0- to 5-fathom range is composed mainly of sea bobs (Xiphopenaeus kroyeri).

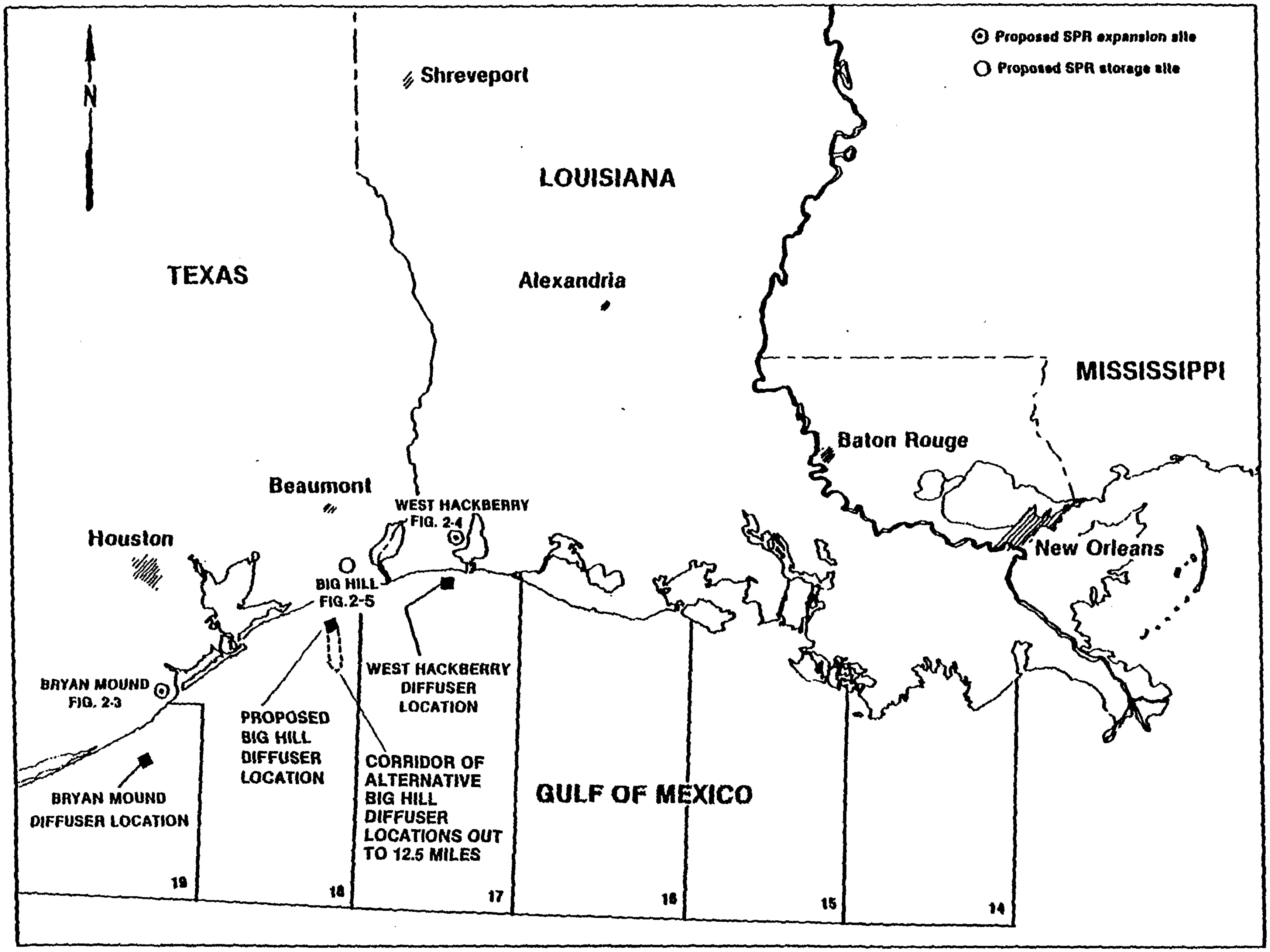

Figure 3-6. National Marine Fisheries Service statistical fishing grid zones. Source: NOAA (1979).

Table 3-8. Annual summary of Gulf Coast shrimp data for 1977 as reported by area and depth for statistical areas 17 and 18

Total catch (lb) expressed by species

AREA CODE	DEPTH FATHOMS	TRIPS NUMBER	DAYS FISHED NUMBER	BROWN	PINK	WHITE	1/ OTHER	TOTAL POUNDS	TOTAL DOLLARS
				. . . . POUNDS					
MISSISSIPPI RIVER TO TEXAS									
0170	000-005	3,234.2	6,611.5	210,153	-	1,901,626	178,728	2,290,507	4,103,778
0170	006-010	1,874.1	4,537.8	1,275,984	-	1,176,878	-	2,452,862	5,099,157
0170	011-015	705.8	1,959.1	1,149,818	-	62,904	-	1,212,722	2,670,405
0170	016-020	501.8	2,152.9	1,257,177	-	-	-	1,257,177	2,796,546
0170	021-025	231.5	1,053.7	834,947	4,672	-	2,264	841,883	1,997,081
0170	026-030	474.0	930.4	1,154,134	-	-	-	1,154,134	3,110,673
0170	031-035	232.7	1,036.6	743,656	-	-	-	743,656	2,104,739
0170	036-040	157.7	747.2	381,694	-	-	-	381,694	1,189,892
0170	041-045	35.4	138.0	29,339	-	-	-	29,339	122,936
0170	046-050	23.5	98.3	37,464	-	-	-	37,464	141,150
	TOTAL	7,440.7	19,265.5	7,074,366	4,672	3,141,408	180,992	10,401,438	23,336,357
0172	000-005	61.1	136.3	-	-	16,988	3,700	20,688	35,035
	TOTAL	61.1	136.3			16,988	3,700	20,688	35,035
TEXAS COAST									
0180	000-005	1,910.7	5,424.9	69,896	-	1,071,073	61,147	1,202,116	2,597,476
0180	006-010	2,282.6	6,574.8	2,056,574	-	940,155	-	2,996,729	6,653,247
0180	011-015	909.1	2,932.8	2,124,116	-	15,888	8,901	2,148,905	4,360,782
0180	016-020	841.7	3,006.5	2,254,444	-	-	24,068	2,278,512	4,861,733
0180	021-025	186.9	693.3	543,108	-	-	-	543,108	1,299,477
0180	026-030	179.9	736.3	543,787	-	-	-	543,787	1,506,561
0180	031-035	83.4	390.9	159,594	-	-	-	159,594	514,757
0180	036-040	99.2	481.5	309,086	-	-	-	309,086	826,166
	TOTAL	6,393.5	20,241.0	8,060,605		2,027,116	94,116	10,181,837	22,620,199
0181	000-005	15,390.0	2,370.0	858,092	-	1,516,996	1,525	2,376,613	3,018,240
	TOTAL	15,390.0	2,370.0	858,092		1,516,996	1,525	2,376,613	3,018,240

Source: NOAA (1979).

Table 3-9. Annual summary of Gulf Coast shrimp data for 1977 as reported by area and depth for statistical areas 17 and 18

Total catch for brown shrimp (P. aztecus) and white shrimp (P. setiferus) expressed by size class

TOTAL BROWN SPECIES BY SIZE

AREA CODE	DEPTH FATHOMS	UNDER 15	15-20	21-25	26-30	31-40	41-50	51-67	68 & OVER	TOTAL
		SIZE (HEADS-OFF PER POUND)								
MISSISSIPPI RIVER TO TEXAS-		. . . . POUNDS . . .								
0170	000-005	1,215	6,413	5,827	327	13,513	66,912	2,524	113,338	210,153
0170	006-010	2,009	7,073	40,982	27,606	663,953	349,179	172,862	11,682	1,275,984
0170	011-015	7,720	14,503	103,313	172,902	621,030	186,921	34,946	1,862	1,149,818
0170	016-020	6,782	61,134	199,955	133,836	410,587	161,071	213,441	43,456	1,257,177
0170	021-025	4,599	55,475	183,531	112,002	320,215	67,289	59,442	19,831	834,947
0170	026-030	6,446	275,683	534,512	164,980	159,407	8,167	2,676	-	1,154,134
0170	031-035	14,969	122,319	528,877	19,471	38,785	9,791	4,575	-	743,656
0170	036-040	12,176	88,360	275,065	5,893	-	-	-	-	381,694
0170	041-045	-	29,339	-	-	-	-	-	-	29,339
0170	046-050	9,568	24,477	-	3,419	-	-	-	-	37,464
	TOTAL	65,484	684,776	1,872,062	640,436	2,226,490	849,230	490,466	190,169	7,074,366
TOTAL AREA		322,117	2,376,607	4,207,041	2,473,113	5,497,300	3,154,121	6,563,695	22,243,533	46,952,150
TEXAS COAST										
0180	000-005	-	-	-	-	69,896	-	-	-	69,896
0180	006-010	3,812	15,908	62,359	187,919	1,268,987	363,332	123,166	29,159	2,056,574
0180	011-015	1,894	21,935	70,369	368,522	1,077,557	309,115	190,003	61,690	2,124,116
0180	016-020	232	38,670	393,228	377,267	918,347	226,631	248,256	32,252	2,254,444
0180	021-025	-	102,658	109,414	131,000	145,294	54,742	-	-	543,108
0180	026-030	9,127	116,797	244,649	168,693	3,757	331	189	-	543,787
0180	031-035	3,702	41,990	83,318	616	29,968	-	-	-	159,594
0180	036-040	2,981	43,201	179,468	10,205	34,163	19,853	7,229	612	309,086
	TOTAL	21,748	381,159	1,142,805	1,244,222	3,547,989	974,004	568,843	123,713	8,060,605
0181	000-005	-	832	10,964	1,115	9,719	34,406	150,579	650,477	858,092
	TOTAL		832	10,964	1,115	9,719	34,406	150,579	650,477	858,092

TOTAL WHITE SPECIES BY SIZE

AREA CODE	DEPTH FATHOMS	UNDER 15	15-20	21-25	26-30	31-40	41-50	51-67	68 & OVER	TOTAL
		SIZE (HEADS-OFF PER POUND)								
MISSISSIPPI RIVER TO TEXAS-		. . . . POUNDS . . .								
0170	000-005	14,625	73,096	272,872	250,532	596,557	172,459	170,136	346,852	1,901,626
0170	006-010	45,149	192,957	276,570	164,050	210,932	46,520	95,163	137,095	1,176,878
0170	011-015	303	8,878	28,746	677	11,784	9,018	3,438	-	62,904
	TOTAL	60,077	274,931	578,188	415,259	819,273	227,997	268,737	483,987	3,141,408
0172	000-005	-	-	-	-	14,780	-	-	2,208	16,988
	TOTAL					14,780			2,208	16,988
TOTAL AREA		569,967	2,535,102	3,338,601	2,516,709	4,756,656	2,065,600	3,781,826	11,708,820	31,331,568
TEXAS COAST										
0180	000-005	5,864	18,028	120,272	431,283	373,458	46,049	54,183	21,936	1,071,073
0180	006-010	32,974	80,325	258,300	280,320	262,496	9,640	5,552	10,548	940,155
0180	011-015	1,740	2,930	2,309	2,970	4,864	1,075	-	-	15,888
	TOTAL	40,578	101,283	380,881	714,573	640,818	56,764	59,735	32,484	2,027,116
0181	000-005	20	1,360	27,007	90,135	497,729	168,397	349,961	382,387	1,516,996
	TOTAL	20	1,360	27,007	90,135	497,729	168,397	349,961	382,387	1,516,996

Source: NOAA (1979).

Table 3-10. Catch data (lb) for selected depth intervals (subareas) in statistical area 17 for 1977[1]

Depth interval (fathoms)	Area (acres)[2]	Brown shrimp	White shrimp	Pink shrimp	Others[3]	Total	Value ($)
0 to 5	318,836.6	210,153	1,901,626	0	178,728	2,290,507	4,103,778
6 to 10	1,296,797.6	1,275,984	1,176,878	0	0	2,452,862	5,099,157
0 to 10	1,615,634.2	1,486,137	3,078,504	0	178,728	4,743,369	9,202,935
11 to 15	1,074,701.2	1,149,818	62,904	0	0	1,212,722	2,670,405

[1]Catch data from Gulf Coast Shrimp Data, Annual Summary 1977 (NOAA, 1979).

[2]Converted from hectare values given by Patella (1975).

[3]Mostly sea bobs (Xiphopenaeus kroyeri).

Table 3-11. Catch data (lb) for selected depth intervals (subareas) in statistical area 18 for 1977[1]

Depth interval (fathoms)	Area (acres)[2]	Brown shrimp	White shrimp	Pink shrimp	Others[3]	Total	Value ($)
0 to 5	197,400.4	69,896	1,071,073	0	61,147	1,202,116	2,597,476
6 to 10	1,268,693.3	2,056,574	940,155	0	0	2,996,729	6,653,247
0 to 10	1,466,093.7	2,126,470	2,011,228	0	61,147	4,198,845	9,250,723
11 to 15	663,326.9	2,124,116	15,888	0	8,901	2,148,905	4,360,782

[1]Catch data from Gulf Coast Shrimp Data, Annual Summary 1977 (NOAA, 1979).

[2]Converted from hectare values given by Patella (1975).

[3]Mostly sea bobs (Xiphopenaeus kroyeri).

Tables 3-12 and 3-13 were derived by converting catch data to catch per unit area, using Patella's (1975) values (see Tables 3-10 and 3-11). Given are the catch values for 1 acre of offshore water for each depth interval, under the assumption of equal productivity over the whole statistical area for that depth interval. The most productive area, in terms of both poundage and dollar value, is the 0- to 5-fathom area, where each acre yields 7.2 and 6.0 lb of shrimp for statistical areas 17 and 18, respectively. Within both areas, the 6- to 10- and 11- to 15-fathom subunits are of approximately equal value, but the species composition of the catch is very different. The values for the 0- to 10-fathom areas are approximately the same, totaling around 3 lb and $6 value per acre.

To date, no detailed reporting system, equivalent to the shrimp landing data, exists for menhaden catch records. A detailed discussion of the fishery is presented in Appendix G. Menhaden were reportedly landed as early as 1900 in the Gulf of Mexico. The first menhaden landings in Texas occurred before 1920 and not until after 1945 in Louisiana. The annual catch remained small until after World Wor II. From 1946 to 1970, there was a 15-fold increase in menhaden landings (35,000 to 546,000 metric tons). The increase was not continuous; decreases in landings occurred several times in the 1950s and 1960s.

The number of operating menhaden reduction plants increased from 2 in 1946 to 14 in 1968, and there were 13 plants in 1970. Each plant is supplied by 6 to 10 vessels, and between 70 to 90 vessels make up the Gulf fleet. The wholesale value of Gulf menhaden products in 1971 was greater than $43 million, and the 80 menhaden vessels fishing the Gulf were valued at $31.2 million. The 13 processing plants in operation at that time were valued at greater than $42 million, and more than 2000 people were employed in menhaden operations along the Gulf.

Through the 1960s there was a distinct trend for the landings at Louisiana ports to increase and the landings at ports in other Gulf states to decrease. Florida and Mississippi landings decreased from 30 percent of the total Gulf landings in 1961 to 17 percent in 1970. For Texas, the annual landings decreased from 13 percent of the total in 1961 to 4 percent in 1970. The Texas commercial fishery for menhaden, which began in 1950, essentially ended with the closing of the menhaden fish plant at Sabine Pass, Texas, in 1972.

According to Fisheries of the United States (NMFS, 1981), the Gulf menhaden catches in 1979 and 1980 were 1.72 and 1.55 billion pounds, respectively. Of the 1.55 billion pounds of menhaden caught in the Gulf in 1980, 1.31 billion pounds were caught within 3 miles of the coast. The 1979 Gulf catch was valued at $73.4 million, whereas that for 1980 was valued at $69.1 million. For the 5-year period, 1975 to 1979, the average annual catch of Gulf menhaden was 1.39 billion pounds.

3.2.2 Crude Oil Distribution System

The crude oil distribution system, as discussed in Sect. 2.0, would consist of one preferred pipeline route to Sun Terminal in Nederland, Texas, and two possible alternative routes to either the Oil Tanking of

Table 3-12. Catch data (lb/acre) for selected depth intervals (subareas) in statistical area 17 for 1977[1]

Depth interval (fathoms)	Catch (lb/acre)					Catch value ($/acre)
	Brown shrimp	White shrimp	Pink shrimp	Other[2]	Total	
0 to 5	0.659	5.964	0	0.561	7.184	12.87
6 to 10	0.984	0.908	0	0	1.892	3.93
0 to 10	0.920	1.905	0	0.110	2.935	5.70
11 to 15	1.070	0.060	0	0	1.13	2.49

[1]Catch data calculated from Gulf Coast Shrimp Data, Annual Summary (NOAA, 1979) and water surface area data (from Patella, 1975).

[2]Mostly sea bobs (Xiphopenaeus kroyeri).

Table 3-13. Catch data (lb/acre) for selected depth intervals (subareas) in statistical area 18 for 1977[1]

Depth interval (fathoms)	Catch (lb/acre)					Catch value
	Brown shrimp	White shrimp	Pink shrimp	Other[2]	Total	($/acre)
0 to 5	0.354	5.426	0	0.310	6.09	13.16
6 to 10	1.621	0.741	0	0	2.362	5.24
0 to 10	1.450	1.372	0	0.042	2.864	6.31
11 to 15	3.202	0.024	0	0.013	3.239	6.57

[1]Catch data calculated from Gulf Coast Shrimp Data, Annual Summary (NOAA, 1979) and water surface area data (from Patella, 1975).

[2]Mostly sea bobs (Xiphopenaeus kroyeri).

Texas, Inc., Terminal (OTTI) in Houston or the Pelican Island Terminal in Galveston. Either pipeline could be constructed in addition to, or in lieu of, the pipeline to Sun Terminal. The proposed Big Hill to Sun Terminal line would extend to the northeast similar to the routes discussed in the Texoma Group FEIS, Sect. A.7.4.1.5 (see Fig. 2-6).

The alternative pipeline routes are shown in Fig. 2-6. A southern route would extend to the southwest from Big Hill to Smith Point on Galveston Bay. The line would pass southwesterly across Galveston Bay to a point south of the Texas City Dike and then turn southeast to extend to the proposed Pelican Island Terminal. The northern route would extend westerly to a point east of Cedar Gully, which is a shore point west of Trinity Bay. It then traverses southwesterly, crossing Highway 1405, Hogg Island, and Spillman Island, to a point north of Barbour Cut. The line then would pass under the Houston Ship Channel to Morgan Point and proceed westerly to the Deer Park area and a point west of the existing Shell refinery. The route then would turn north and cross the Houston Ship Channel to OTTI.

3.2.2.1 Land Features

Preferred Pipeline Route

Land features of the Big Hill to Sun Terminal pipeline route have been documented in the Texoma Group FEIS, Sects. 3.3.4.5 and B.3.4.5.4. The route, as proposed, would cross prairie grassland, agricultural land, and a small amount of wetlands. These wetlands include an area near Alligator Hole Marsh and regions along Taylor Bayou and Hillebrandt Bayou (see Fig. 2-6). Some deciduous floodplain forest and cypress swamp exist along Hillebrandt Bayou (USACE, 1979).

Alternative Pipeline Routes

Land features of the alternative pipeline routes have been extensively documented in two recent studies (Gosselink et al., 1979; USACE, 1979). The on-land portions of the pipeline routes are within the East Bay-Galveston Bay and Sabine drainage basins of the Chenier Plain and Strand Plain ecosystems. Pleistocene deposits form the geologic substrate of the region. These deposits are overlain in the coastal zone by geologically recent sequences of cheniers. These topographic highs are interlaced with extensive wetlands that lie near sea level between the ridges. Land use in the region of the alternative pipeline routes is primarily agricultural, consisting of improved pastureland and rice farming. To the south of the routes are extensive wetlands, part of which make up the Anahuac National Wildlife Refuge (see Fig. 2-6).

A chenier ridge extends in a northeast direction from Smith Point toward the Big Hill complex. Extensive wetlands composed of fresh, intermediate, and brackish marshes, which function as prime waterfowl and nursery habitats, exist seaward of this ridge. The southern pipeline, as proposed, would follow existing ROWs along the ridge, avoiding wetlands where possible. From a point near Oyster Bayou to the Big Hill complex, the line would pass primarily through an agricultural setting. The northern route is also primarily in an agricultural region. However, areas of narrow riparian habitat and wetlands are present along bayous, such as East Fork Oyster Bayou or Spindletop Ditch. After crossing Trinity Bay, the northern line would pass almost entirely through an urban/industrial setting.

3.2.2.2 Water Environment

Preferred Pipeline Route

Water environments crossed by the Big Hill to Sun Terminal pipeline include two bayous, several canals, and numerous irrigation ditches. The two bayous, Taylor and Hillebrandt, are considered navigable waters by the USACE and are periodically monitored for flow rate and water quality (USACE, 1979). Recent water quality data are presented in Tables 3-14 and 3-15 [Texas Department of Water Resources (TDWR), 1980]. Water use classification of the bayous, applicable state water quality standards, and Federal water quality criteria have been discussed in the Texoma Group FEIS, Sects. D.2 and D.3. Occasionally, state standards for dissolved oxygen, pH value, and dissolved solids are violated in the Taylor Bayou drainage basin.

Residues of polychlorinated biphenyl (PCB) compounds have been identified as potential pollutants in Taylor and Hillebrandt bayous (Texoma Group FEIS, Sects. B.3.4.2.1 and D.8). A survey conducted by the Texas Water Quality Board (TWQB) (1974) found that sediment PCB concentrations ranged from 0 to 72 µg/kg in the Taylor Bayou watershed, with the highest levels detected in Hillebrandt Bayou immediately downstream from the Beaumont area. Detection of these compounds was attributed to treated wastewater discharges (TWQB, 1974). The PCB concentrations reported for the Taylor Bayou watershed are considerably less than values reported for highly industrialized areas subjected to routine dredging such as the Houston Ship Channel (range: 2 to 13 g/kg) and Calumet Harbor in Chicago (range: 31 to 301 µg/kg) (Fulk et al., 1975). However, the relatively low concentrations of these compounds reported in other area waterways suggest that Taylor and Hillebrandt may have localized PCB pollution. Levels of PCBs in sediment collected in other bodies of water near the Big Hill site (Salt Bayou at 5 Mile Cut, Gulf ICW at Big Hill Road, Spindletop Ditch at the bend of Big Hill Road, and Salt Bayou at Big Hill Road) which are sampled by the TWQB (1977) and waterways located in more rural areas along the Gulf Coast (USACE, 1976) were less than 20 µg/kg.

The fate of any sediments dredged for pipeline construction would fall under the jurisdiction of the USACE, as established under Sect. 10 of the 1899 Rivers and Harbors Act and Sect. 404 of the Federal Water Pollution Control Act of 1972. The applicability of the new EPA Proposed Testing Requirements for Dredge or Fill Disposal Site Specification [45 FR 85360, December 24, 1980] would be determined during the permitting procedure (see Sect. 4.2.3.3).

Surface flow in the region is generally to the southeast toward Sabine Lake. Numerous canals and impoundments have been created in the area to enhance water resource management for agricultural, industrial, and recreational usage.

Table 3-14. Selected water quality parameters for Taylor Bayou, Jefferson County, Texas

Water quality parameter	Taylor Bayou state highway 73 west of Port Arthur (1978 - present)	Taylor Bayou at Labelle Road (1978 - present)
Water Temperature, °C		
Average	21.39	27.13
Minimum	5.0	8.0
Maximum	31.8	31.0
Number of determinations	43	32
Turbidity, Jackson candle units		
Average	71.71	--
Minimum	25.0	--
Maximum	132.0	--
Number of determinations	7	--
Specific conductance, mmhos/cm @ 25°C		
Average	779.55	374.22
Minimum	200.0	140.0
Maximum	6500.0	1400.0
Number of determinations	40	32
Dissolved oxygen (analysis by probe), mg/L		
Average	5.60	5.34
Minimum	3.4	3.2
Maximum	7.8	7.9
Number of determinations	35	32
pH, standard units		
Average	7.02	6.94
Minimum	6.2	6.3
Maximum	8.0	7.9
Number of determinations	41	32

Table 3-14 (continued)

Water quality parameter	Taylor Bayou state highway 73 west of Port Arthur (1978 - present)	Taylor Bayou at Labelle Road (1978 - present)
Fecal coliform (membrane filter, M-FC broth), #/100 mL		
Average	273.8	136.7
Minimum	2.0	30.0
Maximum	2300.0	500.0
Number of determinations	20	9
Total filterable residue (calc. 50% conductance), mg/L		
Average	361.1	187.2
Minimum	100.0	70.0
Maximum	3250.0	700.0
Number of determinations	42	32

Table 3-15. Selected water quality parameters for Hillebrandt Bayou, Jefferson County, Texas

Water quality parameter	Hillebrandt Bayou at state highway 365 (1978 - present)	Hillebrandt Bayou at Hillebrandt Road (1978 - present)
Water temperature, °C		
Average	20.9	21.3
Minimum	5.0	5.5
Maximum	32.0	31.5
Number of determinations	32	32
Specific conductance, mmhos/cm @ 25°C		
Average	457.0	468.0
Minimum	150.0	130.0
Maximum	1200.0	1150.0
Number of determinations	32	32
Dissolved oxygen (analysis by probe) mg/L		
Average	5.0	4.6
Minimum	3.4	2.9
Maximum	7.4	10.0
Number of determinations	32	32
pH, standard units		
Average	6.95	6.91
Minimum	6.2	6.3
Maximum	7.5	7.4
Number of determinations	31	32
Fecal coliform (membrane filter, M-FC broth), #/100 mL		
Average	162.5	1185.6
Minimum	10.0	10.0
Maximum	1000.0	6000.0
Number of determinations	8	9

Table 3-15 (continued)

Water quality parameter	Hillebrandt Bayou at state highway 365 (1978 - present)	Hillebrandt Bayou at Hillebrandt Road (1978 - present)
Total filterable residue (calc. 50% conductance), mg/L		
Average	228.6	233.5
Minimum	100.0	65.0
Maximum	600.0	575.0
Number of determinations	32	32

Alternative Pipeline Routes

The two alternative pipeline routes have major water crossings associated with the Trinity-San Jacinto Estuary, which is composed of Trinity, Galveston, East, West, and several smaller bays (TDWR, 1979). Minor water crossings, associated with the on-land portion of the pipeline ROW, are shown in Table 3-16. Both alternatives would intersect the Oyster, East Bay, Elm, and Spindletop bayou drainage basins. These are all freshwater crossings (USACE, 1979).

The region of Galveston Bay that is traversed by the southern pipeline route has been extensively characterized by the USACE (1979). Waters of lower Galveston Bay are generally of good quality. Average seasonal salinity varies from 28 ppt at the surface to 30 ppt at the bottom during the dry season (late summer to winter). From spring to early summer, surface salinities average 20 ppt and bottom salinities average 30 ppt. The reduced surface salinity is directly attributable to increased freshwater inputs. Surface temperatures generally range from 12 to 30°C during winter and summer, respectively. Dissolved oxygen values are generally above 5.0 mg/L, with deficits occurring primarily in deep channels or backwater areas. The bay crossing by this route is projected to be 18 miles in length and would transect an area with natural maximum depths of approximately 9 ft. Shoaling occurs in the region of Hannas Reef, with depths less than 4 ft common. Ship channel depths are maintained at 40 ft.

The northern pipeline route would cross about 9.5 miles of Trinity Bay (see Fig. 2-6). Depths are normally 3 to 6 ft. Salinities fluctuate widely because of the Trinity River discharge and generally range between 5 and 17 ppt. Temperatures range between 10 and 30°C. Two other major crossings would be made under the Houston Ship Channel, one at Morgan Point and Tabbs Bay and one north of Deer Park to OTTI. Water depths in these reaches of the ship channel are maintained at 40 ft. Water quality in the channel is generally poor because of the high industrial activity along the shoreline.

3.2.2.3 Climate and Air Quality

Climatology and air quality features in the region associated with the crude oil distribution system are similar to those presented in Sects. 3.1 and 3.2.1.3.

3.2.2.4 Ambient Sound Levels

Sounds in the region associated with the crude oil distribution system are similar to those described in Sect. 3.2.1.4. Detailed discussions of ambient sound levels are presented in the Texoma Group FEIS, Sect. B.2.4.

3.2.2.5 Species and Habitats

The ecosystem that would be transected by the crude oil distribution system has been described in detail in the Texoma Group FEIS, Sect. B.2.5.2.4, by Gosselink et al. (1979) and the USACE (1979). The habitats crossed by the preferred pipeline route to Sun Terminal include primarily prairie grasslands, which are used for agricultural purposes

Table 3-16. **Minor water crossings associated with preferred and alternative crude oil distribution systems, Jefferson and Chambers Counties, Texas**

Big Hill to Sun Terminal (preferred)	Big Hill to OTTI (Alternative)	Big Hill to Pelican Island (Alternative)
Rhodair Gully	Spindletop Bayou	Spindletop Bayou
John's Gully	Elm Bayou	Elm Bayou
	East Fork Double Bayou	East Fork Oyster Bayou
	West Fork Double Bayou	West Fork Oyster Bayou
	Cedar Bayou	Lone Oak Bayou

such as pasture and farming. These upland environments and their resident flora and fauna have been described in Sect. 3.2.1.5. Open freshwater habitats would be crossed at Taylor and Hillebrandt bayous. The bayous are likely to contain fish species which are representative of east Texas creeks (alligator gar, spotted gar, red and blacktail shiners, bullhead minnow, golden topminnow, mosquitofish, bluegill, and warmouth) (USACE, 1979). Wetlands existing along shores of these bayous and northeast of the Big Hill site in the vicinity of Alligator Hole Marsh are freshwater in nature. In the Sabine Basin freshwater marshes are characterized by such vegetation as bulltongue, alligatorweed, spikerush, coontail, white water-lily, horned bladderwort, giant bulrush, and other plants (Gosselink et al., 1979). Nutria are the most abundant mammals in this type of habitat. Bird life in freshwater wetlands is diverse, particularly during the winter months when migratory waterfowl inhabit the marshes.

The alternative pipeline routes are projected to traverse a wide variety of environments (Sect. 3.2.2.1). Both routes would cross portions of the Trinity-San Jacinto Estuary. This estuary is the largest of eight major Texas estuarine systems and ranks first in commercial shellfish production (blue crab, American oyster, white shrimp, and brown shrimp) and fourth in finfish production (croaker, black drum, red drum, flounder, sea catfish, spotted seatrout, and sheepshead). Because of the estuary's high productivity, extensive information is available on its biological resources (Christman et al., 1978). Oyster reefs, located south of Smith Point, are the only unique benthic habitat associated with the projected southern alternative pipeline route (Fig. 3-7).

Terrestrial habitats which would be crossed by the alternative northern pipeline route are similar to those encountered by the preferred pipeline route from Big Hill to Sun Terminal. They consist largely of prairie grasslands, now used for pastureland and crops, and some freshwater marshlands. More extensive wetlands, including intermediate and brackish marshes, are located along the southern pipeline route. The dominant plant in the intermediate and brackish wetlands is saltmeadow cordgrass (Gosselink et al., 1979). These habitats have an important biological function, serving as nursery areas for shrimp and Gulf menhaden and as feeding grounds for waterfowl.

3.2.2.6 Natural and Scenic Resources

Preferred Route

The environmental setting of the oil distribution route is prairie grassland, agricultural land, and freshwater marshes. The wetlands have the highest natural and scenic value, primarily because they provide habitat for migratory waterfowl, furbearers, and other animals (see Sect. 3.2.1.6).

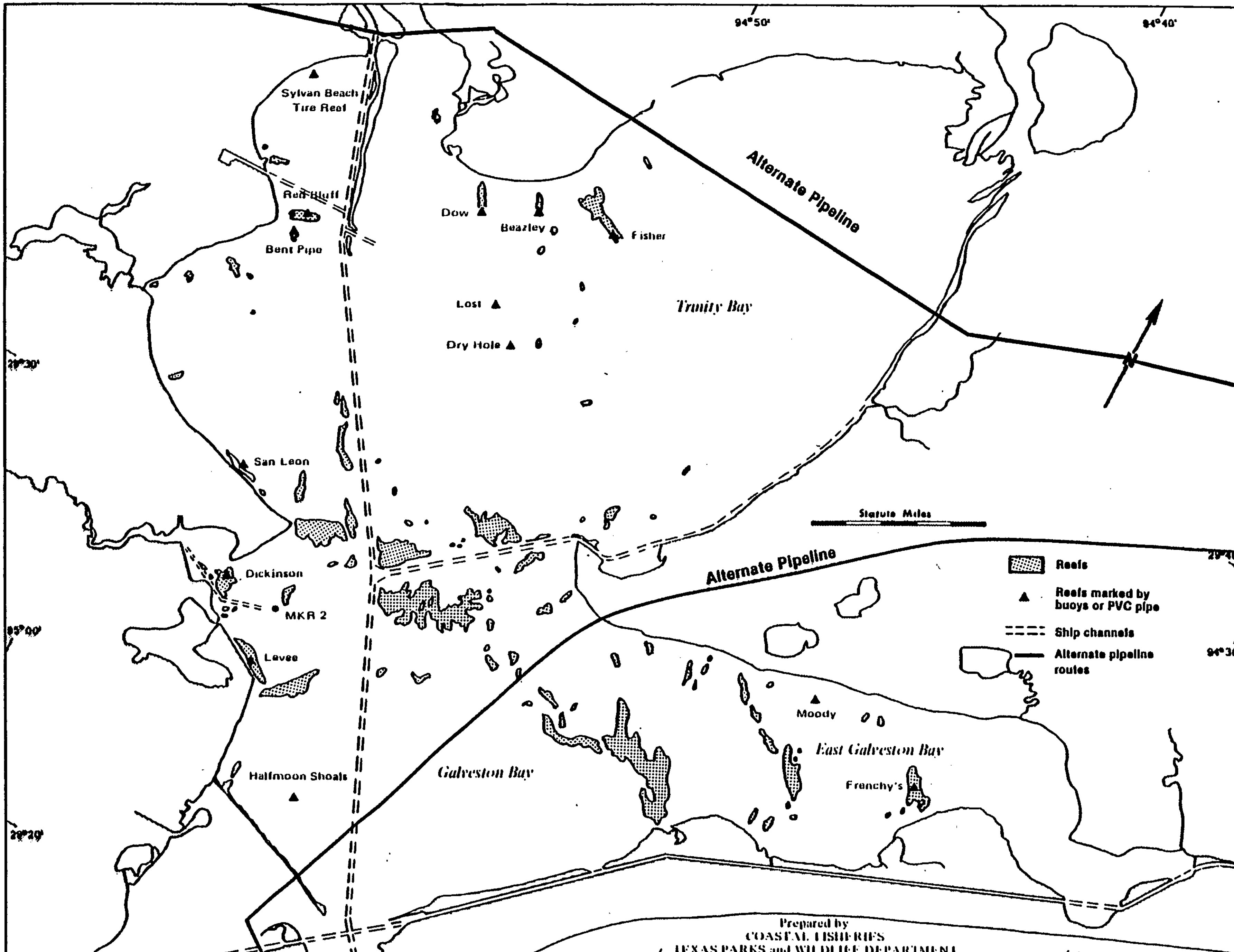

Figure 3-7. Distribution of oyster reefs in Galveston Bay

Alternative Routes

The natural and scenic resources which would be crossed by the alternative northern pipeline route consist primarily of numerous bayous in Chambers County and the northern portion of Trinity Bay. These areas are attractive predominately to sportsfishermen and waterfowl hunters. Most of the upland habitat along this route is pastureland or cropland; only small areas of deciduous forest occur in Chambers County (USGS, 1973).

Bayous and marshes dominate the natural and scenic resources located along the projected southern pipeline corridor. The abundant marshes in this area provide coastal wintering habitat for migratory waterfowl in the Central Flyway (USFWS, 1977a). This proposed pipeline route trends to the north of Anahuac National Wildlife Refuge and to the west of McFaddin National Wildlife Refuge (see Fig. 2-6). Other wetlands in the southern part of Chambers County (Oyster Bayou, Robinson Bayou, and Lake Surprise) have also been considered as candidate sites for national wildlife refuges (USFWS, 1977a). The USFWS is purchasing land only for the Oyster Bayou refuge (USFWS, Anahuac, Texas, personal communication, November 1980).

3.2.2.7 Archaeological, Historical, and Cultural Resources

Preferred Route

A cultural resources survey was conducted along the preferred and alternative oil distribution pipeline routes to Sun Terminal in the Texoma Group FEIS, Sect. B.3.4.7. Although the preferred Big Hill to Sun Terminal route for the proposed action differs slightly from routes considered previously, the findings in the Texoma Group FEIS are considered representative of those likely to occur along the new route.

The survey verified the existence of a shell midden on the east bank of Taylor Bayou (Thomas et al., 1977). Three other deposits were located, one of which was found south of the Port Arthur Country Club. These areas were secondarily deposited and did not warrant further consideration until the source area was established. There are no properties in the pipeline ROW listed or proposed for the National Register of Historic Places.

Alternative Routes

Although field surveys have not been conducted to delineate the archaeological, historical, and cultural resources along the proposed alternative pipeline routes, the Texas Historical Commission has been consulted (letter communication, November 1980; see Appendix D). The commission indicated that the northern route would pass through an extremely sensitive area which has numerous archaeological and historical sites, and some sites near the town of Anahuac are listed on the National Register of Historic Places. These include Chambersea and Fort Anahuac.

Most of the archaeological, historical, and cultural resources near the southern route are located in the Galveston-Texas City area. Galveston's resources have been extensively reviewed by the USACE

(1979). Galveston's history has focused mainly around maritime activities, as indicated by the many recorded shipwrecks in this area (USACE, 1979). The Texas Historical Commission reported that the southern route would pass through a historically and archaeologically sensitive area from Pelican Island through the Texas City Dike region. A Civil War era schooner is believed to have been sunk in the area of the Texas Dike. Material dredged at this location has contained prehistoric artifacts (Texas Historical Commission, letter communication, November 1980; see Appendix D). Surveys undertaken for the USACE project to construct a multipurpose deepwater port and crude oil distribution system at Galveston have recorded shell middens in the southern coastal regions of Chambers County (USACE, 1979). These sites are located fairly close to the projected pipeline route at Smith Point.

3.2.2.8 Socioeconomics

Preferred Route

The socioeconomic characteristics of this area are similar to those described for Jefferson County in Sect. 3.2.1.8. Sun Terminal at Nederland is located within the Beaumont-Port Arthur-Orange industrial complex, where the economy is dominated by the petrochemical industry and petroleum refining operations.

Alternative Routes

The alternative northern pipeline route would transect essentially two different types of socioeconomic environments: (1) the relatively rural portions of Jefferson and Chambers Counties and (2) the highly industrialized area in Harris County between Baytown and Deer Park. The economic base of the prairie upland area between the Big Hill salt dome and Trinity Bay is mineral extraction (oil and natural gas production), rice farming, and livestock (beef cattle) production. Housing, goods, and services may have restricted availability within the small rural communities. The towns of Anahuac and Winnie are the largest communities near this portion of the proposed pipeline corridor (see Table 3-6).

After crossing Trinity Bay, the pipeline is projected to cross Baytown and extend up to OTTI facilities near Deer Park. This area has experienced rapid growth during the past decade as a direct result of industrial development. Population estimates are presented in Table 3-6. The economy of Baytown and Deer Park is based on petroleum products and the petrochemical industry. As satellite communities to Houston, Baytown and Deer Park use goods and services provided by the Houston metropolitan area to supplement their own resources (USERDA, 1977).

The alternative southern pipeline route would transect essentially two different types of socioeconomic environments: (1) the relatively rural portions of Jefferson and Chambers Counties and (2) the highly industrialized area in Galveston County between Texas City and Galveston. In the rural areas of Jefferson and Chambers Counties, both upland prairie and coastal wetland habitats occur. The economy is based on oil and gas production, rice farming, and livestock production. The portions of these counties potentially affected by this pipeline corridor have low population densities and are fairly inaccessible by road. The largest communities near the projected pipeline route are at least 8 miles away. They include Anahuac and Winnie in Chambers County and towns along the Bolivar Peninsula in Galveston County.

After crossing Galveston Bay, the pipeline is projected to roughly parallel the Texas City Ship Channel and extend to the Pelican Island Terminal facilities at Galveston. The Galveston-Texas City area has experienced steady population growth in recent years. Population estimates are presented in Table 3-6. Existing land use in this area varies from heavy industrial to relatively undeveloped areas along the tidal flats, beaches, and marshes. The economies of Galveston, Texas City, and Houston, when combined, constitute one of the largest in the United States (USACE, 1979). Important components of this economy include manufacturing (refining, petrochemicals, chemicals, and processing sectors), port traffic, services, trades, and commercial fishing.

3.2.3 Bryan Mound Expansion

The preferred action described in Sect. 2.0 would involve creation of four new caverns at the Bryan Mound site. An alternative to this would be the creation of six new storage caverns. No new land acquisition is required by the project, as all expansion would occur within existing properties. Environmental conditions related to the site and its operation are described in detail in existing documents (Seaway Group FEIS; Hann et al., 1979; Comiskey et al., 1980; Metzbower et al., 1980).

3.2.3.1 Land Features

Bryan Mound is located about 3 miles southwest of Freeport, Texas, in the Gulf Coastal Plain Physiographic Province. This area is characterized as a relatively flat, featureless prairie terrace with abundant swamps and marshes. Low-gradient streams are common, and natural levees are often found along the streams (Seaway Group FEIS, Sect. 3.2.1.1). The Bryan Mound salt dome is a major topographic relief feature in this coastal area, rising to a maximum elevation of 16 ft above mean sea level. The dome is bounded by a man-made flood and hurricane protection levee system. The bathymetry of the offshore area is relatively flat, with a small shell ridge and rock formation located near the diffuser site (Seaway Group FEIS, Sect. 3.3.1.1).

All land required for the Phase III expansion is within existing properties described in detail in the Seaway Group FEIS, Sect. 2.3.

3.2.3.2 Water Environment

Bryan Mound is bordered by four major surface water bodies: the Brazos River Diversion Channel, the Freeport Harbor, the ICW, and the Gulf of Mexico. The site is located between the diversion channel and the ICW in an area protected by a man-made levee system. Several lakes and reservoirs exist within the triangular region delineated by the levee system, and others, including Mud and Bryan lakes, are outside the levees. Texas water quality standards classify the tidal portion of the lower Brazos River as suitable for both contact and noncontact recreation and for propagation of fish and wildlife. Subsurface water resources include (1) the Chicot aquifer to a depth of about 1,100 ft, of which the upper 80 ft is fresh, (2) the slightly saline Evangeline aquifer from 1,100 to about 3,500 ft, and (3) the deep, highly saline Oakville sands. Surface waters and groundwaters are discussed in more detail in the Seaway Group FEIS, Sects. 3.3.2 and B.3.2.

3.2.3.3 Climate and Air Quality

The climate of the region containing Bryan Mound is considered humid. Because of its location near the Gulf Coast, the site is more strongly influenced by offshore meteorological conditions. Generally, higher wind speeds, more frequent east to southeasterly winds, smaller diurnal temperature ranges, slightly higher humidity, and greater storm activity are characteristic of the coastal area where the salt dome is located. Wind and storm conditions off the Gulf Coast have a pronounced influence on variations in water height near the dome (Seaway Group FEIS, Sect. 3.3.3.1).

Air quality data for the Bryan Mound site are unavailable; however, the Texas Air Control Board maintains a monitoring station nearby in Clute/Freeport (see Table 3-3), which may be considered a worst-case representation of Bryan Mound background air quality because of the proximity of the monitoring station to a major petrochemical industrial complex. In 1979, the 1-h ozone standard was exceeded on 99 days. In addition to petroleum refineries and petrochemical industries, significant local pollution sources include transportation and combustion of industrial fuels.

3.2.3.4 Ambient Sound Levels

Activities influencing sound levels in the vicinity of Bryan Mound include SPR Phase I and II operations at the dome itself, traffic on the ICW and Brazos River, petrochemical activity at Freeport, and vehicular traffic. Channel dredging in the Freeport Harbor also affects local sound levels at the site. To the west of Bryan Mound, in essentially unpopulated areas more distant from industrial activity, sound levels are dominated by animals and wind rustling foliage. Bryan Beach Recreational Area, an undeveloped recreational site, borders the salt dome on the south (Seaway Group FEIS, Sect. 3.3.4).

3.2.3.5 Species and Habitats

Habitats found at the Bryan Mound site consist of coastal prairie, Gulf Coast marshland and open bodies of water. The coastal prairie is dominated by medium to tall grasses characterized by an open to moderately dense wildlife cover. Domestic (cattle) as well as wild (numerous birds, rabbits, and rodents) animals are found in the prairie grasslands. Brackish marshlands are the most abundant habitat type found on the site. The flora and fauna common to these wetlands include coastal sacahuista, marsh hay cordgrass, big cordgrass, bulrush, cattail, rushes, small animals, snakes, and waterfowl. Many ducks, seabirds, roseate spoonbills, and wading birds have been observed in the marshland to the northeast of the site (Seaway Group FEIS, Sect. B.3.5.1). The numerous bodies of water provide a diverse range of aquatic habitat: small fresh, brackish ponds, and offshore areas in the Gulf of Mexico. Coastal and inland waters are important to biological communities for feeding, cover, and nursery areas. Gulls, terns, herons, and egrets use these areas for feeding, resting, and nesting (Seaway Group FEIS, Sect. B.3.5.2).

Threatened and Endangered Species

Phase III expansion of Bryan Mound would occur within existing DOE property. The region is industrially developed and no threatened or endangered species are known to occur at the site (Seaway Group FEIS, Sect. B.3.5.2). Migratory birds, such as the bald eagle and peregrine falcon, may fly over the area and use adjacent wetlands for feeding.

3.2.3.6 Natural and Scenic Resources

The marsh and prairie areas surrounding Bryan Mound are typical of those found throughout this region along the coast of Texas and have no unique natural or scenic features. Because of prior industrial development, the area in the immediate vicinity of the project site has a relatively low aesthetic value. Bryan Beach State Park and San Bernard and Brazoria National Wildlife Refuges are located near the salt dome (Seaway Group FEIS, Sects. 3.3.5.2 and 3.3.6).

3.2.3.7 Archaeological, Historical, and Cultural Resources

A cultural resources study conducted at Bryan Mound salt dome did not uncover any archaeological, historical, or cultural resources (Chaffin-Lohse, 1977). This survey included three components:

(1) An on-ground search through the 1-mile diameter of the dome and 8.1 miles of pipeline ROWs.

(2) Record checks of the Texas Archaeological Research Laboratory files and the Texas Historical Commission Inventory of Historical Sites.

(3) Five test-pit excavations within the domal area.

During construction of the existing facilities at Bryan Mound, one historical artifact, a wagon wheel, was uncovered in the brine disposal pipeline route (Parsons-Gilbane, personal communication, December 1980). Construction was halted until a state official from the Texas Department of Parks and Wildlife could determine its significance. It was not considered a find worthy of further investigation, and construction operations were resumed. No properties at the Bryan Mound site are listed or proposed for the National Register of Historic Places.

3.2.3.8 Socioeconomics

The Bryan Mound project is located within the group of communities known collectively as Brazosport, which includes the city of Freeport. Petroleum-related facilities represent a significant share of this area's highly industrialized economy. Population estimates that are more recent than those included in the Seaway Group FEIS (Sect. 3.3.8) are presented in Table 3-17 and indicate that the Brazosport area is rapidly growing. More information on the socioeconomic environment of the Bryan Mound site is included in the Seaway Group FEIS, Sect. 3.3.8.

3.2.4 West Hackberry Expansion

The proposed Phase III plan is to create three new 10-MMB oil storage caverns at the West Hackberry site. An alternative would be the construction of only one 10-MMB cavern at this facility. A detailed discussion of the site facilities and local environment are presented in the Texoma Group FEIS, Sects. A.4.4.1 and B.3.1.

3.2.4.1 Land Features

The dominant topographic feature in Cameron Parish are the cheniers or stranded former beach lines. Marshland is also extensive in this area. Man-made levees and dredge spoil disposal areas have modified the topography in many parts of these wetlands (Texoma Group FEIS, Sect. B.2.5.2.1). The West Hackberry salt dome is located near the western end of Hackberry Ridge. Open water areas exist northwest of the dome, and marshlands predominate to the south and west. The dome itself is covered by prairie grasslands which, prior to SPR development, had been converted to pastureland. Phase II construction operations described in the Texoma Group FEIS, Sect. 2.4.2, currently dominate the landscape at the West Hackberry dome. Expansion at the site would require the purchase of lands to the west and/or south of the existing facilities (see Fig. 2-4). These tracts of land are now developed for residential and/or agricultural use. There are ten homes inside the 34-acre region proposed for expansion, with surrounding lands consisting primarily of pasture. The expansion sites are located on prime farmlands of the Crowley-Morey-Mowata association, but are not currently under cultivation. There are about 103,000 acres of prime farmland and 10,500 acres of potential prime farmland in Cameron Parish (SCS, 1981). No wetlands are within the potential expansion areas.

3.2.4.2 Water Environment

The West Hackberry salt dome is located in hydrologic unit 9 of southwestern Louisiana within the estuarine part of the Calcasieu River Basin. This hydrologic unit consists largely of ponds, lakes, and marshes, with less than 10 percent dry land. Water features of the West Hackberry site are dominated by Black Lake along the northern edge of the site. This is a brackish lake with salinities generally between 5 and 10 ppt (Texoma Group FEIS, Sect. 3.3.1.2). No water environments are located within the proposed expansion areas.

3.2.4.3 Climate and Air Quality

The regional climate of the West Hackberry area is classified as "humid-subtropical with strong marine influences" (Texoma Group FEIS, Sect. B.2.3.1). Seasonal fluctuations are moderate. Winters are generally cool and clear with occasional periods of overcast skies. In summer the days are generally warm and humid, with little daily variation. Afternoon showers and thundershowers occur frequently. Rainfall averages about 54 in./year at Hackberry (Texoma Group FEIS, Sect. B.2.3.1).

Table 3-17. **Population estimates for communities located within Brazoria County, Texas**

Location	Population estimate[1] 1970	1978	1980 (projected)
County (total)	108,298	163,920	178,099
Lake Jackson	13,376	19,810	
Angleton	9,770	14,752	
Freeport	11,997	14,427	
Clute	6,023	10,575	

[1]Information provided by personal communication (November 1980) with Houston-Galveston Area Council.

The available data for regional air quality indicate that the NAAQS for NMHC and ozone are violated at monitoring stations near the West Hackberry site. Sulfur dioxide, nitrogen dioxide, carbon monoxide, and hydrogen sulfide are presently in compliance with all applicable air quality standards, indicating a lack of heavy regional concentrations of combustion processes (Texoma Group FEIS, Sect. B.2.3.3.1). Phase II construction activities at West Hackberry were projected to result in temporarily increased combustion and fugitive emissions in the project area; however, offsite violations of applicable air quality standards were not likely to occur from these operations (Texoma Group FEIS, Sect. 4.3.3.1).

3.2.4.4 Ambient Sound Levels

Before development of the West Hackberry dome for the SPR program, background noise levels in and around the site were typical of a secluded, essentially flat area. In the winter and spring, the major contributing noise sources were wind and periodic bird calls. In summer, because of the high humidity and warmth, noise was dominated by the sounds of insects and frogs in addition to bird calls and the sounds of wind in the foliage and brush (Texoma Group FEIS, Sect. 3.2.4). At present, construction operations for Phase II are contributing to the background noise levels. Diesel engines were considered to be the most consistent source of noise, while drilling equipment was projected to create the peak sound levels. More information on existing construction and operational sound levels is presented in the Texoma Group FEIS, Sects. 4.3.4.1 and 4.3.4.2.

3.2.4.5 Species and Habitats

The region encompassing West Hackberry's storage facility and its water supply, brine disposal, and oil distribution connections is ecologically varied. The dome itself is an upland habitat of prairie grassland that has been converted to pastureland. Native prairie grasses, pasture cover, and animal life are similar to those described for the dome area at Big Hill (Sect. 3.2.1.5). The grasslands at West Hackberry also contain scattered trees such as oak, ash, American elm, and sweetgum. The biotic environment of the water supply corridor and part of the oil distribution system includes estuarine organisms (found in Black Lake, the marshland north of the lake, and the ICW) and the flora and fauna of upland terrestrial environments south of the ICW. The segment of the oil distribution system extending westward along the ICW and across the Sabine and Neches rivers to Sun Terminal transects freshwater to brackish marsh, spoil banks, and agricultural land (Texoma Group FEIS, Sect. B.3.1.5.4). These ecosystems are described in detail in the Texoma Group FEIS, Sects. B.2.5.2.2 and B.2.5.2.3. The project's brine disposal pipeline route crosses dry land (pastureland and spoil banks), wetlands (brackish marsh), and both estuarine and marine open water environments. The wetland and estuarine habitats along this route are biologically important environments because they provide nursery areas for shellfish and finfish and nesting and feeding areas for abundant waterfowl. Many commercially important species such as menhaden, Atlantic croaker, mullet, and brown and white shrimp are found in offshore areas in the Gulf. The American alligator, a threatened species (threatened by similarity of appearance), is known to inhabit West Hackberry.

Threatened and Endangered Species

Expansion of the West Hackberry site may require the acquisition of up to 34 acres of land adjacent to the existing site. This land is managed rural pasture and residential and is not considered prime habitat for any threatened or endangered species. No wetlands occur within the proposed area of expansion.

3.2.4.6 Natural and Scenic Resources

The West Hackberry site is located north of the Sabine National Wildlife Refuge on the southern shore of Black Lake. Natural and scenic resources of the area consist of a rich variety of wildlife which is primarily associated with the abundant wetlands. More information is presented in the Texoma Group FEIS, Sect. B.2.6.

3.2.4.7 Archaeological, Historical, and Cultural Resources

Cultural resources surveys conducted in 1977 and 1979 did not reveal any evidence of prehistoric or historically important resources that would be affected by the project described in the Texoma Group FEIS (Weinstein et al., 1977, 1979). A coastal shell midden is located south of Black Lake and west of both the current SPR project at West Hackberry and the land under consideration for the proposed expansion (Fig. 2-4). Before construction of the brine discharge pipeline from the West Hackberry project site to the Gulf of Mexico, another cultural resources survey was conducted along the pipeline route (Weinstein and McCloskey, 1980). Three previously described sites were known to exist in proximity to the route. All of these sites, however, were far enough away from construction operations so that no adverse impacts would occur. Two new sites and a spot find were recorded during the survey. These finds consisted of two plain prehistoric shards (broken ceramics, glass, etc.) and what appeared to be remains of a twentieth century hunting camp. Neither was considered significant in terms of National Register criteria. None of the property evaluated for West Hackberry expansion is listed or proposed for inclusion in the National Register of Historic Places.

3.2.4.8 Socioeconomics

All of Cameron Parish is considered a rural, coastal environment. Because no incorporated communities exist within the parish, population estimates for Hackberry, Cameron, and Holly Beach cannot be updated from the rough figures provided in the Texoma Group FEIS, Sect. B.3.1.8.2. The 1979 population estimate for the entire parish is included in Table 3-8. This figure is similar to the estimate of 10,620 predicted for this parish during 1980-1990 (Texoma Group FEIS, Sect. B.3.1.8.2). The metropolitan area located closest to the West Hackberry project site is Lake Charles and its satellite communities in Calcasieu Parish. Recent population estimates for these towns (Table 3-6) indicate that steady growth has occurred over the past decade.

The socioeconomic environment of Cameron Parish is the only environment of relevance in evaluating the proposed Phase III expansion at West Hackberry. The rationale is that Cameron Parish, and specifically the

Hackberry district, was the only locale significantly affected by Phases I and II. There is no reason to expect a change in the distribution of impacts in Phase III.

The socioeconomic environment of any impacted area consists of aspects that, under normal conditions, are not easily quantifiable, such as the number of parish residents employed at one time at the site or the increase in retail sales associated with the project. Certain aspects cannot be quantified at all, but are nevertheless important. In Cameron Parish, the latter case is probably the overriding one.

The information used in the following discussion of salient characteristics of the socioeconomic environment in Cameron Parish was derived from recent and previous site visits, field work, data gathering by telephone, and examination of pertinent literature.

The three basic[1] sectors of the Cameron Parish economy are fishing/shrimping, rice farming, and petroleum production. There are no incorporated towns in the parish; consequently, all nonjudicial governmental functions are carried out by the elected police jurors. Goods and services are not elaborate, but are sufficient for the needs of local residents. Opportunities for outdoor recreation are plentiful.

To understand the socioeconomic environment as it now exists, while Phase II construction is being completed, it is important to consider three factors: (1) few workers were hired from the parish, (2) a large number of workers moved into the Hackberry vicinity during their employment,[2] and (3) Hackberry is relatively distant from most of the other towns in the parish. Many of the towns are located on the Gulf Coast and are much more heavily dependent on fishing as an economic base. These three factors are sufficient to explain the existing socioeconomic environment.

At Hackberry, some public services were strained by the influx of Phase II construction workers. The school system experienced an increase in enrollment which was previously fairly stable. There was an increase in traffic, both by volume and by weight, that caused rapid deterioration of local and state roads (DOE repaired some roads and stated an intention to repair others). Roadside litter increased along routes taken by commuting workers despite DOE efforts to clean the area. The parish sheriff noted an increase in disturbances requiring the attention of law enforcement officers, although this could be expected for any population increase. Finally, problems related to sewage treatment (only septic systems are available) were perceived to be sufficiently serious that parish officials began efforts to develop a community-wide treatment system. The local officials attribute the influx of workers to Hackberry for SPR Phase I and II as aggravating the sewage treatment problem.

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[1]A basic sector is one which provides material for trade outside of the county/parish.

[2]No precise number can be given, but a detailed site examination suggested at least 100 workers moved to the area, with about 30 bringing their families.

Although the problems have not been offset by increased sales or tax revenues, local merchants have benefited from the additional population. Since they did not over-expand, there is now a temporary boom in sales. An extreme decline in sales at a future date is not anticipated. In general, the socioeconomic environment of Hackberry can be described as one with some problems.

For the rest of the Parish, the socioeconomic environment is quite different. There has been virtually no economic gain for the rest of the parish as a result of the project. Unemployment has been historically low, and there is essentially no chance for increased retail sales. Although the rest of the parish has experienced no adverse socioeconomic impacts to date, there is a great deal of concern that the disposal of brine in the Gulf or the withdrawal of raw water from the ICW will undermine two of the basic sectors of the economy: (1) fishing and shrimping and (2) rice farming. There is a possibility that increased salinity would damage fishing and shrimping opportunities and that withdrawal of raw water would cause an inflow of salt water from the Gulf, further damaging fishing and shrimping, as well as rice farming. These concerns are discussed in Sects. 4.2.2 and 4.2.5 of this statement. However, since the local economic base largely determines all socioeconomic conditions in Cameron Parish, the concerns about possible damages to basic economic sectors are pervasive throughout the Parish. This is the only salient socioeconomic characteristic of Cameron Parish exclusive of the Hackberry district.

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4.0 ENVIRONMENTAL IMPACTS OF THE PROPOSED AND ALTERNATIVE ACTIONS

4.1 INTRODUCTION

This section describes impacts that would result from implementation of 212 million barrels (MMB) of oil storage for Phase III. These impacts would be associated with (1) the construction and operation of a 140-MMB Strategic Petroleum Reserve (SPR) storage facility at Big Hill, Texas, and (2) expansion of the Bryan Mound and West Hackberry sites to accommodate an additional 70 MMB of crude oil. Expansion at Bryan Mound and West Hackberry would involve one of two possible scenarios:

	Bryan Mound	West Hackberry
Preferred	40 MMB	30 MMB
Alternative	60 MMB	10 MMB

As discussed in Sect. 2.2.1.1, the preferred alternative consists of leaching four new storage caverns at Bryan Mound [at an increased leach rate of 980,000 barrels per day (bbl/d)] and three new caverns at West Hackberry. A secondary alternative, discussed in Sects. 2.2.1.1 and 2.3.1.1, would place six expansion caverns at Bryan Mound and one at West Hackberry. Even if an increased leach rate at Bryan Mound from 680,000 to 980,000 bbl/d is assumed, such an uneven distribution of the seven Phase III expansion caverns between the two sites would result in a cavern development period lasting 6 months longer than the preferred 40:30 scenario (see Fig. 2-2). Although this time loss is undesirable, the 60:10 alternative appears to be the most practicable alternative to the preferred 40:30 scenario.

If the 40:30 alternative were developed without increasing the leach rate at Bryan Mound, Phase III expansion would be delayed by 14 months because it would not be practical to integrate the Bryan Mound Phase II and III leaching schedules (see Fig. 2-2). Development of the 60:10 alternative without increasing the leach rate at Bryan Mound would result in a delay of 21 months.

In evaluating the possible impacts of these actions, an initial scoping of similar and associated SPR construction projects was made (Appendix A). The creation of a new SPR facility at Big Hill with raw water, brine disposal, and crude oil distribution systems would have the greatest potential for impacts under Phase III. Expansion of the Bryan Mound site would occur on existing Department of Energy (DOE) property by using existing site facilities. At West Hackberry, expansion would require the purchase of nearby lands, but as with the Bryan Mound expansion, existing onsite facilities would be used for leach/fill, refill, and drawdown operations.

Impact significance is related to the magnitude and duration of impacts on the environment. Based on the experience gained during implementation of Phases I and II at Bryan Mound and West Hackberry, it appears that impacts related to offshore brine disposal, wetlands, air quality, crude oil transportation, and local socioeconomics are of primary significance. Impacts related to ambient sound levels, natural and scenic resources, terrestrial species and habitats, archaeology, and historical-cultural resources have generally been less significant in the SPR program. This hierarchy is derived from the scope and nature of the project:

- o Large volume of brine disposal.
- o Large volume of crude oil transport.
- o Site facilities confined to a relatively small (several hundred acres) area consisting of wellpads, ponds, pump houses, and a few operations and maintenance buildings.
- o Peak labor force of several hundred employees in a rural setting.
- o Intermittent operations based on a maximum of five cycles over a 20-year period.

Expansion of the West Hackberry site would result primarily in minor incremental impacts to those described in the Texoma Group Final Environmental Impact Statement (FEIS). The duration of impacts described for this site (such as brine disposal) would be longer, but their magnitude would not increase since crude oil fill, water intake, and brine discharge flow rates would remain constant.

4.2 BIG HILL (140-MMB CRUDE OIL STORAGE FACILITY)

Construction of a 140-MMB storage facility at Big Hill, Texas, is the major component of the proposed Phase III SPR expansion. The creation of the new storage facility with an oil distribution system represents the greatest potential for environmental impacts under Phase III SPR expansion.

4.2.1 Land Features

Big Hill Site

The Big Hill complex of storage caverns has been designed so as to provide for five fill/drawdown cycles which leave sufficient salt (web) between the caverns to support the overlying strata. The geometry of the cavern placements provides for a minimum of 480 ft of salt web between adjacent caverns for structural support. To maintain internal hydrostatic pressure and thus reduce the effects of salt creep on cavern closure, caverns would always contain brine or crude oil and brine. There would be no significant alteration of geologic structure (subsurface) or surface land forms as a result of leaching, and no impact on geologic structure would occur during normal facility operation and maintenance activities.

Exploitation of salt deposits in the Gulf Coast region centers around industrial (petrochemical feedstock for chlorine manufacture) and commercial (retail sales) markets. Salt structures similar to the Big Hill dome, of which there are hundreds in the region, represent a significant and ample reserve.

Future salt production in the immediate area of the proposed storage caverns would be incompatible with the SPR development of Big Hill. Extraction of other minerals, namely sulfur, from the overlying caprock would also be precluded; however, this is not a significant issue at Big Hill as extensive sulfur exploration has shown that no economic deposits exist.

The topography of the site would be altered slightly by grading and diking activities; about 250 acres would be affected. The Big Hill storage site would have a landscaping plan as part of the overall construction program. This plan would utilize, to the extent practicable, existing trees, shrubs, and meadows to enhance the visual impact of the facility. Because of the extensive amount of site grading required, some of the existing oak trees within the site boundary would be removed. Plants used for landscaping would be of a variety adapted to the climate and growing conditions at Big Hill. Dikes would be constructed around each wellhead to contain oil or brine that might escape from a cavern in the event of leakage from the wellhead. These dikes would be constructed in compliance with the Spill Prevention Control and Countermeasures (SPCC) plan developed and approved as part of the project permitting process. During construction, minor soil loss and some alteration in the onsite drainage pattern due to disturbance or compaction could be expected. Soil loss at Big Hill because of site construction-related erosion was conservatively estimated at about 10 tons/acre. This soil would be transported by runoff to the marshes south and east of the dome and to gullies and sloughs to the north (Texoma FEIS, Sect. 4.6.2). Soil conservation measures, such as contouring and seeding, would be used to keep these losses to a minimum.

A policy statement developed by the President's Council on Environmental Quality (CEQ) requires that all Federal agencies be concerned about the encroachment of projects on prime farmlands (Federal Register, September 8, 1980). The development of oil storage facilities at Big Hill would potentially remove from current use as pastureland approximately 250 acres of Hockley silt loam, a soil classified as a prime farmland soil in its native state (see Sect. 3.2.1.1). Although suitable for use as cropland, it is unlikely that the land within the site boundaries would be cultivated because of past and current industrial development for liquid petroleum gas (LPG) storage and oil extraction. Operation of the facility would affect 4.9 percent of the soils in Jefferson County classified as prime farmland soils in the native state, but only 0.06 percent of prime and potential prime farmland soils (see Sect. 3.2.1.1). Potential prime farmland soils are those that require irrigation or draining to be usable and would no longer be in their native state.

Raw Water Intake and Onshore Brine Disposal Pipelines

Construction of the brine and raw water lines would affect the surface and subsurface soil structure and drainage. Surface and subsurface soil would become mixed where the trench is dug and refilled. Double-ditching techniques would be used to minimize these impacts as required by the permitting agency. Adjacent soils would become compacted from the weight of pipe-laying equipment. The soil associations that would be affected include the Morey-Crowley-Hockley soil association, the Harris-made land-soil association, and the Sabine-coastal land-soil association.

The permanent pipeline right-of-way (ROW) would be allowed to revert to its previous use as cropland or grassland, but any trees recolonizing the ROW would be periodically removed. The land needed for permanent pipeline ROWs for the Big Hill site amounts to 48 acres for the raw water, brine, and utility cables to the Intracoastal Waterway (ICW). From the ICW to the coast, a maximum of about 36 acres would be required as permanent easement.

4.2.2 Water Environment

Big Hill Site

There are no onsite bodies of water that would be directly affected by construction activities (see Sect. 3.2.1.2). Site preparation, however, would be expected to accelerate the erosion in this area, resulting in slightly higher sediment loads to the two small freshwater ponds located on the northern and eastern edges of Big Hill salt dome and to the wetlands located to the south and east of the site. In addition to suspended solids, concentrations of certain dissolved and adsorbed chemicals could be elevated from ambient levels in localized reaches of wetlands or watercourses near the site. Pollutants associated with miscellaneous construction activities are discussed in the Texoma Group FEIS, Sect. 4.3.2.1. Because of the relatively flat topography around the Big Hill salt dome, the limited areal extent of the disturbance, and the temporary nature of the disturbance, construction-related impacts to the waters around Big Hill are not significant.

Impacts to the quality of surface waters and groundwaters associated with the area around the Big Hill salt dome could result from the disposal and discharge of wastes. However, current plans call for the collection of precipitation runoff from the oil surge tank and wellpad (excluding wellpad sumps) areas in a storm water transport system that would contain runoff from a 25-year, 24-h rainfall event. Before discharge into Spindletop Marsh, located southwest of the project area, storm water would be tested for compliance with effluent limitations for one water quality parameter, oil, and grease. Based on design criteria and National Pollutant Discharge Elimination System (NPDES) permit requirements for Bryan Mound, concentrations of oil and grease in the effluent would not exceed a daily maximum of 15 mg/L, with a daily average of 10 mg/L. If the effluent did not comply with this requirement, it would be treated by the oil-brine separator and then discharged off shore. An impermeable lining in the brine pond would prevent the contamination of surface or groundwaters by brine leakage.

A sewage treatment system would be designed and operated so that pollution of groundwater or surface water resources would not occur. Sludges accumulated in treatment facilities would be disposed of off site in compliance with local, state, and Federal requirements (see Sect. 9.0). The water environment at Big Hill would not be significantly affected.

Raw Water Intake, Raw Water, and Onshore Brine Disposal Pipelines

Construction of the raw water pipeline is estimated to involve the excavation of 54,000 cubic yards (yd^3) of material from wetlands. Approximately 10,000 yd^3 of spoil would be dredged from the raw water intake channel prior to installation of the intake structure. All dredge spoil would be handled according to the permitted requirements of the regulatory agency. Construction of the brine disposal pipeline would require an additional excavation of 34,000 yd^3 for a total of 98,000 yd^3. These operations and decant water from the stockpiled spoil materials would cause temporary, short-term perturbations to the water quality of the ICW, Salt Bayou, Star Lake, and other watercourses connected with wetlands transected by the pipeline routes. The effects of dredging and dredge material disposal on water quality are well characterized from studies conducted by the Dredge Material Research Program, U.S. Army Corps of Engineers (USACE), Waterways Experiment Station. Water quality perturbations could result from an increase in turbidity, the release of nutrients, toxic chemicals, or other undesirable materials, and oxygen depletion. These potential impacts are discussed in the Texoma Group FEIS, Sect. 4.3.2.1. The fate of any sediments dredged for Big Hill site construction would fall under the jurisdiction of the USACE, as established under Sect. 10 of the 1899 Rivers and Harbors Act and Sect. 404 of the Federal Water Pollution Control Act of 1972 as amended. All dredge spoil materials would be handled as required by the regulatory authority (see Sect. 4.3.2.2). Mitigation measures, which could be utilized to reduce adverse environmental impacts, include construction techniques, such as horizontal directionally drilling the pipeline under waterways and the use of turbidity screens in the ICW. Measures to be used would be determined in consultation with local, state, and Federal authorities during the permitting process.

During operation of the Big Hill facility, the raw water intake pipeline and the brine disposal pipeline would not adversely affect the water quality of the ICW, Salt Bayou, Star Lake, or watercourses connected with wetlands transected by the pipeline routes. The potential impacts of spills from the raw water intake and brine disposal pipelines have been addressed in the Seaway Group FEIS, Sects. 4.2 and E.2.2, and the Texoma Group FEIS, Sect. 4.2.3. Although the raw water obtained from the ICW for the Big Hill project may be brackish, spills from this pipeline would cause only minor perturbations to the dry land and wetland areas between the ICW and the site. Spills from the onsite and offsite brine disposal pipelines and from the onsite brine pond would have more severe ecological consequences. If the brine entered a body of water not subjected to turbulent mixing, it would, because of density differences, form a stratified layer at the bottom of the water column. This could impact localized aquatic habitats, particularly those of benthic organisms. If the body of water is well-mixed, the brine could be rapidly diluted to near negligible concentrations. For brine disposal pipeline spills on shore, the greatest risk would be those in which water supplies (including groundwater), agricultural land, or sensitive freshwater or marine nursery zones would be affected (Seaway Group FEIS, Sect. E.2.2.5).

The withdrawal of water from the ICW during leaching and oil withdrawal would only minimally affect water surface elevation, currents, and water quality. The point of withdrawal would be on the ICW, about 6,700 ft east of the junction with Spindletop Ditch. The rate of withdrawal during leaching would be 1.4 x 10^6 bbl/d over a period of 37 months. The maximum rate of withdrawal during drawdown would be 9.4 x 10^5 bbl/d.

The Massachusetts Institute of Technology (MIT) Water Quality Network Model (Harleman et al., 1976), which is described in Appendix B, has been used to quantify the effect of withdrawing water from the ICW during leaching. Salinity, water depth, and flow velocities at a given point along the ICW, and in the tidal cycle, reach equilibrium values within 10 days after the onset of withdrawal (i.e., system behavior at a given point remains constant from tidal cycle to cycle). The effects during oil drawdown operations should be somewhat less than those obtained during leaching.

Based on model results presented in Appendix B, the water level in the ICW would be depressed by a maximum of 0.04 ft near the withdrawal point. To the west, halfway between the withdrawal point and Galveston Bay, a water-level depression of less than 0.02 ft is predicted. At the junction of the ICW and Port Arthur Canal, the depression would be less than 0.01 ft.

Flow in the segment of the ICW between Galveston Bay and the Sabine Lake is generally east to west (Gosselink et al., 1979). Withdrawal would cause a maximum change of 0.06 ft/s to this existing current. No appreciable impact on the water supply due to the withdrawal is anticipated.

The water quality in the ICW depends on the quality of water flowing into the waterway from Sabine Lake and Galveston Bay and, to a lesser extent, on the relatively smaller amount of water entering from other sources such as Spindletop Ditch and runoff from adjoining wetlands. Observed salinities in the ICW typically range from near 0 to 10 parts per thousand (ppt). Model results indicate that the salinity near the withdrawal point would increase by less than 1 ppt due to the induced water flow patterns. Likewise, the salinity in the nearby water bodies such as Spindletop Ditch may be increased by less than 1 ppt. Therefore, the intake of water for the Big Hill site should not significantly impact salinity in the ICW or any other water bodies. Saltwater intrusion resulting from the withdrawal of water would be undetectable from normally varying salinity regimes.

Offshore Brine Disposal

Construction of the offshore brine disposal system would require dredging a pipe ditch in the Gulf floor. Approximately 21 acres of benthic habitat would be disturbed for construction to the 3.5-mile disposal site if the impact area is 50 ft wide. Increased turbidity, which would be the major water quality perturbation, is considered a short-term impact. Recovery of benthic habitat should occur within 1 to

2 years. Extension of the brine line to the 12.5-mile site would increase the bottom area impacted to 76 acres. Detailed discussions of the brine line construction impacts are presented in the Texoma Group FEIS. Operational impacts of the offshore brine disposal system are addressed in Sect. 4.2.5.

4.2.3 Climate and Air Quality

The region that would be impacted by the SPR Phase III program has been designated as a nonattainment area with regard to photochemical oxidants. As discussed in Sect. 3.0, EPA air quality standards are now the same as those presented in the Texoma Group FEIS (Sect. C.3.1.3.3), except for ozone, which has been elevated from 0.08 parts per million (ppm) to 0.12 ppm, and lead, which has been set at 1.5 $\mu g/m^3$. Air quality impacts related to similar site construction activities are discussed in detail in the Texoma Group FEIS (Sect. C.3.1.3). The primary sources of air emissions during construction are paint vapors, combustion products, and fugitive dust. Land preparation activities would have the greatest effect on ambient air quality. The 24-h particulate standard of 260 $\mu g/m^3$ inside the site boundary could be exceeded for limited periods, depending in part on meteorological conditions during construction. Changing the design of the Big Hill site from 100 to 140 MMB would only increase construction impacts slightly beyond those discussed in the Texoma Group FEIS (Sect. 4.6.3). This would be primarily because of the construction of four additional storage caverns and the associated wellpads and access roads.

During cavern leaching and fill activities, hydrocarbon emissions are released from the oil/brine separators, brine pond, pumps, and other site facilities. Most emissions emanate from the oil/brine separators as a result of the vaporization of the lighter hydrocarbon fractions dissolved in brine.

Emission rates for the four possible activities (leach, leach/fill, final fill, and refill) at the Big Hill site are presented in Table 4-1. As planned, all 14 caverns at Big Hill are to be leached simultaneously (not in groups), and the duration (in days) given in Table 4-1 for each of the four activities reflects this procedure. As with the modeled dispersion results, these values should be considered worst-case. No adjustments for downtime or intermittent operations have been included in the estimates. Detailed information on how these values were derived is given in Appendices C.2 and C.3.

As indicated in Appendix C.2, the emission rates for the leach/fill and fill activities were estimated from data taken during leaching because these activities have not as yet occurred. These values are "best estimates" at this time and may be refined at a later point. The emission rate for leach/fill indicates that this facility may be classified as a major stationary source, >100 tons per year (tpy) emissions. Emissions in excess of 100 tpy occur only during periods of significant oil flow during the leach/fill phase, which accounts for less than 45 percent of the total leaching period. Surge tankage is not considered in determining onsite hydrocarbon emission levels at Big Hill as these processes occur at Sun Terminal. Other drawdown emissions at the site are insignificant.

Table 4-1. Hydrocarbon emission rates for Big Hill (140 MMB)

SOURCE OR ACTIVITY	HYDROCARBON EMISSION RATE SHORT-TERM (g/s)	ANNUAL* (tons)
LEACH ONLY - 638 d		
BRINE EMISSIONS (.26 ppm)	.80	27.8
VALVES, SEALS, SLOP TANKS	.06	2.2
10,000 bbl, 45 ft DIAMETER BLANKET OIL TANK		
5,500-bbl/d throughput		
STANDING LOSS	.04	1.4
WITHDRAWAL LOSS	.02	.7
TOTAL	.92	32.1
LEACH/FILL - 539 d		
BRINE EMISSIONS (1.5 ppm)	4.64	161.2
VALVES, SEALS, SLOP TANKS	.06	2.2
TOTAL	4.70	163.4
FINAL FILL - 200 d		
BRINE EMISSIONS (2.6 ppm)	1.61	55.9
VALVES, SEALS, SLOP TANKS	.06	2.2
TOTAL	1.67	58.1
REFILL ONLY - 500 d		
BRINE EMISSIONS (1.90 ppm)	1.18	41.0
VALVES, SEALS, SLOP TANKS	.06	2.2
TOTAL	1.24	43.2

*these values include a significant percentage of ethane

Another factor also contributes to the emissions of Table 4-1 being an overestimate. As defined by the Texas Clean Air Act, Sect. 101.1, a volatile organic compound (VOC) excludes ethane. The brine emission levels of Table 4-1 include ethane, which is a significant constituent during several activities. Major source status is based on VOC emissions only (i.e., excluding ethane).

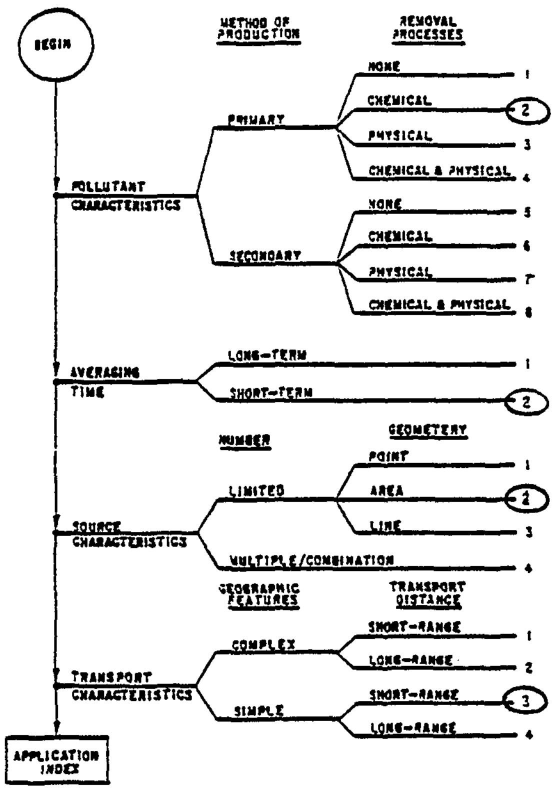
Computer modeling was used to project potential contributions to the ambient atmosphere from NMHC emitted from the Phase III sites. The computer model for projecting NMHC concentrations from the proposed sites was selected by using the Workbook for the Comparison of Air Quality Models (EPA 1977). This document contains a scheme for classifying model applications (Table 4-2) that was used to select an appropriate model for use. A 4-digit index number is first generated on the basis of the pollutant's characteristics, averaging time desired, source characteristics, and transport characteristics of the pollutant of interest. The flow diagram of Table 4-2 indicates that NMHC is a primary pollutant (i.e., one that is emitted directly from the source rather than forming in the atmosphere) that is removed primarily by chemical means. Short-term (1-h) averaging times are desired since the ozone standard is a 1-h standard. The source is essentially an area source, and only short-range transport would be relevant from reactive hydrocarbons emitted from a non-stack source. The resultant index number (2223) indicates that the Efficient Gaussian Plume Multiple-Source Air Quality Algorithm Model (RAM) would be most suited to this application.

The RAM model is suitable for locations with level or gently rolling terrain, where a single wind vector for each hour is a reasonable approximation of the flow over the source area considered. A single mixing height and a single stability class for each hour are assumed to be representative of the area. In this study, the rural version of RAM, RAMR (with Pasquill-Gifford dispersion parameters), and rural mixing height values was used.

Emission information required of area sources consists of southwest corner coordinates, source side length, total area emission rate, and effective area source height. Output consists of calculated air pollutant concentrations at each receptor for hourly averaging times, as specified by the user. Concentrations from area sources are calculated by considering the sources at various distances on a line directly upwind from the receptor to be representative of sources at those distances that affect the receptor. Modification of the vertical distribution by eddy reflection at the ground or at a stable layer aloft is also allowed. This eddy reflection is accomplished by a "folding back" of the portion of the distribution that would extend beyond the barrier if it were absent. This is equivalent to a virtual image source beneath the ground (or above the stable layer).

The meteorological input for RAM consists of a value for each of five parameters--wind direction, wind speed, temperature, stability class, and mixing height--all of which are representative of the region containing the sources and receptors. Mixing height is required only if

Table 4-2. Scheme for classifying model applications



Index Number	Reference Model	Index Number	Reference Model	Index Number	Reference Model
1111	Valley, CRSTER (b,c)	2211	Valley	4111	Valley
1112		2212		4112	
1113	CDM, CRSTER (c,i)	2213	STRAM	4113	CDM
1114		2214	STRAM	4114	
1121	Valley	2221		4121	Valley
1122		2222		4122	
1123	CDM	2223	RAM	4123	CDM
1124		2224		4124	
1131		2231		4131	
1132		2232		4132	
1133	ATM	2233		4133	
1134		2234		4134	
1141	Valley	2241		4141	Valley
1142		2242		4142	
1143	CDM	2243	RAM	4143	CDM
1144		2244		4144	
1211	Valley, CRSTER (b,c)	3111	Valley	4211	Valley
1212		3112		4212	
1213	RAM, CRSTER (c,j)	3113	ATM	4213	STRAM
1214		3114		4214	STRAM
1221		3121	Valley	4221	
1222		3122		4222	
1223	RAM	3123	ATM	4223	RAM
1224		3124		4224	
1231		3131		4231	
1232		3132		4232	
1233	HIWAY, APRAC (d)	3133	ATM	4233	
1234		3134		4234	
1241		3141	Valley	4241	
1242		3142		4242	
1243	RAM, APRAC (e)	3143	CDM, ATM (f)	4243	RAM
1244		3144		4244	
2111	Valley	3211	Valley	5111	
2112		3212		5112	
2113	CDM	3213	STRAM	5113	
2114		3214	STRAM	5114	
2121	Valley	3221		5121	
2122		3222		5122	
2123	CDM	3223	RAM	5123	
2124		3224		5124	
2131		3231		5131	
2132		3232		5132	
2133		3233		5133	
2134		3234		5134	
2141	Valley	3241		5141	
2142		3242		5142	
2143	CDM	3243	RAM	5143	
2144		3244		5144	

the stability is neutral or unstable (EPA, 1978a). For this analysis, 1964 Houston surface data and Lake Charles upper air data were used for modeling because only 1964 data were readily available. In trying to predict future meteorology, 1964 is as representative as any other (i.e., more recent) year. Lake Charles upper air data are used with Houston surface data because they are the closest upper air readings available.

Running RAM for an entire year with hourly meteorological input would result in about 8000 pages of computer output (1 page for each of 8760 h), with over 52,000 generated concentrations (six location-specific concentrations are printed for each hour). For this reason, the Single Source Model (CRSTER) was first run to determine which day's meteorological data would result in "worst-case" concentrations. CRSTER has the advantage of printing only the highest 1-h concentration each day and ranking these values in descending order (Appendix C.4, Table C.4-1), thus making identification of the "worst-case" meteorological day apparent. CRSTER also uses identical meteorological data input as RAM. The disadvantage of using this model is that it will not accept area sources. Therefore, the area source was approximated as a "stack" of 3-m release height, 56.4-m diameter (equivalent to a source 50 m square which is the approximate area of the oil-brine separators), 0.01-m/s flow rate (natural draft), and 23°C (ambient) temperature. Although this procedure may not produce the exact 1 h of "worst-case" meteorological conditions that running all 8760 h via RAM would indicate, it is expected that a typically "very poor" meteorological day (one resulting in high concentrations) will be obtained.

CRSTER output results (Appendix C.4, Table C.4-1) indicated that the maximum 1-h concentration occurred on day 176 (June 25 of the hypothetical modeled year). This day also produced yearly maximum 3-h and 24-h concentrations, definitely indicating a "worst-case" meteorological day.

RAM was subsequently run for day 176 (Appendix C.4, Table C.4-2). The emission source input was an area source 50 m square with a 3-m effective release height--which is a reasonable assumption for an evaporative non-stack source. The combined area of all sources listed in Table 4.1 is actually somewhat larger than 50 m square, resulting in a slight overestimate of emissions. Concentrations derived from RAM were calculated at 0.5-km intervals over a rectangular grid of approximately 31 km^2, with the single area source (the oil brine-separator area) located at the center of this grid. Non-zero concentrations occur at random (as a function of hourly meteorology) throughout the grid area, but most occur very close (many on DOE property) to the source; this would be expected for a small area source. The nearest plant property boundary at Big Hill is about 0.3 km to the east of the oil-brine separator. All other plant boundaries are at least 0.6 km from the oil-brine separator.

The maximum projected 1-h NMHC concentration of 1008.8 $\mu g/m^3$ occurred 1.0 km SE of the source from 6:00 to 7:00 am. RAM modeling results shown in Appendix C.4, Table C.4-2, are for a source emitting 1 g/s of NMHC. Ambient NMHC levels at any emission rate can be derived from this output as ambient levels are directly proportional to the NMHC emission rate. Thus, RAM modeling results at 1 g/s can be used to estimate ambient NMHC concentrations for the four activities at the Big Hill site by simply multiplying by the short-term emission levels given in Table 4-1. This procedure would indicate the following absolute maximum "worst-case" 1-h concentrations for the four activities:

Activity	Emission Rate (g/s)	Maximum 1-h Impact ($\mu g/m^3$)
Leach only	.92	928.1
Leach/fill	4.70	4741.3
Final fill	1.67	1684.7
Refill only	1.24	1250.9

Overall, ambient NMHC impact from any of the four activities for any hour-specific receptor location, as indicated in the RAM printout of Appendix C.4, Table C.4-2, can be obtained by multiplying by the short-term emission rate for that activity. The levels projected as maximum 1-h NMHC impacts indicate that violations of the 3-h NMHC (160 $\mu g/m^3$) standard are likely. Some 1-h values in excess of 160 $\mu g/m^3$ (i.e., violations of the NMHC standard if they persist for 3 h) are projected by RAM up to 3.5 km from the site. Background NMHC, as typified by the Texas Air Control Board (TACB) Texas City monitoring site yearly mean 1-h value, is about 400 $\mu g/m^3$. This background would tend to increase (slightly) ozone levels projected from site NMHC emissions if included.

Although projected ambient NMHC concentrations are of some utility in quantifying effects of the proposed Phase III expansion on overall air quality, such hydrocarbon levels are generally only of concern in that they contribute to the much more serious photochemical oxidant (ozone) problem. Additionally, the 3-h NMHC standard (160 $\mu g/m^3$), which was used only as a guide in developing State Implementation Plans (SIPs) to achieve the ozone standards, was proposed for revocation by the Environmental Protection Agency (EPA) on May 8, 1981. EPA stated that the standard (40 CFR 50) should be revoked because it does not directly protect health or welfare and therefore is unnecessary and inappropriate as a national health standard. Hydrocarbons are precursors of ozone, for which there is a national ambient air quality standard.

Ozone (O_3) and other oxidants are formed in polluted atmospheres as a result of a rather wide variety of photochemical reactions, the main components of which include hydrocarbons, oxides of nitrogen, and sunlight. The most important photochemical reactions involve the very reactive single oxygen atom. Oxidants can be formed by several reactions:

$$NO^2 + hv = NO + O \ ,$$
$$O_3 + hv = O_2 + O \ ,$$
$$R + O = R'O + \text{products such as } R'' \ ,$$

where hv represents a photon of light and R', and R" represents hydrocarbon groups which could differ from R; R'O is the very reactive oxygen-bearing free radical. The third reaction can take numerous forms, depending on the hydrocarbon R (Williamson, 1973). Saturated hydrocarbons (alkanes), such as those constituting the major portion of evaporative emissions from crude oil, are much less reactive than unsaturated hydrocarbons such as olefins, where the carbon-carbon double bond is readily available for breaking and pairing with an oxygen electron.

Because such reactions depend on available sunlight, the typical photochemical smog episode is initiated on a warm, sunny day. Likewise, oxidant values peak during the daytime and fall to near-zero at night. The effect of increased hydrocarbons and oxides of nitrogen will be a buildup of ozone and will be most pronounced on such days.

Because the Phase III sites are in nonattainment areas for ozone, the ultimate issue is the extent to which the potential NMHC emissions from the Phase III expansion sites will contribute to pre-existing photochemical oxidant levels in these vicinities. Although this is a complex situation to ascertain, a reasonable estimate of this relationship can be made by using the Empirical Kinetic Modeling Approach (EKMA). This approach employs the Ozone Isopleth Plotting Package (OZIPP) computer model to relate NMHC and NO_x concentrations to maximum 1-h ozone concentrations via an isopleth diagram. OZIPP is essentially a state-of-the-art model, similar in concept to a trajectory- type photochemical model. A column of air consisting of initial concentrations of ozone and precursors is transported along an assumed trajectory. The column is assumed to act like a large smog chamber in which the precursors react according to the kinetic mechanism of Table 4-3 to form ozone and other products. The column extends from the earth's surface to the base of an elevated inversion. The diameter of the column is such that concentrations inside and just outside the column are similar, so that the horizontal exchange of air in and out of the column can be ignored. The volume of the column increases only as the inversion rises. Thus, the pollutants within the column are diluted as they are mixed with the air aloft. The model mathematically simulates these physical and chemical processes.

OZIPP operates in two stages. The first stage performs computer simulations to calculate maximum ozone concentrations as a function of initial NMHC and NO_x concentrations. After the NMHC and NO_x concentrations at which simulations are to be performed have been selected, the simulations are actually performed by the differential equation integrator, and a set of first-order, differential equations is solved numerically. The differential equation integrator calculates the concentrations of 32 chemical species in the kinetic mechanism as a function of time during the simulation period. In the second stage, interpolation schemes are used to determine the isopleth lines from the calculated diagram points and to draw the isopleth diagram that is the model's major output.

Thus, after all simulations have been performed, the calculated diagram points are passed to the interpolation and plotting section. In the first interpolation stage, spline interpolation (a cubic polynomial or a hyperbolic function) is performed between the calculated diagram points

Table 4-3. Kinetic mechanism used in OZIPP

Number	Reaction	Rate Constant*
1	$NO_2 + h\nu \rightarrow NO + O(^3P)$	k_{vary}
2	$O(^3P) + O_2 + M \rightarrow O_3 + M$	2.0×10^{-5} ppm^{-2}min^{-1}
3	$O_3 + NO \rightarrow NO_2 + O_2$	25.0
4	$NO_2 + O_3 \rightarrow NO_3 + O_2$	0.045
5	$NO_2 + O(^3P) \rightarrow NO + O_2$	1.3×10^4
6	$NO_3 + NO \rightarrow 2NO_2$	1.3×10^4
7	$NO_2 + NO_3 \rightarrow N_2O_5$	5.6×10^3
8	$N_2O_5 \rightarrow NO_2 + NO_3$	22.0 min^{-1}
9	$N_2O_5 + H_2O \rightarrow 2HNO_3$	2.5×10^{-6}
10	$NO + NO_2 + H_2O \rightarrow 2HONO$	1.0×10^{-9} ppm^{-2}min^{-1}
11	$2HONO \rightarrow NO + NO_2 + H_2O$	1.0×10^{-3}
12	$HONO + h\nu \rightarrow OH + NO$	k_{vary}
13	$OH + NO_2 \xrightarrow{M} HNO_3$	8.0×10^3
14	$OH + NO \xrightarrow{M} HONO$	3.0×10^3
15	$HO_2 + NO \rightarrow NO_2 + OH$	1.2×10^3
16	$HO_2 + HO_2 \rightarrow HOOH + O_2$	8.4×10^3
17	$HOOH + h\nu \rightarrow 2OH$	k_{vary}
18	$O_3 + h\nu \rightarrow O(^1D)$	k_{vary}
19	$O_3 + h\nu \rightarrow O(^3P)$	k_{vary}
20	$O(^1D) + M \rightarrow O(^3P) + M$	8.7×10^4
21	$O(^1D) + H_2O \rightarrow 2OH$	5.1×10^5
22	$OH + O_3 \rightarrow HO_2 + O_2$	84.0
23	$O_3 + HO_2 \rightarrow OH + 2O_2$	2.4
24	$PROP + OH \rightarrow ADD$	2.5×10^4
25	$ADD + NO \rightarrow X + NO_2$	1.0×10^3
26	$ADD + ADD \rightarrow 2X$	1.2×10^4
27	$ADD + MeO_2 \rightarrow X + MeO$	1.0×10^3
28	$ADD + C_2O_2 \rightarrow X + C_2O$	1.0×10^3
29	$ADD + C_3O_2 \rightarrow X + C_3O$	1.0×10^3
30	$X \rightarrow HCHO + ALD2 + HO_2$	1.0×10^5 min^{-1}
31	$PROP + O_3 \rightarrow OH + HO_2 + ALD2$	8.0×10^{-3}
32	$PROP + O_3 \rightarrow OH + C_2O_3 + HCHO$	8.0×10^{-3}
33	$BUT + OH \rightarrow ScO_2$	1.8×10^3
34	$BUT + OH \rightarrow C_4O_2$	1.8×10^3
35	$NO + C_4O_2 \rightarrow NO_2 + C_4O$	1.8×10^3
36	$NO + ScO_2 \rightarrow NO_2 + ScO$	1.8×10^3

Table 4-3. (continued)

37	$NO + C_3O_2 \rightarrow NO_2 + C_3O$	1.8×10^3
38	$NO + C_2O_2 \rightarrow NO_2 + C_2O$	1.8×10^3
39	$NO + MeO_2 \rightarrow NO_2 + MeO$	1.8×10^3
40	$C_4O \rightarrow HCHO + C_3O_2$	$7.5 \times 10^4\ min^{-1}$
41	$ScO \rightarrow ALD2 + C_2O_2$	$1.0 \times 10^5\ min^{-1}$
42	$C_3O \rightarrow HCHO + C_2O_2$	$8.0 \times 10^3\ min^{-1}$
43	$C_2O \rightarrow HCHO + MeO_2$	$4.0 \times 10^3\ min^{-1}$
44	$C_4O + O_2 \rightarrow ALD4 + HO_2$	0.7
45	$ScO + O_2 \rightarrow MEK + HO_2$	1.4
46	$C_3O + O_2 \rightarrow ALD3 + HO_2$	0.5
47	$C_2O + O_2 \rightarrow ALD2 + HO_2$	0.4
48	$MeO + O_2 \rightarrow HCHO + HO_2$	0.4
49	$HCHO + h\nu \rightarrow$ Stable Products	k_{vary}
50	$HCHO + h\nu \rightarrow 2HO_2$	k_{vary}
51	$HCHO + OH \rightarrow HO_2$	1.5×10^4
52	$ALD2 + h\nu \rightarrow$ Stable Products	$4.2 \times 10^{-6}\ min^{-1}$
53	$ALD2 + h\nu \rightarrow MeO_2 + HO_2$	k_{vary}
54	$ALD2 + OH \rightarrow C_2O_3$	1.5×10^4
55	$ALD3 + h\nu \rightarrow$ Stable Products	$6.0 \times 10^{-5}\ min^{-1}$
56	$ALD3 + h\nu \rightarrow C_2O_2 + HO_2$	$2.5 \times 10^{-3}\ min^{-1}$
57	$ALD3 + OH \rightarrow C_3O_3$	4.5×10^4
58	$ALD4 + h\nu \rightarrow$ Stable Products	$6.0 \times 10^{-5}\ min^{-1}$
59	$ALD4 + h\nu \rightarrow C_3O_2 + HO_2$	$1.9 \times 10^{-3}\ min^{-1}$
60	$ALD4 + OH \rightarrow C_4O_3$	4.5×10^4
61	$ADD + C_4O_2 \rightarrow X + C_4O$	1.0×10^3
62	$ADD + ScO_2 \rightarrow X + ScO$	1.0×10^3
63	$C_4O_3 + NO \rightarrow C_3O_2 + NO_2$	8.0×10^2
64	$C_3O_3 + NO \rightarrow C_2O_3 + NO_2$	8.0×10^2
65	$C_2O_3 + NO \rightarrow MeO_2 + NO_2$	8.0×10^2
66	$C_4O_3 + NO_2 \rightarrow PAN$	1.0×10^2
67	$C_3O_3 + NO_2 \rightarrow PAN$	1.0×10^2
68	$C_2O_3 + NO_2 \rightarrow PAN$	1.0×10^2
69	$C_4O_2 + HO_2 \rightarrow$ Stable Products	4.0×10^3
70	$C_3O_2 + HO_2 \rightarrow$ Stable Products	4.0×10^3
71	$ScO_2 + HO_2 \rightarrow$ Stable Products	4.0×10^3
72	$C_2O_2 + HO_2 \rightarrow$ Stable Products	4.0×10^3
73	$MeO_2 + HO_2 \rightarrow$ Stable Products	4.0×10^3
74	$C_4O_3 + HO_2 \rightarrow$ Stable Products	4.0×10^3
75	$C_3O_3 + HO_2 \rightarrow$ Stable Products	4.0×10^3
76	$C_2O_3 + HO_2 \rightarrow$ Stable Products	4.0×10^3

Table 4-3. (continued)

* Units of $ppm^{-1}min^{-1}$ unless otherwise indicated

Symbol	Definition
k_{vary}	Diurnal 1-hour average photolytic rate constant
PROP	C_3H_6
BUT	$n\text{-}C_4H_{10}$
ADD	$CH_3CH(OH)CH_2OO$
X	$CH_3CH(OH)CH_2O$
MeO_2	CH_3O_2
C_2O_2	$CH_3CH_2O_2$
C_3O_2	$CH_3CH_2CH_2O_2$
C_4O_2	$CH_3CH_2CH_2CH_2O_2$
ScO_2	$CH_3CH(O_2)CH_2CH_3$
ALD2	CH_3CHO
ALD3	CH_3CH_2CHO

Source: U.S. Environmental Protection Agency 1978b to determine specific NMHC and NO_x concentrations (i.e., a level for which an isopleth is to be drawn). The diagram points for the isopleths are then passed to the second interpolation stage, which uses the spline interpolation scheme to determine the final coordinates for the isopleth points (EPA, 1978b).

Although the model is basically a tool for calculating emission reductions necessary to achieve ambient air quality standards for photochemical oxidants in urban atmospheres, reasonably accurate approximations of the downwind ozone concentrations resulting from proposed Phase III NMHC emissions can be obtained by appropriate choice of site-specific input data to the model. Input assumptions consider initial precursor concentrations, light intensity, dilution, diurnal and spatial emission patterns, transported pollutant concentrations, and reactivity of the precursor mix.

Input assumptions that were modified (from default values) for the Phase III site-specific runs include latitude and longitude of the emission source site, time zone, day of year, inversion heights, inversion start and stop times, propylene fraction, and NO_2/NO_x ratio. The day of year was set at June 25 because that day was used in the RAM modeling (it provided "worst-case" NMHC values); mixing height data were also obtained from the meteorological data for this day. The propylene (which is extremely reactive) fraction was lowered from the default value of 0.25 to 0.01 to reflect the relatively low reactivity of the crude oil emissions, and the NO_2/NO_x ratio was raised from default value of 0.25 to 0.65 to reflect the higher proportion of NO_2 that would be expected in a rural atmosphere.

Results of the site-specific (typically, near Winnie, Texas) OZIPP run are shown in Fig. 4-1. Input data and actual HC, NO_x, and O_3 concentrations used to construct the isopleths are shown in Appendix C, Table C.4-3. In Fig. 4-1, Level I represents the 1979 yearly mean NO_x concentration (0.02 ppm) at the TACB Texas City monitoring site; Level II indicates the 1979 yearly 1-h maximum reading (0.17 ppm) at this site. Level II represents a worst-case maximum. Using the conversion factor of 1000 $\mu g/m^3$ = 1.5 ppm for NMHC and the 1-h worst case, NMHC maxima for the four activities, which range from 928 to 4741 $\mu g/m^3$ (during leach/fill), indicate that these worst-case NMHC levels would result in 1-h ozone concentrations in the range of 0.16 to 0.20 ppm at Level I (normal) NO_x concentrations (Fig. 4-1). The ozone isopleths tend to flatten out past 1.5 ppm NMHC, and ozone levels do not increase significantly, regardless of how high NMHC concentrations become.

Because it is highly improbable that the worst-case NMHC emission (which occurs on June 25) and the yearly 1-h maximum NO_x concentration (Level II) would occur at the same time, ozone levels that might occur as a result of such elevated NO_x concentrations should be considered as those resulting from typical rather than worst-case NMHC concentrations. Typical NMHC concentrations from Big Hill (as indicated by the RAM modeling) range from 0 to 4.0 ppm, resulting in potential 1-h ozone concentrations as high as 0.5 ppm. Such concentrations would occur only if elevated NO_x levels occurred during leach/fill (which has the highest

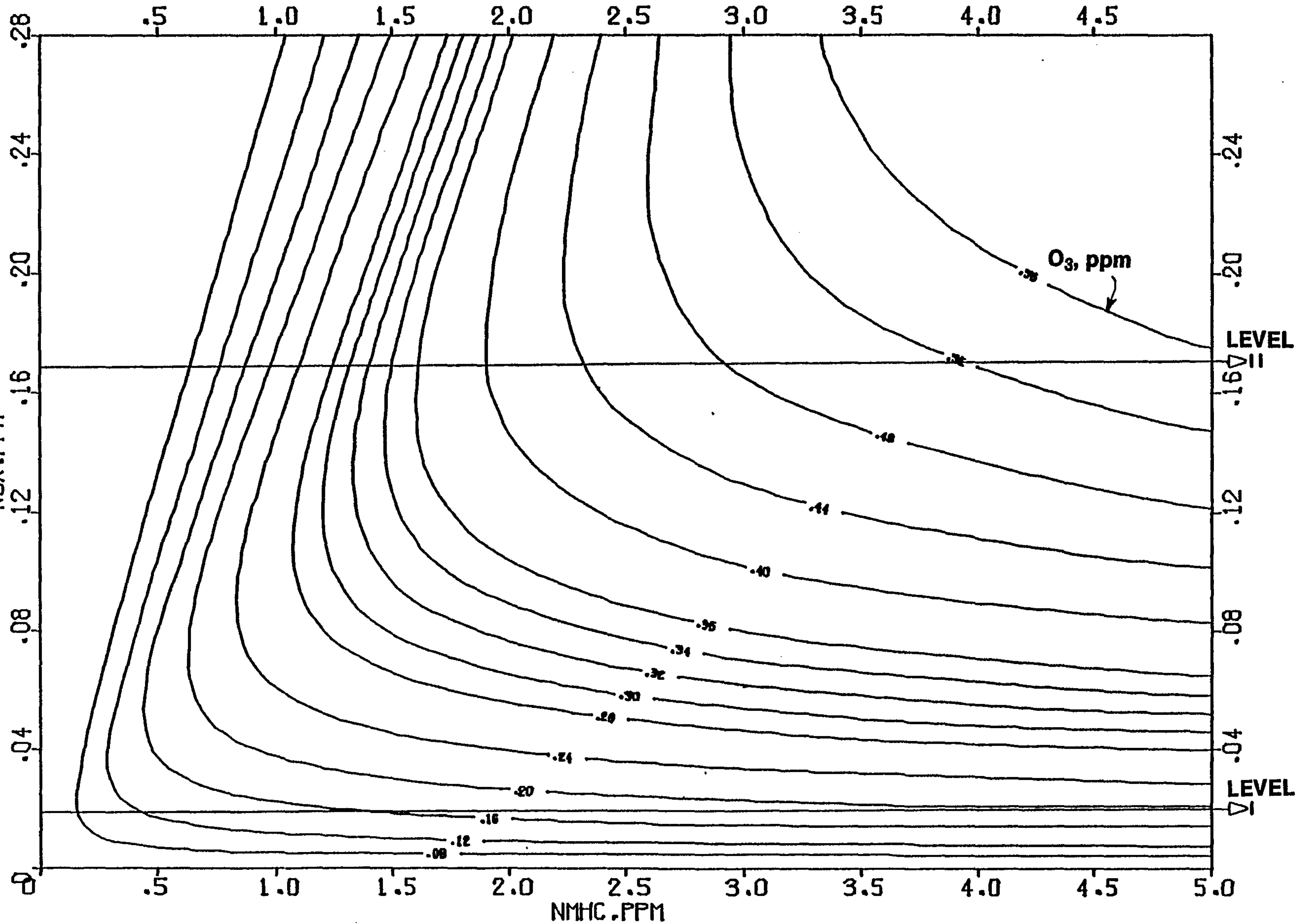


Figure 4-1. Ozone concentration as a function of NO_X and NMHC.

NMHC emission rate). During other activities, 1-h ozone contributions from this site would be expected to range up to 0.16 ppm during worst-case meteorological conditions for a typical year. The National Ambient Air Quality Standard (NAAQS) for ozone (which is frequently violated in this area) is 0.12 ppm for 1 h.

Results of the NMHC modeling analysis for the three additional terminals are shown in Figs. 4-2 to 4-5. Phase III emissions at the Sun Terminal are not an addition to the present levels; they would replace the existing emission because oil flow rates cannot exceed the permitted levels. During tanker loading and unloading operations at Sun Terminal, the NMHC guideline (160 $\mu g/m^3$) would be exceeded under the preferred alternative. Under the most adverse meteorological conditions, the fill/refill operations would result in 3-h NMHC concentrations exceeding this level for distances exceeding 12 miles downwind from the terminal for the short-term emissions scenario. Such levels for average emissions would be limited to areas less than 6 miles from the site.

The major emissions source responsible would be ballasting activities. As stated in the emissions development section (Appendix C.3), the emissions used in this analysis are conservative because they assume that all ballasting occurs at the dock and that tankers do not have segregated ballast tanks. Actual impacts should be substantially less than predicted here. If all tankers have segregated ballast holds, impacts could be reduced below the level of the standard, even under the most adverse meteorological conditions.

During drawdown there could be substantial emissions from tanker loading operations at the terminal resulting in NMHC levels of up to 3.1 ppm at downwind distances of up to 22 miles for short-term maximum emissions. Average emissions (long-term) could produce significant concentrations up to 12 miles downwind of up to 0.4 ppm. During drawdown, oil passing from the SPR across the terminal would be replacing oil lost because of a foreign supply interruption. As with the fill scenario, flow rates would not exceed the permitted capacity of the terminal. Mitigation of these impacts, if necessary, appears limited to (1) pipeline distribution of crude oil during drawdown, (2) vapor recovery and control of ship loading emissions, or (3) use of an alternative terminal. Under the alternative terminal or pipeline distribution options, the impacts would be reduced essentially in proportion to the volume of crude oil diverted from tanker loading at Sun Terminal.

An alternative pipeline to the Houston Ship Channel area connecting the dome site to either the Oil Tanking of Texas, Inc., Terminal (OTTI) or the Pelican Island Terminal would substantially reduce the air quality burden in the Sun Terminal area by transferring emissions. The fill/refill activities at the alternative terminals would result in significant adverse impacts only under maximum emissions (short-term) and worst-case meteorological conditions. Again, segregated ballast tanks on the tankers would adequately mitigate these impacts. The impacts associated with drawdown operations at either of the alternative terminal sites are significant because NMHC levels sufficient to contribute to additional 1-h ozone violation are anticipated for up to 12 miles for short-term emissions and for 3 miles for average emissions

	Maximum NMHC Impact (mg/m³)				
Source	5 km	10 km	15 km	20 km	>20 km
Sun Terminal	3.60	1.02	0.51	0.28	0.13
Oil Tank. of Texas	2.60	1.02	0.51	0.28	0.13
Pelican Island	2.60	1.02	0.51	0.28	0.13

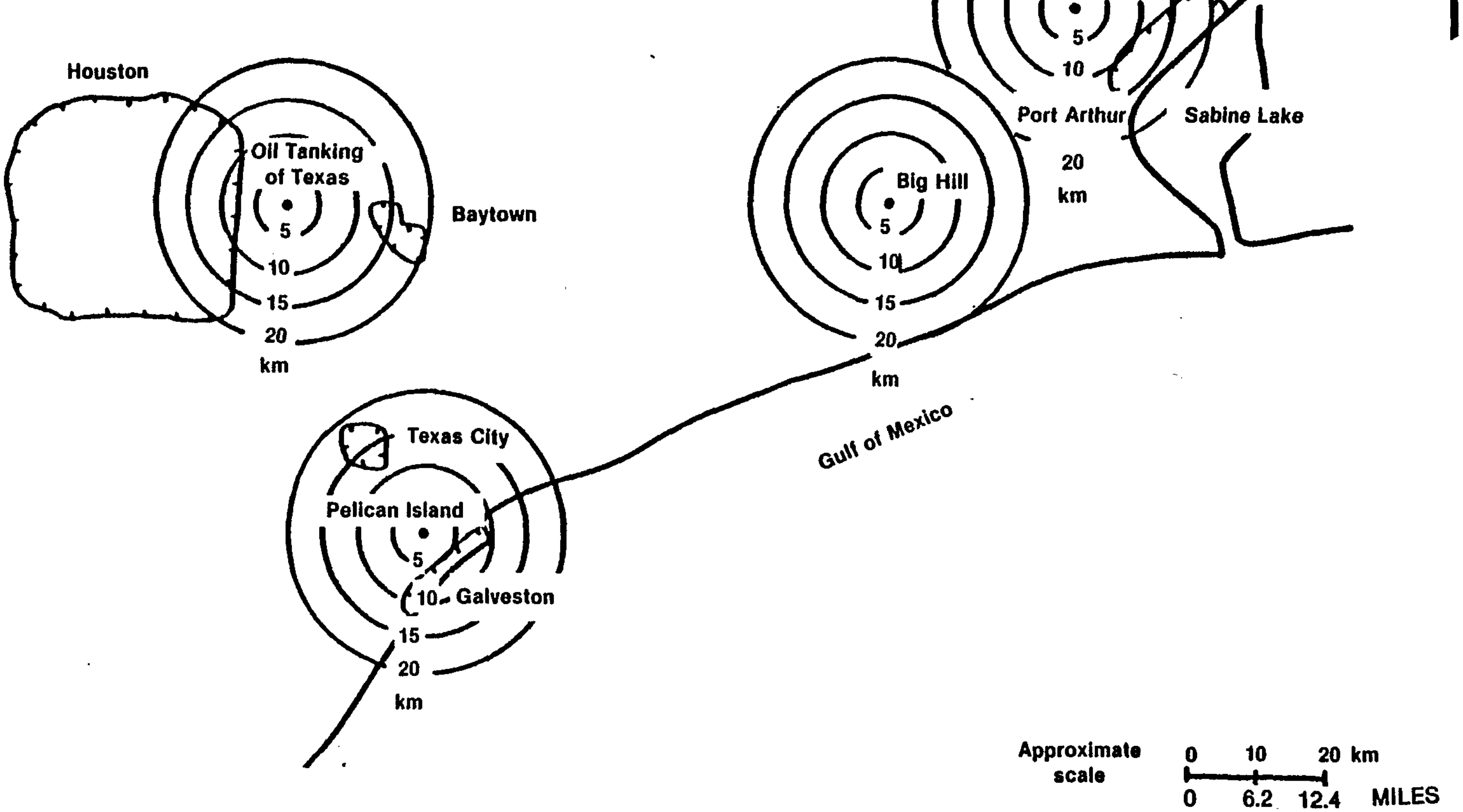


Figure 4-2. Short-term fill/refill emissions scenario, maximum NMHC impacts.

	Maximum NMHC Impact (mg/m^3)				
Source	5 km	10 km	15 km	20 km	>20 km
Sun Terminal	12.75	6.63	3.57	2.55	2.04
Oil Tank. of Texas	6.63	3.32	1.79	1.28	1.24
Pelican Island	6.63	3.32	1.79	1.28	1.24

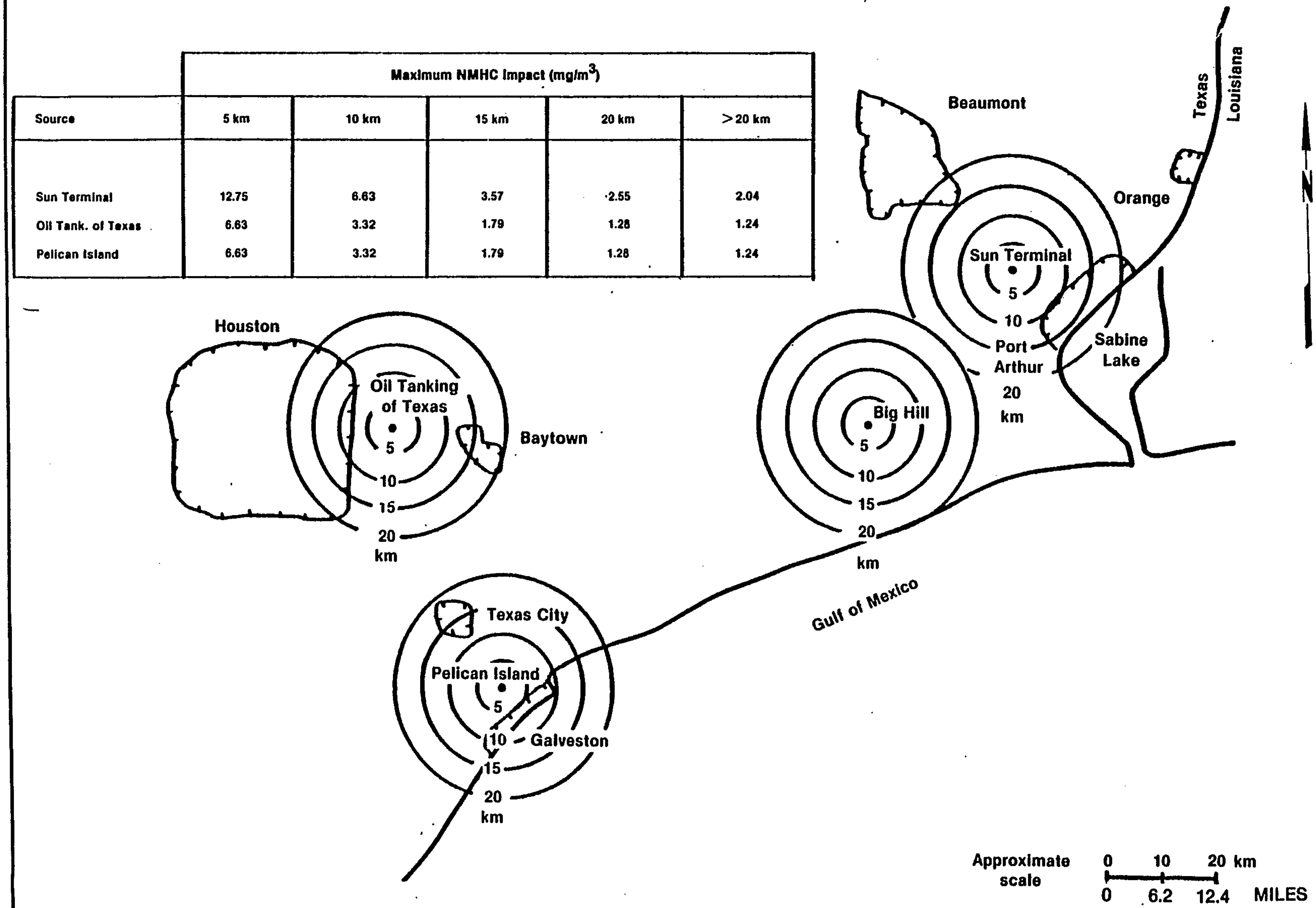


Figure 4-4. Short-term withdrawal emissions scenario, maximum NMHC impacts.

	Maximum NMHC Impact (mg/m^3)				
Source	5 km	10 km	15 km	20 km	>20 km
Sun Terminal	0.17	0.08	0.05	0.03	0.02
Oil Tank. of Texas	0.17	0.08	0.05	0.03	0.02
Pelican Island	0.17	0.08	0.05	0.03	0.02

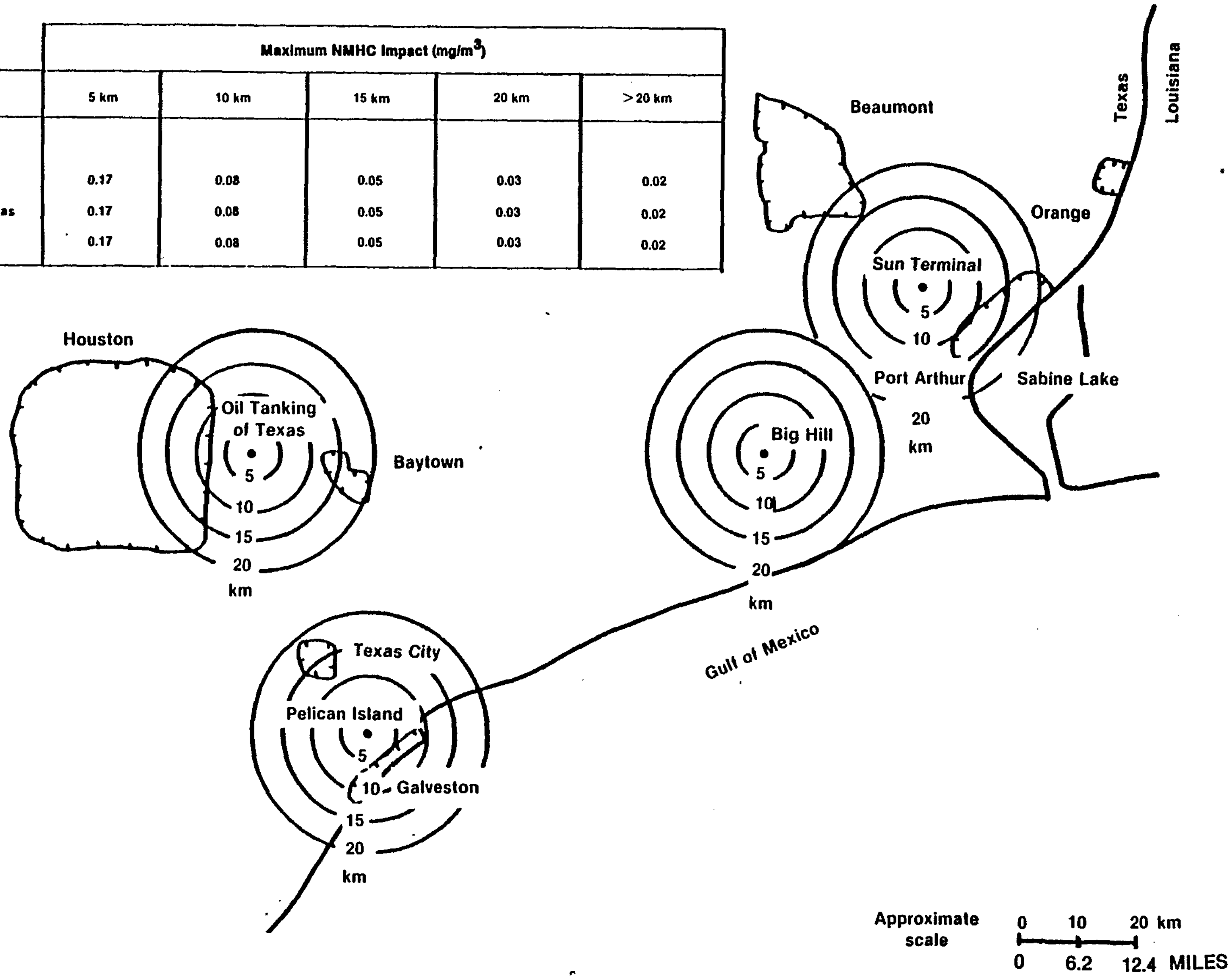


Figure 4-3. Long-term fill/refill emissions scenario, maximum NMHC impacts.

	Maximum NMHC Impact (mg/m³)				
Source	5 km	10 km	15 km	20 km	>20 km
Sun Terminal	1.53	0.76	0.51	0.26	0.20
Oil Tank. of Texas	0.50	0.27	0.15	0.09	0.05
Pelican Island	0.50	0.27	0.15	0.09	0.05

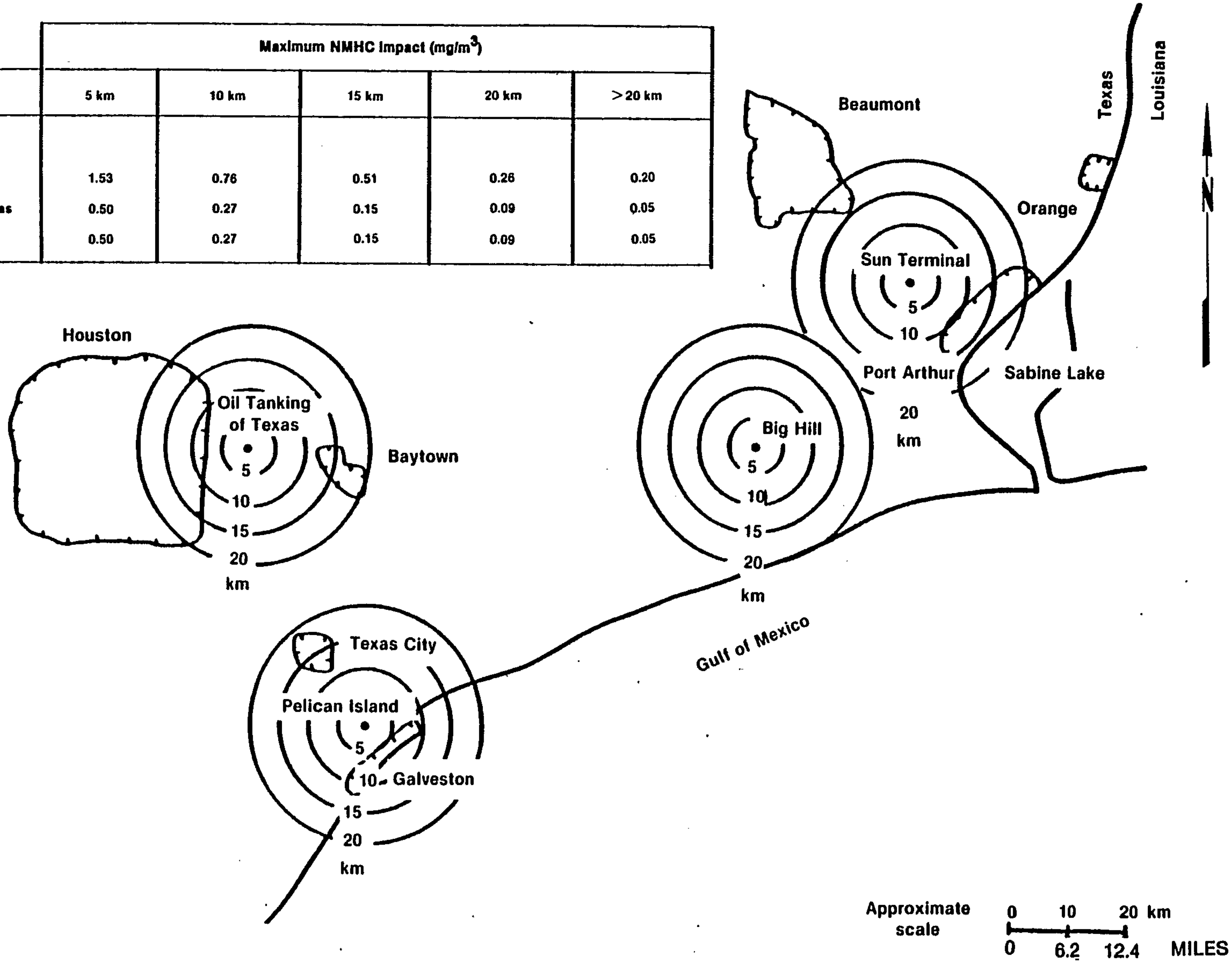


Figure 4-5. Long-term withdrawal emissions scenario, maximum NMHC impacts.

under worst-case meteorological conditions. The primary emissions source is tanker loading, although only 35 percent of the crude oil distribution is projected for this method.

Based on available information and the foregoing analysis, the overall level of hydrocarbon emissions is probably insufficient to have an important impact on nonlocal, regional levels of photochemical oxidants (i.e. other than in the immediate site area). In fact, an imbalance in the ratio of NMHC and oxides of nitrogen in a given air mass may even retard oxidant formation. This effect has been demonstrated by EPA and others in numerous "smog chamber" studies and is also apparent from the isopleths of Fig. 4-1 (see Appendix C).

In summarizing the air quality impact, the Big Hill dome and Sun Terminal facilities would be significant sources of NMHC and, to a lesser extent, combustion contaminants under the preferred alternative. Additional violations of the 1-h ozone standard, immediately downwind from the Sun Terminal and Big Hill facility, are predicted. Tanker loading and ballasting emissions dominate the terminal emissions; it is unlikely that the other sources would independently cause violations of the ozone standard outside terminal boundaries. The use of efficient vapor control technology would significantly reduce the impacts on regional ambient air quality.

Also, although the annual tonnage emission rates for this project appear fairly large, they are relatively small when compared with regional hydrocarbon emission levels in this area of heavy petrochemical activity (>500,000 tpy in Jefferson, Harris, and Galveston counties combined in 1977).

If this site is classified as a major stationary source, Lowest Achievable Emission Rate (LAER), as defined by the TACB, would be implemented if the facility is not given an exemption because of the intermittent nature of emissions. LAER for the Big Hill site would probably consist of covering the oil-brine separators, which are the major emission sources, and venting collected VOC emissions to a vapor recovery system. Offsetting emission reductions may have to be obtained from nearby sources.

4.2.4 Ambient Sound Levels

Noise sources during construction at Big Hill would include air compressors, trucks, drilling rigs, pile drivers, and other types of general construction-related equipment. It was estimated that equivalent sound level contributions would be no more than 55 dB at 2,000 ft from the center of the site (Texoma Group FEIS, Sect. 4.6.4.1). The area that would be impacted by this noise is basically uninhabited pastureland. The nearest residence is over 1 mile from the storage site. There are no state or Federal noise regulations applicable to the construction of underground caverns in salt domes. Construction contractors would be required to meet all state and Federal regulations related to the exposure of employees to extreme noise levels, as defined by Occupational Safety and Health Administration (OSHA) regulations.

During leach/fill or drawdown/refill operations, primary noise sources would be pump motors. Pumps could be placed in a noise-dampening enclosure to reduce impacts if required.

4.2.5 Species and Habitats

4.2.5.1 Big Hill Site

The proposed Big Hill site would involve about 250 acres of prairie-pasture habitat that is managed primarily for cattle grazing. Fencing of the site would preclude this use. Construction activities would cause the emigration of wildlife from the area and would destroy the burrows of small animals such as mice and rabbits. It is expected that the area would be seeded and periodically mowed for maintenance, thus reducing the probability of natural plant succession on the site. Construction of the Big Hill site would add about 0.2 percent to the decline in pasture habitat in the Sabine Basin as described by Gosselink et al. (1979).

Salt drift from brine ponds is expected to have only very localized effects and, thus, are not likely to affect offsite vegetation. The pond lining would prevent any leakage of brine.

Raw Water and Brine Diffuser Systems

Impacts on species and habitats from construction of the raw water and brine diffuser pipelines would be locally minimal and of short duration. Substantial recovery of the on-land and aquatic/marine portions of pipeline ROW should occur within 1 to 3 years with the use of modern mitigation techniques. Impacts related to the construction of raw water and brine diffuser pipelines in the northwest Gulf of Mexico are discussed in detail in the Texoma and Seaway Group FEISs.

Construction of the preferred brine diffuser pipeline across McFaddin National Wildlife Refuge would require the temporary (1- to 3-year) destruction of 73 acres of brackish-to-intermediate marsh habitat assuming a worst-case 150-ft ROW. Coordination efforts with the U.S. Fish and Wildlife Service (USFWS) refuge manager are underway to minimize environmental effects and assure compliance with regulatory agency requirements (see Appendix D). Routing the pipeline around the refuge to the south would require more impacts to a greater variety of habitats, including rice farms, pastures, freshwater ponds, and wetlands. Existing pipeline ROWs could be used to minimize effects where practicable; several ROWs now cross McFaddin National Wildlife Refuge to the Gulf. Only minor impacts would be expected during operation. These impacts could include disturbance to wildlife during ROW maintenance. Although a brine spill would have some major environmental consequences (see Sect. 4.2.2), such as destruction of habitat, its probability for occurrence would be less than 0.075 for a spill greater than 100 bbl (Texoma Group FEIS, Sect. 4.2.2).

Withdrawal of water from the ICW during leach/fill and drawdown phases of operation could result in the loss of some aquatic biota via entrainment and impingement. Most fish and larger organisms would be excluded by the proposed trash bars and traveling screens. Impingement of these organisms would present some problems, but the expected velocities (0.5 ft/s) are considerably less than the swimming speeds of most fish; therefore, this would not be a significant problem. The primary, and probably unavoidable, loss would be through entrainment of plankton which would pass into the raw water line. The loss of plankton would be proportional to the volume of water withdrawn. This volume, although large in absolute terms, would be insignificant compared with the volume of the ICW. Therefore, entrained loss of plankton is not considered significant.

The potential for biofouling exists at the Big Hill intake structure. To address this problem, a "slug" chlorination treatment has been proposed. Treatment duration and occurrence would depend on observed needs. Given a continuous withdrawal rate, no chlorine should be released into the ICW. During prolonged periods of shutdown, key structures subject to biofouling would either be removed from the water or cleaned before startup.

4.2.5.2 Brine Disposal

The original plan of brine disposal at Big Hill involved the use of underground injection to aquifers at the periphery of the storage site. This plan was abandoned when it became clear that problems associated with injection, such as continual plugging of the wells, and sand inflow, could not be overcome in a cost-effective, timely fashion (see Appendix H). Offshore brine disposal is the only reasonable alternative because of the large quantity involved. Discharge from the Big Hill site would be subject to the Ocean Discharge Criteria (40 CFR 125M) promulgated October 3, 1980, under Sect. 403(c) of the Clean Water Act as amended.

General Characteristics of the Diffuser Area

No threatened or endangered species that would use the discharge areas to any appreciable extent have been found in the baseline studies. The biota appears to be typical of the near-shore northwest Gulf of Mexico. Basically, the same communities exist at the Bryan Mound and Texoma sites. The dominant trends in the northwest Gulf for virtually all biological communities is long-shore similarity and onshore-offshore changes.

Little sport fishing occurs in the area of the proposed discharge sites. Some may occur near Sabine and Heald banks, which are located further off shore, and at oil platforms in the region.

The diffuser area is located in a heavily industrialized portion of the Gulf of Mexico with a great deal of petrochemical activity in the immediate vicinity. Little recreational activity can be linked to the diffuser sites. The beaches are used for limited recreational purposes, with some private beach property and Sea Rim State Park located in the area. Most recreational activity associated with this coastal area involves waterfowl hunting, which cannot be directly related to the brine discharge.

Diffuser Design

The diffuser has been designed to minimize interference with shrimping. The depth of coverage of the pipeline header (about 6 ft) would ensure that neither the pipeline nor the diffuser head would be uncovered or exposed during storm events, which are known to displace large amounts of sediment along the northwest Gulf coast. A diffuser guard, installed on each diffuser port, should prevent entanglement of nets with the ports before backfilling. The flexible discharge hose, the only portion of the diffuser that would be exposed, provides for passage of fishing nets with a minimum possibility of damage to the diffuser or fishing equipment. The diffuser site would be well marked with witness buoys. In addition, every attempt would be made to inform the shrimping community about the project (and to receive their inputs for possible project improvements). There should be little occasion for shrimpers' nets to cross the diffuser.

Brine Discharge Experience at Bryan Mound

Brine has been discharged into the Gulf of Mexico from Bryan Mound since March 1980. Initially, discharge was limited to about 200,000 bbl/d or less until July 1980, when discharge was increased to the permitted rate (600,000 to 680,000 bbl/d).

Because the plume is negatively buoyant, it collapses to the bottom. Extrapolation from other studies indicates that the thickness of this plume in the intermediate field at the release zone boundary [330 ft (100 m)] would be less than 3 ft. Therefore, impacts, if they occur, should be most easily detected in the bottom community. The sedentary benthos in the immediate area of the diffusers would probably be affected, whereas the more motile nekton would simply move out of the area. Based on the small salinity increase 330 ft from the diffuser, a relatively small area of the Gulf floor should be impacted. The following discussion summarizes the results of the Bryan Mound monitoring program presented by Hann and Randall (1981).

The brine plume was tracked regularly by ships using a bottom-towed conductivity probe. Data were plotted to show the extent and orientation of the plume and were related to discharge conditions and environmental factors, such as bottom current and ambient salinity. In addition, regular sampling was conducted throughout the area of brine influence to determine water and sediment quality and the biological components of benthos, nekton, and plankton. The monitoring plan is briefly summarized in Sect. 5.0.

In the Seaway and Texoma FEISs, brine discharge impact assessments were based on outputs from a numerical model in the absence of actual experience with comparable discharge rates and volumes. To determine the reasonableness of these predictions, the brine plume model was evaluated in light of actual discharge at Bryan Mound (NOAA, 1981). Based on the first 8 months of experience, there is reasonable agreement between the model and direct observation, which indicates that the model is a useful planning tool. However, an attempt to quantify the accuracy of the model is particularly complicated by the difficulty in determining ambient bottom salinity.

The determination of ambient bottom salinity precedes each shipboard plume track. Bottom current direction at the diffuser is observed with an over-the-side current meter, and the ship proceeds to an appropriate control station upstream from the diffuser, where bottom salinity is measured. The bottom salinity observed at this station is assumed to be constant throughout the brine field for the purpose of calculating and contouring excess salinities of the brine plume. Although a homogeneous field of ambient bottom salinity may be unlikely, as can be seen in Table F-5 (Appendix F), there is no satisfactory alternative because the ambient field cannot be observed in the presence of discharge.

The variation in the bottom salinity field at a given time, as observed from baseline studies, is significant, as evidenced by Table F-5. For the Big Hill proposed diffuser site, variation of bottom salinity by month ranged from a maximum standard error of 0.7 ppt in September 1977 to a minimum standard error of 0.1 ppt observed in December 1977, May 1978, and October 1978. Variation is not predictable.

The effect of uncertainty in the ambient salinity on contouring excess salinities of the brine plume is illustrated in Fig. 4-6 by a hypothetical treatment of an actual discharge case at Bryan Mound. For this case, the nominal ambient bottom salinity was 34.4 ppt; the area described by the ship's track was 2,700 acres. From observations of absolute salinity, the nominal excess isohalines shown in the figure describe the following areas:

3 ppt	65 acres
2 ppt	300 acres
1 ppt	1,000 acres

If, however, a standard error for the ambient bottom salinity of 0.5 ppt is assumed, there is no assurance at the 95 percent confidence interval that the 3-ppt interval is real or that the 1-ppt contour does not lie beyond the ship's track. In Fig. 4-5, the stippling represents the area within the 95 percent confidence envelope for the 1-ppt contour; the outer boundary is only suggestive. The uncertainty in areas is as follows:

3 ppt	0 to 300 acres
2 ppt	60 to 1,000 acres
1 ppt	300 to >2,700 acres

The preceding discussion indicates that a contour of 1 ppt above ambient salinity may be meaningless in the coastal environment. For this hypothetical treatment, it may be sufficient in terms of biological significance to say that the area of salinity equal to or greater than 3 ppt above ambient is less than 300 acres.

Results of the first 12 months of monitoring data at Bryan Mound indicate the assimilative capacity of the area for brine is not being exceeded. During the months of March through June, the largest areal extent of the 1-ppt-above-ambient contour was 1,383 acres. The highest above-ambient contour was 5 ppt and measured 37.8 ppt, or just 1 ppt above the highest ambient condition measured. By fall the highest above-ambient salinity contour measured was again 5 ppt (38.5 ppt) and covered an area of 222 acres. The 1-ppt contour (34.5 ppt) covered 2,693 acres. During winter the brine discharge system began operating at permitted levels. The highest bottom salinity measured at the

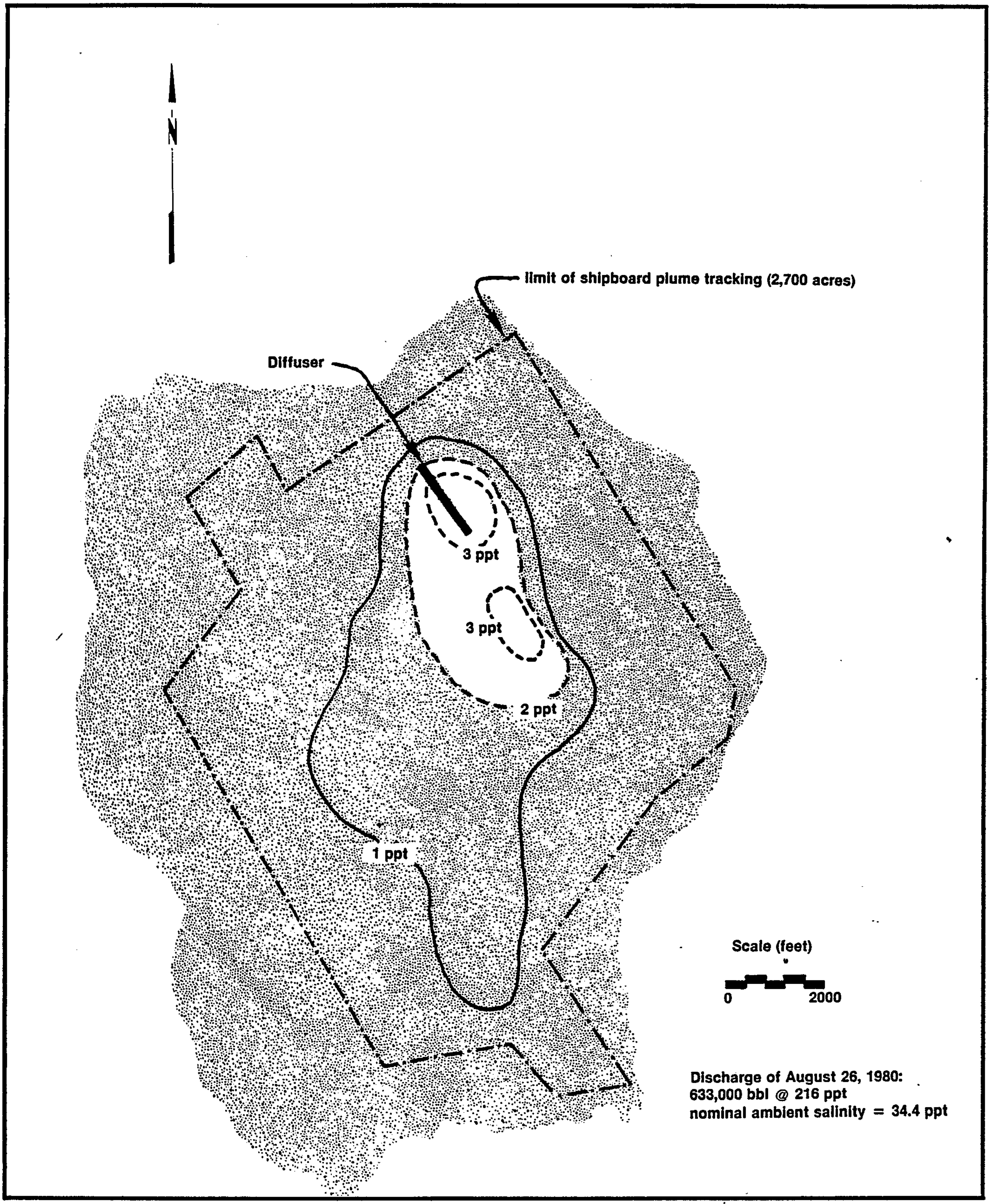


Figure 4-6. Contours of nominal excess salinity for plume tracking observations at Bryan Mound (stippled area represents 95 percent confidence envelope for 1 ppt above ambient).

diffuser was 41.7 ppt. The largest area inside the 1 ppt contour was 4,423 acres.

The maximum vertical extent of the brine plume was measured on August 25, 1980, directly over and in the vicinity of the diffuser ports. Brine discharge was 632,880 bbl/d at a salinity of 216 ppt. The maximum extent of the 1-ppt-above-ambient concentration was 25 ft. At a distance of 1,400 ft down current the plume had collapsed to within 3 to 6 ft of the bottom. At a distance of 250 ft from the diffuser, the plume was about 12 ft thick measured as 1 ppt above ambient. The 2- to 3-ppt above-ambient concentrations were generally confined to the lower 6 ft of the water column.

To date there is little evidence of impact at the brine diffuser, and no catastrophic "die-offs" of fauna have occurred. No impacts have been measured in the plankton community. Nekton species appear to be responding to the plume in a behavioral manner with daytime samples at times suggesting a possible avoidance response. However, nighttime samples do not show the same pattern. On several occasions catches inside the plume were greater than catches beyond the plume boundaries. Monthly patterns in total fish abundance were generally consistent between the predisposal and postdisposal periods.

As expected, benthic samples collected near the diffuser indicate a slight depression in species number (diversity) and population density.

In-situ tests were conducted in the spring of 1980, with brown shrimp (P. aztecus) held in cages at various locations around the diffuser. After 72 h of exposure, shrimp held within 25 to 250 ft downstream from the diffuser suffered only a 5 percent mortality, much of which is attributed to the handling of shrimp rather than excess salinity (NOAA, 1981).

Brine Plume Projections for Big Hill

The National Oceanic and Atmospheric Administration (NOAA) has provided MIT Transient Plume Model outputs for several current conditions at the Big Hill 3.5-mile site based on current data collected during the Texoma baseline survey and using Big Hill discharge criteria (1.4×10^6 bbl/d of concentrated brine). These particular current conditions are presented in Appendix F. "Snapshots" taken at 3-h (real-world) intervals of model outputs have been used to calculate areal coverage of various salinity overages. The largest overages occurred during sustained low energy current conditions. Based on far-field model runs, the following areal coverages were predicted:

3 ppt	207 acres
2 ppt	825 acres
1 ppt	2,575 acres

The maximum concentration of brine at the edge of the release zone (as defined by EPA, under Sect. 403 of the Clean Water Act, 40 CFR 125, 100 m from the diffuser), based on inferences from the model runs, should be approximately 5 ppt above ambient. This should be true for both the 3.5- and 12.5-mile sites.

The toxic waste application factor of 0.01 pursuant to marine discharge guidelines, under Sect. 403 of the Clean Water Act (40 CFR 125), is not applicable to discharge of salt because of the range of salt concentration required for marine life. The excess concentration at the edge of the release zone based on model results should be less than the normal seasonal variability in salinity at the 3.5-mile site and only twice as great as the onshore-offshore variations seen on certain sampling cruises in the vicinity.

The maximum estimated concentration of dissolved oil and grease in the brine discharge after vaporization and treatment in the oil brine separator should be less than 6 mg/L (DOE, 1978a). This value is below permit requirements (Sect. 4.2.2). Based on the inferences from other studies for intermediate field concentrations, this initial concentration should be decreased approximately 50-fold at a distance of 330 ft from the diffuser (about 0.1 mg/L). This concentration is low compared with expected ambient levels at either site (0.5 to 1.0 mg/L) and is well below the values for 96-h LC_{50} in the literature. The concentrations of oil and grease at the boundary of the release zone approximate the value of the marine water quality criteria (0.15 mg/L) based on an average LC_{50} of 15 mg/L (EPA, 1976).

Analyses of brine from the Big Hill dome have been conducted for major ions (Table 4-4). Trace metals, hydrocarbons, and other trace organics have not been analyzed. Based on the concentrations of major ions in the Big Hill brine, the data for trace contaminants from other coastal brines, and dilution rates predicted by the MIT Transient Plume Model, the concentrations of all these constituents should be reduced to very low levels at the edge of the release zone. Because of this expected dilution, differences in ratios of major constituents in brine and seawater should not be a concern.

A similar situation exists for pollutants that might be present in the intake water. Based on the expected dilution rates, the concentration of all potential pollutants should be low at the edge of the release zone. No toxic chemicals can be identified that would exceed marine water quality criteria under these conditions.

Although a large quantity of brine would be discharged, the main constituents of brine are also the major dissolved solids in seawater. As such, the brine would certainly have no long-range impacts. There would be no accumulation in the ecosystem, and the biological community impacted in the immediate area of the diffuser should recover quickly. An example of quick recovery of benthic fauna could be seen at Bryan Mound in 1979 (Hann, 1980). Declining dissolved oxygen values through June and July were followed closely by decreases in diversity and numbers of benthic organisms. On return of more normal dissolved oxygen values, opportunistic species rapidly repopulated the area. By the following winter, populations of many species had returned to levels near those previously observed. The rate of repopulation or recolonization depends on the reproductive mechanism of the species (free-floating larval stage versus brooding of young) and mobility. Therefore, there should be no irreparable harm done to the biotic communities.

Table 4-4. Chemical composition of brines from the Gulf Coast salt domes and receiving waters

ELEMENT	OBSERVED CONCENTRATION IN BIG HILL BRINE *	OBSERVED CONCENTRATION RANGE IN COASTAL BRINES**			OBSERVED CONCENTRATIONS IN RECEIVING WATERS***	
					STATIONS	
MAJOR COMPONENTS (mg/l)					Station 37	Station 42
Na	130,200	120,709	-	126,015	9,650[a]	9,750[a]
K	22	10	-	1,920	370[a]	380[a]
Ca	912	242	-	685	375[a]	360[a]
Mg	605	0.2	-	76	700[a]	705[a]
Cl	202,600	186,057	-	194,376	17,860	16,775[a]
SO_4	1,966	750	-	3,100	2,800	2,700[a]
TRACE ELEMENTS (ug/l)						
Cd	---	ND	-	8	<0.3[a]	0.6
Cr	---	ND			---	---
Cu	---	ND	-	420	<3[a]	8
Pb	---	ND	-	20	3	4[a]
Hg	---	ND			<0.5[a]	0.5
Ni	---	ND	-	800	---	---
Zn	---	ND	-	90	2	2
Ba	---	ND	-	3,000	---	---
Fe	---	60	-	31,000	9.5[a]	13[a]
Mn	---	ND	-	1,300	<2[a]	<2[a]
Sr	---	ND	-	7,000	---	---
Co	---	ND			---	---

*Brine analyzed for PB-KBB by Shilstone Testing Laboratories, Inc. New Orleans, La. (Sample taken from LPG Storage Cavern #1 on 3-7-79.)

**Brines analyzed for DOE by Petroleum Laboratories, Inc. Lafayette, Louisiana

***Receiving waters analysis from Final EIS Texoma Group Salt Domes, DOE, November 1978, Appendix U Table 3, 3-17 pg. U 3-86.

[a]Average of concentrations of samples from 1 meter and 8 meter depths.

Evaluation of the 3.5- to 12.5-Mile Brine Disposal Sites

The Texoma sampling program provided a great deal of insight into the composition and distribution of the biological communities at the Big Hill 3.5-mile site. A detailed and intensive sampling program would be conducted for a detailed post-discharge impact assessment. Recently, the National Marine Fisheries Service initiated a comprehensive monitoring and analysis program (Shrimp Population Studies) at the Big Hill site. This study concentrates on aspects of the shrimp life cycle (spawning sites) that may be related to brine disposal impacts.

Historical data out to a 12.5-mile site are not extensive or recent, and there is some uncertainty about the exact species composition of the biota at these locations.

Comparison of the near-shore and offshore sites allows the following conclusions to be drawn:

1. The greater salinity tolerance of the community at the site nearest the shore suggests that this community is better suited to withstand the impacts of brine discharge as compared with the more stenohaline community at the offshore sites.

2. The sediments at the near-shore site are clayey and considered poor benthic habitat, whereas those at the offshore site may be only slightly less clayey. In the context of the near-shore Gulf, both substrates are poor benthic habitat,

3. It is possible that wind-forcing of bottom currents at the site furthest from shore would be less because of the greater depth. However, this difference is not expected to be great and could possibly be nullified by the greater expectation of density stratification at the near-shore site, which would serve to cut off the near-bottom waters from contact with the atmosphere.

4. Although the 3.5-mile site is not located near any special habitat, the offshore site is closer to Sabine and Heald banks, which undoubtedly harbor a somewhat different "hard-bottom" fauna and may serve as an important refuge for certain of these species in the area.

5. Because of the large gaps between Sabine and Heald banks and because the banks are oriented essentially long-shore, they should not restrict the dispersion of brine by interference with long-shore current patterns.

6. No overall topographic differences are seen in the immediate area. Neither the near-shore nor the offshore sites are located near an estuary inlet; therefore, they probably pose little problem to migrating or passively transported organisms.

7. As one proceeds off shore, salinities rise to oceanic levels (≥33 ppt). In the baseline Texoma studies, no salinities greater than 30 ppt were seen in the vicinity of the proposed 3.5-mile Big Hill diffuser site. Since the effects of salinity overages are related to ambient salinities, the near-shore site, with lower ambient salinities, would be the more prudent locality to discharge brine.

8. A major concern of a diffuser located close to the shore is the proximity to important estuaries. Because of a drastically altered hydrologic regime, Sabine Lake, about 17 miles from the near-shore site, is no longer a "functional" shrimp nursery.

Combined effects (brine plus oil and grease or brine plus low dissolved oxygen) have not been studied in bioassay tests. Of special concern is the interaction of brine with low dissolved oxygen conditions, which have been seen on numerous occasions in the near-shore northwest Gulf and specifically at the Big Hill site (see Appendix F). It is possible that under such stressful conditions brine disposal impacts could be more severe or, in the case of extreme hypoxia, completely masked by natural disruption of the ecosystem.

Impacts on Penaeid Shrimp and Menhaden

A thorough review of literature pertaining to the effects of salinity on penaeid shrimp, menhaden, and other members of the near-shore white shrimp grounds, in conjunction with a thorough review and critique of pertinent aspects of the penaeid and menhaden life cycles in the context of the specific environment at the Big Hill diffuser site (as revealed through preliminary baseline monitoring), has revealed that brine discharge should have a negligible impact on the well-being of these Gulf Coast fisheries.

Bioassay results indicate that toxic effects from salt dome brine on eggs, larvae, and postlarvae of shrimp begin at about 38 to 40 ppt (NOAA, 1979). However, these bioassay results are not statistically defendable and should only be viewed as a first approximation. In bioassay studies conducted by Howe (1981) 50 percent of the adult brown and white shrimp died 48 hr after addition of enough brine to raise salinity by 22 ppt, or 96 hr after addition of enough brine to raise salinity by 18 ppt at 25°C. Both species were more sensitive at 30°C, and white shrimp survival better at lower temperatures. Based on results obtained with various brine types of osmotic stress, rather than toxocity of trace constituents, appears to produce the lethal effects. Where ambient concentrations approximate 30 ppt (such as at the 3.5-mile diffuser site), discharge-enhanced concentrations as high as 38 to 40 ppt would occur only within the immediate vicinity of the diffuser.

Howe (1981) also conducted behavior experiments which showed increased activity for animals exposed to a brine-sea water mixture 10 ppt above ambient. Shrimp appeared somewhat repelled from concentrations 20 ppt above ambient but not from lower concentrations. No bioassay results of Gulf Menhaden, *Brevoortia patronus*, have been found in the literature.

The major shrimp species that would be impacted at the near-shore site is the white shrimp, Penaeus setiferus, which occurs here at all life history stages. The egg stage, and possibly overwintering postlarvae, would get the greatest exposure, but all stages of the shrimp life cycle are euryhaline. Debilitating concentrations should occur only very close to the diffuser. The brown shrimp, P. aztecus, is probably the dominant species at the offshore site, but this is questionable. The area may be transitional from the white to brown shrimp grounds. P. aztecus larvae would pass through the near-shore area during the spring on their way to the estuaries. Tolerance limits are not expected to be exceeded, except in small areas surrounding the diffuser. Because the brine impacts would be confined to the near-bottom waters, many post-larvae or larvae would pass over the plume. Also, penaeid postlarvae may possess significant motility and could possibly avoid the brine plume to a certain extent. Because of the great fecundity of female penaeid shrimp, production of an adequate stock of postlarvae is not density-dependent. Prior attempts to relate offshore catch to post-larvae abundance have not been successful. Most recent studies from a number of shrimp fisheries have strongly suggested that it is factors inside the estuaries (especially temperature and salinity) that determine the success or failure of the shrimp year class. Sabine Lake is no longer a viable shrimp nursery because these same factors are no longer conducive to postlarval and juvenile growth and survival, which have been altered by upland reservoir construction and changes in natural circulation patterns (Gosselink et al., 1979).

The Gulf menhaden is abundant throughout the northern Gulf of Mexico from Galveston Bay, to Apalachicola Bay. Largest concentrations occur near the Mississippi River Delta. The menhaden life cycle is typical of estuarine-dependent euryhaline organisms. Most spawning occurs in the Gulf during late fall and winter. Eggs and larvae are generally pelagic and tend to be found in the upper portion of the water column. As with many taxa the young move into the estuaries to occupy a different habitat than the adults. As the young mature they migrate to deeper waters and eventually move offshore to spawn. Adult menhaden enter the bays and estuaries in the spring to feed upon the rich plankton communities. With the onset of cool weather adults may move offshore but are known to remain in the estuaries during mild winters.

Based on the literature review in Appendix G.2 menhaden would appear to be euryhaline during all life stages. Eggs have been collected in salinities ranging from 6.0 to 36.6 ppt. Juveniles are commonly abundant in salinities below 1 ppt and have been collected in salinities above 40 ppt. The upper range of occurrence for Gulf menhaden has been reported to be 60 ppt.

Because of heavy commercial exploitation of the shrimp stocks and also of many finfish in the northwest Gulf of Mexico including menhaden, the carrying capacity of the environment is greater than the standing stock. The shrimp production should not be lost from areas precluded from shrimp habitation, but could be realized in an adjacent, unstressed area. In view of the pelagic character of menhaden, and the negative buoyancy of the brine plume, menhaden should not generally come in contact with the brine plume (away from the diffuser jets), and accordingly, loss of menhaden habitat should not be at issue, and menhaden catch should not be affected.

The great fecundity of female shrimp and menhaden allows successful recruitment despite the high degree of exploitation by man. It also allows quick recovery from a bad year if environmental conditions are adequate. No studies have shown that the amount of recruitment depends on the size of the parent stock. Therefore, a minor depletion of the parent stock should have little effect on the success of the subsequent year class. Possible loss of spawning area should have no effect on shrimp or menhaden recruitment because of the large numbers produced including those that would have been produced in the area adjacent to the diffuser.

4.2.5.3 Impacts to Threatened and Endangered Species

The threatened American alligator could occur in any fresh to brackish water habitat. Alligators would likely move away from construction activities. Nests in the pipeline ROW could be disrupted, but would be avoided if possible. These impacts would be of short duration and are considered insignificant. This species is now making a resurgence in the Gulf Coast region of east Texas and Louisiana.

Construction of the Big Hill facility and its associated crude oil distribution system would occur in the present range of the red wolf (Appendix E). The small area covered by the project and pipelines in conjunction with the low density of the species greatly reduces the probability of encounter and impact. Pipeline construction activities are of short duration and would not produce significant impacts.

Migratory birds such as the bald eagle and Arctic peregrine falcon use the area as feeding habitat. Because of the limited construction areas, these birds should not be impacted although they might be disturbed. Brown pelicans may also use shallow and estuarine waters for feeding, but they should not be impacted. Attwater's prairie chicken may possibly occur in the coastal prairies around Galveston, Brazoria, and Harris counties, especially in the area near OTTI. These birds have been shown to readily use pipeline ROWs as booming (mating) grounds. There would be no significant impacts to this species. Because of their limited occurrence in the northwest Gulf of Mexico, rare and endangered marine mammals would not be significantly affected by this project. Although few data are available on the frequency of occurrence of sea turtles entering the area, their mobility would prevent them from being impacted by offshore construction or brine disposal.

No threatened or endangered plant species occur in the immediate vicinity of the Big Hill complex, pipeline ROWs, or at the proposed expansion sites at Bryan Mound or West Hackberry. Project construction should have minimal impacts on threatened or endangered plants. It should be noted that consultations required by the Endangered Species Act have been initiated (see Appendix D). The project would be designed to utilize the mitigative measures (or their equivalent) discussed in Appendix D.

4.2.6 Natural and Scenic Resources

Big Hill Site

The northern rim of the Big Hill salt dome has been developed for LPG storage (Sect. 3.2.1.1). The remainder of the area is considered to be relatively homogeneous, rural, and lacking in unique natural and scenic resources (Sect. 3.2.1.6). Wetlands located beyond the dome's periphery could be disturbed slightly during construction because of increased activity, noise, and erosion; but this is projected to be a minor, short-term impact. Operation of the storage facility at Big Hill would likely affect the adjacent wetlands to an even lesser extent.

Raw Water Intake and Onshore Brine Disposal Pipelines

Construction of the raw water intake and onshore brine disposal pipelines would impact a localized portion of the wetlands located between the Big Hill site and the ICW. The projected corridor through these wetlands would be a maximum of 150 ft in width and 5.3 miles in length. Between the ICW and the Gulf, the brine line would also cross about 4 miles of brackish wetlands. Increased activity and noise associated with this disturbance would temporarily affect resident animal life.

4.2.7 Archaeological, Historical, and Cultural Resources

Big Hill Site

Although no known archaeological, historical, or cultural resources would be affected, construction of the oil storage facility at Big Hill could possibly impact archaeological, historical, or cultural resources not identified in the cultural resources survey conducted at Big Hill (see Sect. 3.2.1.7). The State Historic Preservation Officer would be informed of the construction schedule so that arrangements for monitoring could be made if so desired. Further study of this area before construction and careful monitoring during construction operations would be conducted to avoid destruction of heretofore unknown sites. If an archaeological site were uncovered during construction, work would cease and the State Historic Preservation Officer would be contacted immediately. Work would not proceed until the nature and importance of the find was determined.

It is unlikely that the operational phase at Big Hill would impact any archaeological, historical, or cultural resources.

Raw Water Intake and Onshore Brine Disposal Pipelines

A preliminary survey conducted by Thomas et al. (1977) indicated that archaeological, historical, and cultural resources were not found along the raw water intake and onshore brine disposal pipeline routes (Sect. 3.2.1.7). Minor changes have been made in the location of these routes. Study of the location changes and careful monitoring during construction would be conducted to avoid destruction of heretofore unknown sites.

4.2.8 Socioeconomics

Several factors introduce significant uncertainty to the prediction of socioeconomic impacts of construction at the Big Hill site: the experience at West Hackberry (discussed in Sect. 3.2.4.8), increasing transportation costs, possibly altered settlement patterns as a response to increased transportation costs, project hiring and contracting practices, labor availability, and project scheduling. Many of these uncertainties cannot be resolved at present. However, it is possible to place bounds on construction-related socioeconomic impacts and thus provide a realistic range of impact possibilities. Once the range is established, it would be possible to focus on the impacts that are both possible and probable.

The bounds of possible impacts would be determined by two sets of assumptions, which are mutually exclusive. The first assumptions (set I) would produce minimal, adverse socioeconomic impacts on impact area I, which is defined as the region within reasonable commuting distance of the project (about 60 miles) (Mountain West Research, 1975). Set II assumptions would produce the maximum, realistic adverse impacts on impact area II, which is defined as that area in which it is more economical to commute weekly to nearby urban areas for goods and services than to commute to the project daily. The radius of the impact area II is assumed to be 15 miles, a definition which takes into account factors such as availability of land, transportation costs, housing, goods, and services. As fuel prices continue to rise, workers are responding by residing near their work location. During the Hackberry experience many workers elected to live near the site rather than in Lake Charles, which is about 35 miles away.

Two sets of assumptions and their possible and probable socioeconomic impacts are given below. Set I assumptions are that:

- Throughout the construction period there would be an adequate supply of labor within impact area I.

- This labor pool would be tapped for the project (i.e., there would be negligible in-migration to the impact area).

- Construction workers and managers would commute to the site from their present residences (i.e., there would be negligible interregional migration).

Under these assumptions, virtually no adverse impacts beyond an increase in traffic in the vicinity of Big Hill would occur. Secondary impacts could possibly be caused by workers in-migrating into the impact area (area I) seeking jobs that would otherwise have been filled by workers employed at the site.

Positive impacts would include some reduction in unemployment as well as employment and income multiplier effects. However, neither of these impacts would be statistically detectable in impact area I, given its growth rate and large aggregate population.

Set II assumptions are that:

- Regardless of labor availability within commuting distance, many laborers would be hired from outside of the commuting distance.

- Some laborers hired from within the nominal commuting distance would, nevertheless, choose to relocate nearer the project site, within impact area II.

- o Workers hired from outside the nominal commuting distance would also tend to locate within impact area II.

Under these assumptions, the socioeconomic impacts are potentially severe for the defined impact area (area II). A substantial migration of workers into impact area II would likely place significant burdens on the rural portions of Jefferson and Chambers Counties. Local communities within impact area II include Winnie, Stowell, and Hamshire. Population estimates for these communities (Table 3-6) suggest the presence of about 6,000 people. A general guideline used in socioeconomic impact analysis is that existing population centers can absorb an increase in population of about ten percent. However, the exact capability of a community to absorb population increases is dependent on the variety of public and private service sectors available. Based on this guideline, impact area II could accommodate an influx of about 600 people (ten percent of 6,000).

Results of analyses performed by Mountain West Research (1975) and the Tennessee Valley Authority (1980) indicate the average household size (workers and family members) is about 3.0 when single workers are included. Therefore, about 200 workers could move into the area without placing a substantial burden on the local public and private service infrastructures.

As seen in Table 4-5 and Fig. 4-7, the peak construction force, off and on site would number about 500 if the single crude oil pipeline to Sun Terminal were constructed. Construction of another pipeline to either OTTI or Pelican Island would require an additional 150 to 200 workers off site.

Given the short duration of the project (employment exceeds 200 for less than 1.5 years), set II assumptions lead to the conclusion that a "boom and bust" cycle is likely for local merchants. Set II assumptions do not lead to the conclusion that unemployment would be significantly reduced. Secondary employment opportunities would be created, but they would be temporary and could lead to a long-term increase in local unemployment as the economy goes from boom to bust. An income multiplier is possible, but again the boom and bust cycle might cause more losses than gains. However, dissemination of estimates to local businesses of the number of workers who would move into the Winnie area for an extended period and the length of their employment at the project could enable merchants to plan, thereby mitigating the effects of a boom-bust cycle.

Although existing housing is not readily available within impact area II, sites for mobile homes are plentiful, and there are no zoning regulations. According to the latest information, an additional 1,500 units (mobile homes) could be accommodated by the sewage treatment and potable water facilities in Winnie (J. Jones, Trinity Bay Conservation District, personal communication, January 1981). In all other aspects, however, present public and private services and goods in impact area II would be strained if set II assumptions are accurate. Police and fire protection, education, health care, and sanitation would not be adequate to meet increased needs under set II assumptions. Although sewage treatment capacity exists in Winnie, in-migrating workers may choose to use septic or holding tanks, both of which could cause health hazards.

Table 4-5. Manpower analysis for facility construction, Big Hill, Texas

Job category	Projected construction time (months)																										
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
													Onsite manpower loading														
Building											23	46	50	70	58	46											
Civil	16	35	53	53	26	32	46	64	81	81	112	124	124	118	55	47	47	46	37	20							
Piping & mech.											26	52	82	87	95	110	100	100	100	100	87	75	44				
Electrical													23	29	29	46	52	52	52	40	29	23	17	12	12		
Instrumentation															7	10	16	16	16	16	16	16	16	16	10	7	
Miscellaneous																								8	8	8	8
Drilling						32	32	32	32	32	40	40	40	40	40	40	40	40									
Facility prog. mgmt.	4	8	10	10	10	12	14	20	24	26	30	30	30	30	30	30	30	30	30	30	30	28	24	20	20	20	20
Pipeline prog. mgmt.							2	4	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16
Drilling prog. mgmt.					4	16	16	16	16	16	20	20	20	20	20	20	20	20	12	8							
Subcontract (bldg. finish, equip. reps. etc.)													10	10	25	35											
Total on site	20	43	63	63	40	92	110	136	169	171	267	328	395	420	375	400	321	320	263	230	178	158	117	72	66	51	44
													Offsite manpower loading														
Raw water pipeline								45	56	62	56	38															
C. O. pipeline																110	153	165	165	142							
Brine pipeline																					62	72	84	60	126	140	4
Total off site								45	56	62	56	38				110	153	165	165	142	62	72	84	60	126	140	4
Total on project	20	43	63	63	40	92	110	181	225	233	323	366	395	420	375	510	474	485	428	372	240	230	201	132	191	48	13

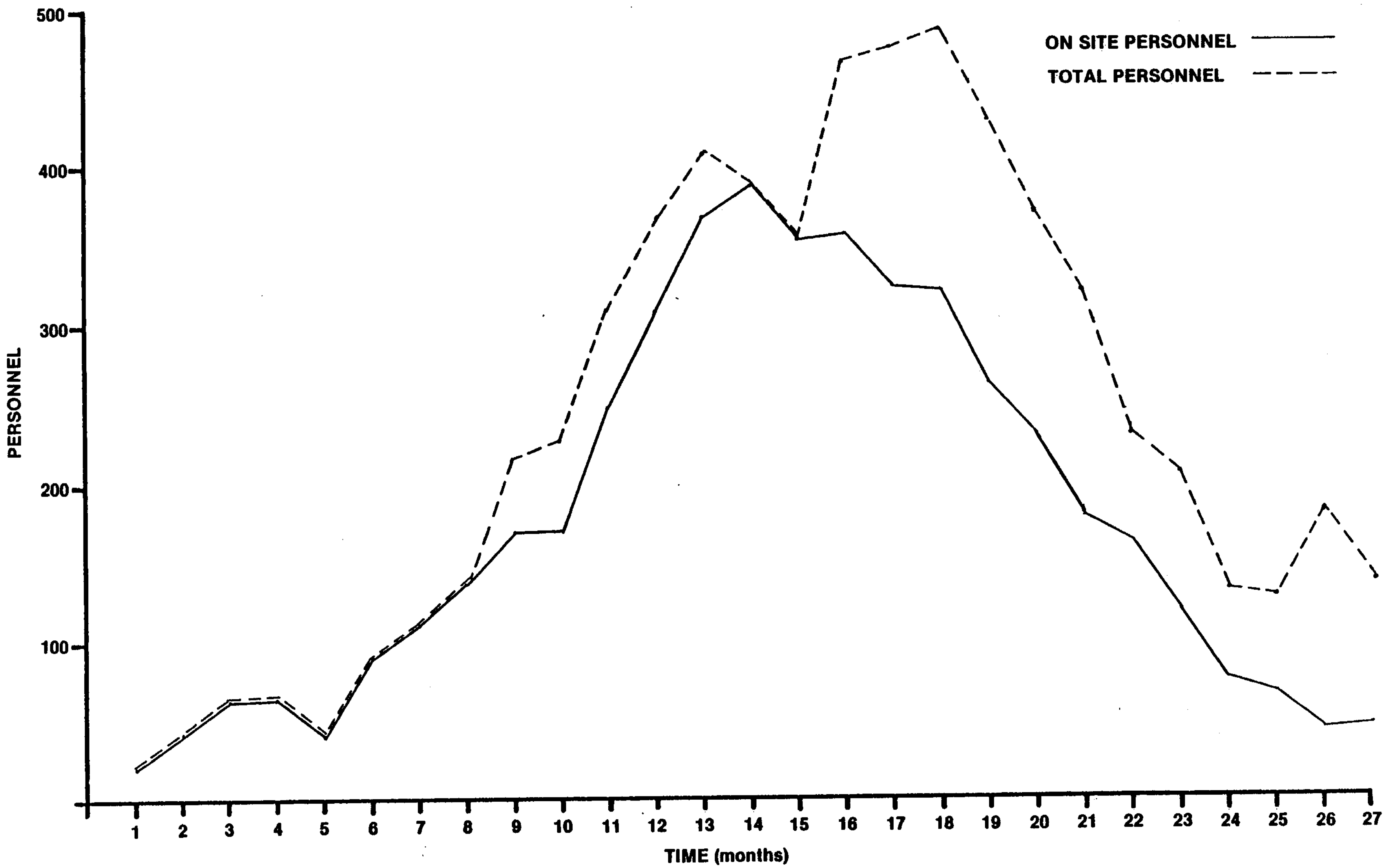


Figure 4-7. **Labor force utilization as a function of time for construction of Big Hill.**

Onsite workers whose jobs could be expected to last at least a year are likely to locate near the site or to commute to the site if they are already near it (i.e., within about 15.5 miles). Because of uncertainties in hiring practices and labor availability, the number of workers that could be obtained from the Port Arthur and Beaumont areas cannot be determined. However, based on the 1-year job expectancy and the experience at West Hackberry, about 150 to 200 workers could be expected to locate or be located near the project (see Fig. 4-7). These workers would be expected to bring their families with them.

The number of workers expected to locate or be located near the project approaches the number required for significant impacts on impact area II under set II assumptions, which is expected to be the more likely event. Set II consequences could be avoided, only if workers locate or reside in Port Arthur or Beaumont, both of which have ample public and private goods and services. If most of the workers locate or reside in Port Arthur and Beaumont, the consequences would be similar to the socioeconomic impacts suggested for set I assumptions.

The offsite workers would be essentially the pipeline workers. Pipeline crews tend to relocate near their work, but do not take their families with them. Table 4-5 (exclusive of consideration of the OTTI or Pelican Island pipelines) suggests three separate crews for the raw water, crude oil, and brine disposal pipelines. Average crew sizes would be 50, 140, and 80, respectively.

Given the terrain, it would be likely that the raw water, and especially the brine pipeline crews, would locate near the coast. The crew for the crude oil pipeline would likely locate near the midpoint of the route to Sun Terminal. All crews would thus be located in impact area II.

Socioeconomic impacts of offsite workers could push total impacts toward the consequences of set II assumptions. Two factors militate against this, however. First, there is no household multiplier effect because workers would not be expected to bring their families with them. Second, most pipeline crews are experienced, integral units which should be regarded as forming transient, self-contained communities which do not impact existing residents significantly. If the crews are hired from impact area I, the consequences are likely to be similar to those derived from set I assumptions, even though the crews could relocate. If the crews are hired outside of impact area I, beneficial employment and income multipliers are likely to be decreased.

Construction of pipelines to the OTTI or Pelican Island terminals would not likely impact area II measurably because the crews would probably locate outside that area. Impacts on the greater Houston or greater Galveston area would probably not be statistically detectable because of the rapid growth and industrialization that is already occurring.

Operations

Leaching and filling would require 20 to 40 long-term workers at the Big Hill site. These workers would undoubtedly move into impact area II, bringing their families with them. Given the preceding analysis, socioeconomic impacts of onsite operations would be negligible.

Socioeconomic impacts of work at any of the three proposed terminals, whether the work is regarded as construction or operations, would also be negligible because of the size of the work force (<40) and the existing industrial development at those sites.

4.2.9. Socioeconomic Impact Mitigation

The two socioeconomic impact scenarios discussed above do not take into account the possibility of mitigating adverse socioeconomic impacts or, more generally, altering socioeconomic impacts by conscious policy decisions. If mitigation efforts are undertaken as a matter of conscious policy, not only may some adverse impacts be mitigated or avoided entirely, but predictions of impacts may become more reliable. The impact scenario resulting from Set I assumptions will become more probable, and any project-related growth that does occur may become more manageable.

Even if impacts could accurately be predicted, many communities do not have the technical capabilities to plan for their mitigation. Providing the services of expert and experienced planners to communities that might be impacted is one way of helping to mitigate impacts. The functions of these experts might include:

- Using sophisticated techniques for impact prediction and evaluation (e.g., computer simulation, the Delphi technique, gaming, and public opinion surveys) (Murdock and Leistritz, 1980; Fowler, 1980; and Schuller et al., 1975).
- Helping place and develop impact mitigation strategies in cooperation with local officials.
- Locating and obtaining fiscal and other types of resources to mitigate impact.
- Gathering data on impacts through both formal means and informal observations.
- Acting as a local contact and liaison between DOE and impacted citizens, officials, and communities.

Experience at the Tennessee Valley Authority's (TVA's) Hartsville, Yellow Creek, and Phipps Bend nuclear plants during construction suggests the importance of onsite personnel for impact mitigation (Fowler, 1977).

In general, socioeconomic impacts depend not only on changes in the social and economic environment caused by the influx of primary and secondary employees and their families into a region, but also the distribution of those employees, in terms of proximity to available existing goods and services. Matching demand for goods and services with existing supply is often an economical way of mitigating adverse impacts by avoiding them altogether.

Available mitigation measures along these lines include:

- o A deliberate policy of local training and hiring. With one set of exceptions, local hiring eliminates adverse impacts by eliminating their cause (e.g., in-migration). However, adverse consequences may be associated with this approach because local hiring may attract workers from existing local businesses, creating labor shortages and fostering in-migration. In addition, pay differentials may cause hardships for local employers.

- o Policies to encourage geographic distribution of in-migrating workers in areas where public and private goods and services are adequate to meet new demands. Policies of this nature may be simple and inexpensive, such as identifying areas where housing and other amenities are readily available. Other policies may be more complex and expensive (and more likely to assure impact mitigation), such as instituting subsidized van or car pools, which encourage workers to locate in more distant areas and, thus, "dilute" impacts (TVA, 1976).

- o Policies to encourage local planners and officials to encourage dilution of impacts by instituting growth controls through zoning and other land use management techniques. (For a brief survey of possibilities and legalities, see Wright and Webber, 1978.)

An additional type of mitigation measure is compensation--payment in cash or kind for disruptions caused during project construction and/or operation. Examples of these types of mitigation include reparation of damages caused by construction such as road repair, revegetation of pipeline ROWs, and provision of additional public services, such as mutual aid services (e.g., ambulance service; area-wide fire protection, as is being done in West Hackberry).

Economic Impact on Shrimp and Menhaden Fisheries

Table 4-6 presents several loss scenarios for depths of less than 15 fathoms for 1977 Gulf Coast shrimp data (NOAA, 1978), averaged over statistical areas 17 and 18. The 3.5-mile diffuser site is located at the interface of the 0- to 5-fathom- and 6- to 10-fathom-depth zones, whereas the 12.5-mile site would be located within the 6- to 10-fathom-depth zone. These values are based on worst-case MIT far-field model outputs of area coverage of the various overages of the salinity plume, using Big Hill currents wherever possible and Big Hill discharge criteria. These current conditions (U and V components) are shown in Appendix F, and the model outputs are discussed in Sect. 4.2.5. This analysis conservatively assumes complete fishing loss for the area covered by a particular salinity overage. It should be stated, however, that salinities less than 3 ppt above ambient are not expected to stress the system, and losses to the fishery would be minimal. These loss

Table 4-6. Mean[1] catch data[2] (lb/acre) for selected depth intervals (subareas) in statistical areas 17 and 18 for 1977 and loss scenarios per year for areal coverage of different salinity overages

Depth interval (fathoms)	Catch (lb/acre) Brown shrimp	White shrimp	Pink shrimp	Other[3]	Total	Catch value ($/acre)	Loss scenarios ($) 3 ppt[4]	2 ppt[5]	1 ppt[6]
000-005	0.542	5.758	0	0.465	6.765	12.98	2,687	10,709	33,424
006-010	1.300	0.825	0	0	2.125	4.58	948	3,779	11,794
000-010	1.172	1.652	0	0.078	3.289	5.99	1,240	4,942	15,424
011-015	1.884	0.045	0	0.005	1.934	4.05	838	3,341	10,429

[1] $\frac{\text{(catch in area 17 + catch in area 18)}}{\text{(acres in area 17 + acres in area 18)}}$

[2]Catch data calculated from Gulf Coast Shrimp Data, Annual Summary (NOAA, 1978) and water surface area data (from Patella, 1975).

[3]Mostly seabobs (Xiphopenaeus kroyeri).

[4]3-ppt overage = 207 acres for worst-case, sustained low energy current.

[5]2-ppt overage = 825 acres for worst-case, sustained low energy current.

[6]1-ppt overage = 2,575 acres for worst-case, sustained low energy current.

Note: The "worst-case" analysis is taken from a low energy regime.

scenarios are as follows: 3 ppt = 207 acres; 2 ppt = 825 acres; 1 ppt = 2,575 acres. Since this analysis includes several depth zones, it is assumed that the various salinity overages affect the biota similarly over depth.

Calculated losses for the 3-ppt-above-ambient contour range from $838 to $2,687. Similarly, a worst-case loss would range between $10,429 and $33,424 if the entire area covered by the brine plume was lost for the year and production was not offset to nearby areas. The estimated cost of extending the brine discharge line from the 3.5-mile site to the 12.5-mile site is approximately $21 million.

When this cost is compared with the value of the total annual (1977) shrimp catch, averaged over statistical areas 17 and 18, for depths less than 10 fathoms, it is seen that the cost of extending the pipeline to the 12.5-mile site is almost twice the dollar value of the shrimp catch.

As stated in Sect. 3.2.1.8 and Appendix G, no standard statistical reporting system has been developed for the menhaden fishery in the Gulf of Mexico. Menhaden landings in 1979 and 1980 were 1.72 and 1.55 billion pounds, valued at $73.4 million and $69.1 million respectively. For the 6-year period, 1975 to 1980, the average annual catch was 1.41 billion pounds. About 85 percent of the catch was made within 3 miles of shore during 1980. On the basis of the extensive literature review of menhaden ecology, no biological or economic impacts to the fishery are expected.

This assessment is based on the following:

1. Menhaden are euryhaline organisms during all life stages and should be tolerant to the small salinity changes projected for brine discharge.

2. Menhaden are possibly the second most abundant fish in the Gulf. *Anchoa mitchilli* is the most abundant taxon.

3. Menhaden life stages are generally pelagic and would pass over the negatively buoyant brine plume.

4. Much of the commercial catch occurs inshore of all proposed diffuser locations.

5. The center of menhaden spawning activity is off the Mississippi Delta. Spawning appears widely distributed and may occur as far off shore as the 50-fathom-depth contour.

6. As with shrimp, little information has been developed to suggest a strong spawner-recruit relationship. The fishery, which is based on age 1 and 2 fish, appears strongly linked to estuarine nursery conditions.

4.3 CRUDE OIL DISTRIBUTION SYSTEM

This section deals with the construction and operations impacts, including spill risk, of the crude oil distribution system for Phase III.

4.3.1 Oil Spill Risk

The transport of crude oil involves environmental risks as a result of accidents and spills. This section presents an analysis of these risks and the frequency and size of spills that may occur during transport of SPR oil through Gulf Coastal areas of the United States.

In this analysis, only accidental discharges of crude oil were considered. These include spills from vessel casualties, such as collisions with other vessels, rammings of fixed objects and groundings, spills at marine terminals during the offloading and loading of tank vessels, spills during vessel-to-vessel transfers (lightering), and pipeline accidents.

Not considered in this analysis were operational discharges of oil, such as those resulting from the disposal of oily bilge and ballast waters since these were adequately treated in the Texoma Group FEIS (Sect. C.2). It has been established that these constitute the bulk of all oil discharges associated with marine operations. However, U.S. Coast Guard regulations (33 CFR 157) and the agreements of the 1973 Inter-Governmental Maritime Consultative Organization (IMCO) would prohibit operational discharges in coastal waters and limit discharges in the open sea (>50 miles from shore) to 1/30,000 of the cargo for new tankships. This number is based on requirements contained in the IMCO International Convention for the Prevention of Pollution from Ships. Similar regulations have been proposed for foreign flag tankers in U.S. waters. If these regulations are followed, operational discharges will tend to be widely dispersed over the open ocean.

In contrast, accidental spills may occur anywhere, especially in coastal and inland waters, including harbors and harbor entrances. Moreover, accidental spills may result in a large outflow at a single location rather than being widely dispersed over a great distance as for operational discharges. Hence, more significant adverse environmental effects are expected from accidental spills of oil.

4.3.1.1 Scenarios Analyzed

The analysis of oil spill risks was performed for three SPR storage sites (Big Hill, West Hackberry, and Bryan Mound), their associated marine terminals (Sun, OTTI, Pelican Island, and Seaway), the pipelines connecting the terminals and storage sites, and the lightering tankers transporting crude oil between transoceanic, very large crude carriers (VLCCs), and the marine terminals. Three scenarios were considered for each storage site:

- Leach/fill
- Withdrawal
- Refill

The leach/fill scenario dealt with two marine terminals (Seaway and Sun), but involved the following options for the West Hackberry and Bryan Mound storage sites:

- West Hackberry - increase of the Phase II storage capacity by 30 or 10 MMB.
- Bryan Mound - increase of Phase II storage capacity by 40 or 60 MMB.

The withdrawal and refill scenarios considered three options for the Big Hill storage site (i.e., use of the following terminal-pipeline connections):

- Sun Terminal - Big Hill
- OTTI - Big Hill
- Pelican Island - Big Hill

The withdrawal scenario was based on the following oil distribution programs:

- Sun Terminal - 50 percent via pipeline, 50 percent via tanker.
- OTTI - 65 percent via pipeline, 35 percent via tanker.
- Pelican Island - same as for OTTI.
- Seaway Terminal - 60 percent via pipeline, 40 percent via tanker.

Two tanker options were also considered:

- 60,000 dead weight ton (dwt) tankers with a nominal capacity of 420,000 bbl.
- 45,000 dwt tankers with a nominal capacity of 320,000 bbl.

Table 4-7 summarizes the estimated number of tanker trips required for each scenario and site. The number of offloadings or loadings at the marine terminals is equal to the number of tanker trips. Table 4-8 summarizes the time duration of use of the crude oil and brine disposal pipelines for each scenario. The number of lightering operations during the leach/fill and refill scenarios is also equal to the number of tanker trips during those two scenarios.

Table 4-7. Summary: Leach/fill, withdrawal, and refill scenarios for storage sites, terminals, and tankers

	Rate (10^3 bbl/d)	Terminal	Number of tanker trips required	
Big Hill leach/fill, 43 months, Oil transfer: 140 MMB	140	Sun	333 (60,000 dwt)	437 (45,000 dwt)
Big Hill withdrawal Oil transfer: 140 MMB Distribution: 50% pipeline, 50% tanker	935	Sun	166 (60,000 dwt)	219 (45,000 dwt)
Big Hill refill, 33 months Oil transfer: 140 MMB	280	Sun or OTTI or Pelican Island	333 (60,000 dwt)	437 (45,000 dwt)
West Hackberry leach/fill, 6 months Oil transfer: 30 MMB	175	Sun	71 (60,000 dwt)	94 (45,000 dwt)
West Hackberry leach/fill (alternative) 2 months oil transfer: 10 MMB	175	Sun	24 (60,000 dwt)	31 (45,000 dwt)
West Hackberry* withdrawal Oil transfer: 263 MMB Distribution: 50% pipeline, 50% tanker	1.4	Sun	313 (60,000 dwt)	411 (45,000 dwt)
West Hackberry* withdrawal (alternative), oil transfer: 243 MMB Distribution: 50% pipeline, 50% tanker	1.4	Sun	289 (60,000 dwt)	380 (45,000 dwt)
West Hackberry* refill, 33 months Oil transfer: 263 MMB	175	Sun	626 (60,000 dwt)	822 (45,000 dwt)
West Hackberry refill, 33 months Oil transfer: 243 MMB	175	Sun	578 (60,000 dwt)	760 (45,000 dwt)

*22 MMB at Sulpher Mines is included with West Hackberry for oil spill risk assessment

Table 4-7 (continued)

	Rate (10^3 bbl/d)	Terminal	Number of tanker trips required	
Bryan Mound leach/fill, 7.4 months Oil transfer: 40 MMB	180	Seaway	96 (60,000 dwt)	125 (45,000 dwt)
Bryan Mound leach/fill (alternative) 11 months, oil transfer: 60 MMB	180	Seaway	143 (60,000 dwt)	187 (45,000 dwt)
Bryan Mound withdrawal Oil transfer: 220 MMB Distribution: 60% pipeline, 40% tanker	1,054	Seaway	210 (60,000 dwt)	275 (45,000 dwt)
Bryan Mound withdrawal Oil transfer (alternative): 240 MMB Distribution: 60% pipeline, 40% tanker	1,054	Seaway	229 (60,000 dwt)	300 (45,000 dwt)
Bryan Mound refill, 33 months Oil transfer: 220 MMB	180	Seaway	524 (60,000 dwt)	688 (45,000 dwt)
Bryan Mound refill, 33 months Oil transfer (alternative): 240 MMB	180	Seaway	572 (60,000 dwt)	750 (45,000 dwt)

Table 4-8. Time duration of usage for storage site-to-marine terminal oil pipelines and the storage site brine pipelines

DOE oil pipeline	Length (miles)	Diameter (in.)	Time of use (years) during: Leach/Fill	Withdrawal	Refill
Big Hill/Sun Terminal	23	36	3.58	0.40	2.75
Big Hill/OTTI	58	40		0.40	2.75
Big Hill/Pelican Island	54	40		0.40	2.75
West Hackberry/Sun Terminal	41.5	42	0.50 (alternative)/0.16	0.40	2.75
Bryan Mound/Seaway Terminal	4.1	36	0.61 (alternative)/0.91	0.40	2.75
Bryan Mound/Jones Creek Tank Farm	4	36		0.40	
Brine disposal pipelines					2.75
Big Hill/Gulf of Mexico Alternate	12.5 19	42 46	3.58 3.58		2.75 2.75
West Hackberry/Gulf of Mexico	23	36	0.50 (alternative)/0.16		2.75
Bryan Mound/Gulf of Mexico	15	36	0.61 (alternative)/0.91		2.75

For purposes of analysis and subsequent comparison and evaluation, the number of areas that could be affected by spills for each scenario was determined to be six:

- In the Gulf of Mexico during lightering (50 miles off shore).
- Transit to the coast.
- Transit through harbors and ports.
- At the terminal.
- Along the pipeline route.
- At the storage site.

The coastal area that would most likely be affected by a major oil spill, during lightering and/or transit to harbor entrances, would reach from about Freeport, Texas, to Pecan Island, Louisiana. Bays, lakes, streams, beaches, and coastal wetlands in the area would be vulnerable to habitat destruction, loss of biological productivity, and animal mortality. The extent of the impacts would depend directly on the distance from shore, the amount and type of oil spilled, and the meteorological/oceanographic conditions. Statistically, however, the amounts of oil estimated to be spilled through normal operations are small, and the likelihood of a major spill is also small (see Appendix I). Table 4-9 lists the average probabilities of a major spill for combined scenarios (i.e., leach/fill + withdrawal + refill), based on the exclusive use of 45,000 dwt tankers.

Table 4-9. Average probability for a major oil spill[1]

Operation	Size of spill (bbl)	Average probability of major spill
Lightering	500	0.049
Transiting to coast	60,000	0.000001
Transiting inland waters, harbors, and ports	60,000	0.001
Offloading/loading	500	0.015
<u>Equipment</u>		
Offsite oil pipelines	10,000	0.003
Brine disposal pipelines	10,000	0.002

[1]A major oil spill is considered the maximum credible spill by tankers (about 60,000 bbl), operations (about 500 bbl), and pipelines (about 10,000 bbl) (Seaway Group FEIS).

The exclusive use of 60,000 dwt tankers would cause a small decrease in the average probability of a major spill.

During the course of the three scenarios, about 1,456 MMB would be transported. Table 4-10 addresses the risk of oil spills for major geographical areas.

Table 4-10. Average probability for a major oil spill in different geographical areas

Area of impact	Average probability of major spill
Gulf Coast pipeline routes[1]	0.003
Gulf Coast inland waters and harbors[2]	0.016
Gulf Coast[3]	0.049

[1]Based on 128 miles of SPR pipelines for a time of 7 years (leach/fill-withdrawal-refill).

[2]Sabine Pass, Sabine Lake, Neches River/Galveston Bay/Freeport.

[3]Reach of the Gulf Coast is from Freeport, Texas, to the western end of Pecan Island, Louisiana.

Spills From Land-Based Operations at the Terminals, Docks, and Storage Sites

The risk of spills was estimated for (1) operations at a typical storage site, (2) operations at the tank farm and distribution system pipeline and pumps at a typical crude oil marine terminal, and (3) loading/offloading operations on and near the dock at a typical marine terminal. The size and frequency of spills associated with loading and offloading operations were estimated from reported spill data obtained from the U.S. Coast Guard PIRS data for the years 1973 through 1976. During this 4-year period, a total of 275 spills from docks throughout the United States occurred during the loading or offloading of tank barges and tankships. During this same period it was estimated, by using U.S. Army Corps of Engineers data (Waterborne Commerce), that a total of 2×10^5 such operations were performed annually. Thus, the average frequency of spills from terminal docks for such operations is approximately

$$\frac{275}{2 \times 10^5} = 14 \times 10^{-4}$$

The distribution of the size of these spills is fitted well by the curve in Fig. I-2 (see Appendix I).

The frequency of spills from operations at a typical storage site and that from operations at a marine terminal were developed by different methods because no usable historical data were available. First, a block diagram, indicating the major systems and components, was prepared for the crude oil receiving and distributing systems at a typical storage site and a typical terminal. These are shown in Figs. 4-8 and 4-9, respectively. With the aid of the results of a fault tree analysis of similar systems (Mastandrea and Simmons, 1978), the frequency of leaks and spills arising from the several subsystems and components of the oil distribution systems was estimated. The values used in this analysis are presented in Table 4-11.

The frequency of leaks from equipment listed in Table 4-11 does not reflect the contribution of human error, such as leaving a drain valve open after maintenance. Based on analysis of the cause of spills at a marine terminal during loading and offloading operations (SAI, 1978), it was determined that spills resulting from human error were approximately three times those resulting from equipment failure. Thus, the sum of the frequency of spills from the oil distribution systems caused by equipment failure was multiplied by 4 to obtain the estimated total frequency from both equipment failure and human error. Spills of oil from leaky components of the oil distribution system may not necessarily reach water or an environmentally sensitive area. All of the more leak-prone equipment is surrounded by curbing or dikes. Both types of enclosures are drained to a catchment basin, where any oil and water are separated and the oil is collected in a slop tank for eventual return to the system (see Figs. 4-8 and 4-9). However, the curbs may overflow, and the dikes have a gate valve for draining excess rain water. This valve could inadvertently be left open for 24 h by mistake after a heavy rain (estimated frequency of occurrence for leaving a valve open is 2×10^{-3}). Assuming 12 such rains per year, the probability of a spill from a dike, given a spill in the dike, is:

$$(2 \times 10^{-3}/\text{demand})\ (12\ \text{demands/year})\ \left(\frac{24\ \text{h}}{8760\ \text{h/year}}\right) = 6.6 \times 10^{-6}.$$

There are other ways in which the dike could be breached, but these are less likely.

It was assumed that the curbed areas could overflow easily, since they are usually drained by gravity flow through small-diameter lines. In particular, it was assumed that 50 percent of all spills would overflow the curbs, which according to Fig. I-2, is equivalent to assuming that all spills greater than 1 bbl in volume will overflow the curbing.

These estimates of the probability of spills escaping from a diked area and a curbed area are combined with the frequencies of leaks from items of equipment in Table 4-11 to compute the frequency of spills from the storage sites and the marine terminal (excluding the dock).

In summary, the following spill frequencies were estimated:

1. Spills <u>from the dock</u> during loading and offloading occur at a frequency of 14×10^{-4} spill/year; the average spill size is 14 bbl.

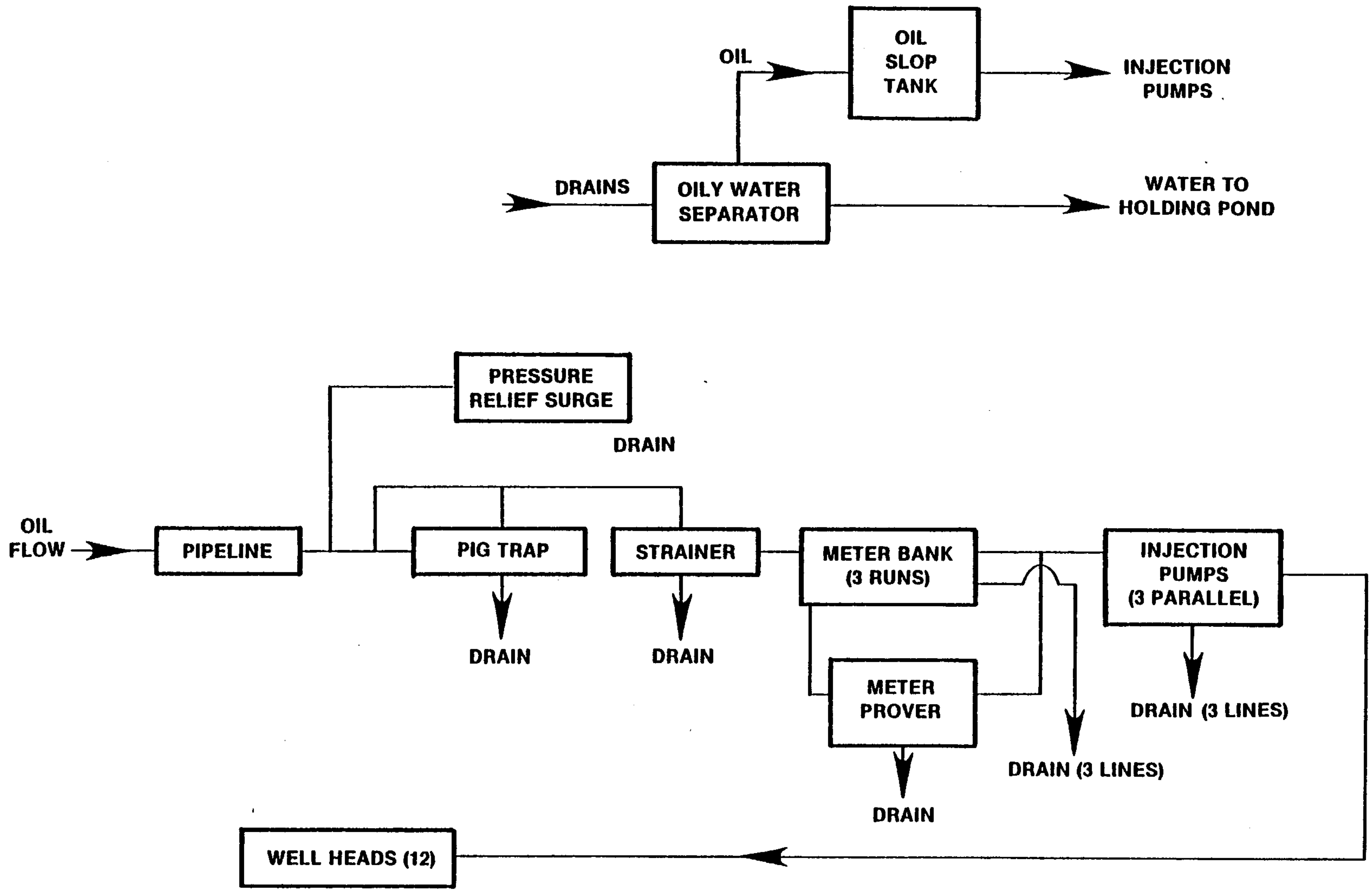


Figure 4-8. Crude oil receiving and injection system for a typical storage site.

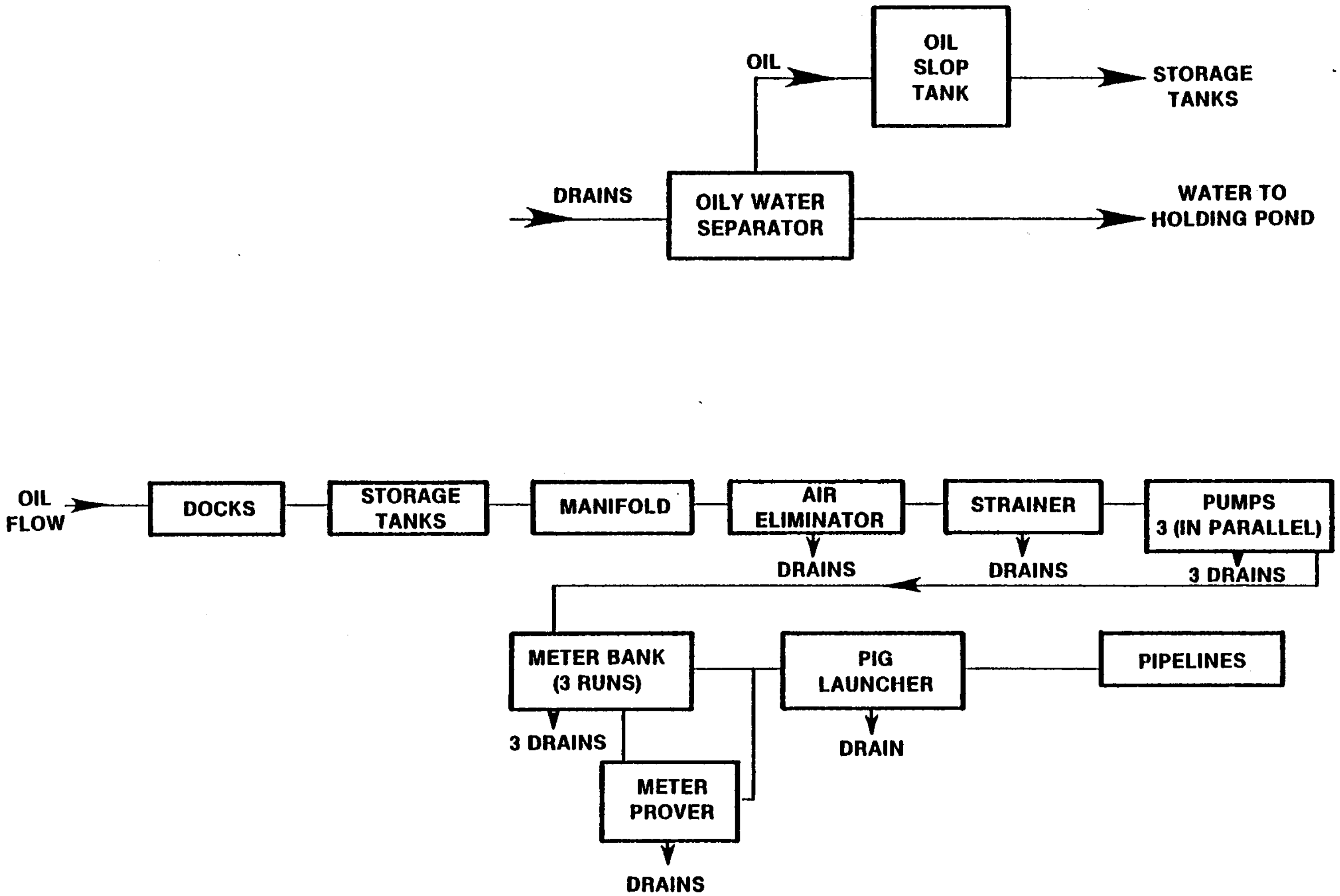


Figure 4-9. Typical marine terminal oil distribution system.

Table 4-11. Frequency of leaks and spills of oil from subsystems and components of crude oil distribution systems

Subsystem or component	Frequency of leaks (per year)	
	No human error	With human error
Strainer	2.6×10^{-2}	1.04×10^{-1}
Pump	4×10^{-4}	1.6×10^{-3}
Air eliminator	0.47	1.88
Manifold	4.4×10^{-4}	1.76×10^{-3}
Pig launcher-receiver	2.6×10^{-2}	1.04×10^{-1}
Meter bank	2×10^{-3}	8×10^{-3}
Meter prover	1.2×10^{-4}	4.8×10^{-4}
Pressure relief surge	2.6×10^{-5}	1.04×10^{-4}
Wellhead	8×10^{-2}	3.2×10^{-1}
Storage tank or oil slop tank	2.8×10^{-2}	1.12×10^{-1}
Oily water separator	1.6×10^{-2}	6.4×10^{-2}
Pipelines (6,000 ft)	6×10^{-4}	2.4×10^{-3}

2. Spills from the terminal (excluding the dock) occur at a frequency of 1 spill/year; the average spill size is 10 bbl. Spills from the terminal pipelines occur at a frequency of 6×10^{-4} spill/year; the average spill size is 3,500 bbl.

3. Spills from the storage site occur at a frequency of 0.15 spill/year; the average spill size is 10 bbl. Spills from site pipelines occur at a frequency of 6×10^{-4} spill/year; the average spill size is 3,500 bbl.

4.3.1.2 Oil Spills from Salt Dome Caverns

A failure mode and effects analysis determined that the most significant loss mechanisms involve various failures of the wellhead and associated pipeline. The most frequent of these is the development of a leaky gasket on the isolation valves or the wellhead connections. Such leaks, as based on industrial experience, would occur rather frequently (0.05 per year per wellhead), but would be small (much less than 100 bbl) and easily contained by a small dike. These leaks, if too small to be detected by abnormal behavior of pressure at the wellhead, would be detected during routine daily checks of the wellhead.

Much larger spills, but with a very much smaller probability, could occur from more substantial damage to the wellhead such as "shearing off" or fracture of the wellhead as the result of some accident. This, together with such failures as corrosion or rupture because of a defective weld or pipe seam, was estimated to occur at a frequency of 1×10^{-6} per wellhead per year. This estimate is believed to be conservatively high because it is based on the reported failure frequency for ordinary line pipe for transporting liquid petroleum products (see Sect. 4.2.1.3). Wellhead components are made of much thicker steel.

Such failures could result in substantial losses of oil because of a relief of pressure and subsequent expansion (creep) of the cavern walls. This decrease in volume squeezes oil out of the cavern, which is similar to what occurred at West Hackberry in 1978. Assuming that the brine-oil interface would be at a depth of 3,000 ft in a typical cavern, the planned storage mode is to maintain the oil under a pressure of 450 pounds per square inch (psi), which is equivalent to the differential pressure between 3,000-ft heads of oil and brine plus 50 psi. If the wellhead is sheared off or if the oil-side piping is fractured, the entire 450 psi pressure on the oil is relieved since the heavier column of brine sinks to a level such that the oil head and brine head are equal at the oil-brine interface in the cavern. Because the cavern is so large (1×10^7 bbl), the resulting elastic expansions are also large (but less than 1 percent of the cavern volume): 22,500 bbl, based on a compressibility of $\Delta V/V = 5 \times 10^{-6}$ per psi, for the oil; 15,200 bbl, based on a compressibility of $\Delta V/V = 3.4 \times 10^{-6}$, for the salt; and 2,250 bbl, for the brine in the sump (assumed to be 10 percent of the oil). The total oil displaced would be 40,000 bbl, but as mentioned above, this would be a very rare occurrence.

A sudden loss in pressure caused by the fracture or shearing off of the wellhead could lead to rapid expansion followed by severe slabbing (falling away of large masses of salt) from the roof of the cavern and the triggering of a general collapse. Because the top of the caverns would be located 500 to 1000 ft below the top of the salt, this occurrence is believed to be highly unlikely (Seaway Group FEIS, Sect. F). This, combined with the already low probability of fracturing or shearing off of the wellhead, makes cavern collapse by this mechanism extremely remote, $<1 \times 10^{-6}$ per wellhead per year.

On September 21, 1978, there was a blowout and fire at cavern 6 of the West Hackberry oil storage site (DOE, 1978b). During well workover operations, mud, a packer, and oil were forced up out of the well by the pressure on the oil. An explosion and fire occurred, killing one man and injuring another. It was estimated that 67,510 bbl of oil were forced out of the cavern. A nonburning oil spill (31,200 bbl) went into nearby Black Lake, but was contained by a prevailing wind from the north and oil spill containment booms. Most of this oil was recovered, and apparently Black Lake suffered little damage.

Investigations into the cause of the accident concluded that exposure to single-point failure at the cavern and wellhead, failure to follow the written workover procedure, an inadequate safety valve on the rig, and inadequate emergency response equipment and procedures on site contributed to the accident (DOE, 1978b). To reduce the possibility of future accidents and to minimize the impacts of any that occur, DOE has implemented a variety of safeguards. Specifically, workover operations of the type being performed at the time of the accident are now performed only after the pressure at the wellhead has been reduced to zero. Also a comprehensive safety and contingency plan has been developed for the SPR program. Firefighting equipment, water supplies, oil spill containment procedures, oil spill cleanup procedures, and increased security have become standard at all SPR storage sites.

4.3.1.3 Related Risks

The risk of fire and explosions to people and private property off site is expected to be negligible. The reason for this is the relatively low vapor pressure of the crude oil to be stored. Although flammable plumes may be generated from leaks and spills of the crude oil, calculations show that these can extend no more than 1,000 to 1,500 ft in the downwind direction even under the most adverse meteorological circumstances. Hence, fires from such spills are primarily a hazard to onsite personnel and to the crews of vessels transporting the oil.

The crude oil itself does not explode; only mixtures of its vapor with air or oxygen explode. Thus, explosive mixtures may exist within the ullage spaces of fixed-roof storage tanks and vessel cargo tanks. However, ignition of these mixtures is rare, provided the tank vents are equipped with flame arrestors and precautions are taken to reduce the presence of nearby ignition sources (e.g., no smoking near facilities handling crude oil, static electricity protection). Current U.S. Coast Guard regulations (46 CFR 32) require that, after May 31, 1983, both U.S. and Foreign Flag tankers between 20,000 and 70,000 dwt be equipped with inert gas systems to prevent explosions. Tankers greater than 70,000 dwt have been required to have inert gas systems since May 31, 1981. These systems greatly reduce the risk of fire and explosion on tank ships.

Hazards to onsite construction personnel are assumed to be comparable to the oil field machinery portion of the construction industry. The occupational injury incidence for this industry, which resulted in lost work days in 1978 was 8.6 cases per 100 full-time workers (U.S. Department of Labor, 1980). Pipeline construction injury incidence was 1.9 cases per 100 full-time workers. The most significant risk of injury and death would occur in the case of onsite employees during the construction and fill phase, particularly in the case of drilling rig crew members. It is generally recognized that drilling and oil well workover is a relatively high-risk occupational category.

Historically, accidental deaths of nonemployees from fires and explosions at bulk petroleum products terminals in the United States are rare: 6×10^{-5} deaths per year per terminal. More than 90 percent of these deaths resulted from accidents with more volatile products than crude oil, such as gasoline and fuel oil. Moreover, many of the terminals experiencing accidents were located in metropolitan areas. Because Sun Terminal and the storage sites would be in sparsely settled areas, fires and explosion-caused accidental deaths are expected to be even fewer than the nationwide figure.

Oil spills caused by natural events such as earthquakes, hurricanes, and tornadoes are not expected. The areas in which Sun Terminal and the alternative storage sites are located have been classified by NOAA as having zero seismic risk. Both hurricanes and tornadoes lack sufficiently intense winds to damage the aboveground piping of a storage facility. A direct hit of a storage tank by a tornado could damage its roof and cause the loss of some oil. However, such an event would be very rare. Storage tanks, if left full, would be resistant to damage and will likely survive flooding and the strong winds associated with most hurricanes.

Late in 1980 some speculative concern was raised about the integrity of salt domes when a salt mine was flooded at Jefferson Island, Louisiana. Apparently, the flooding of the mine occurred in association with oil/gas drilling operations on Lake Peigneur in the vicinity of the mine. A similar occurrence at an SPR location would be impossible to reproduce since the only mine site that exists within the SPR has no lake or large body of water located directly above it, and no drilling is allowed by the government or adjacent property owners in the immediate vicinity of the mine.

4.3.1.4 Conclusions

It is estimated that, during the 7 years spanned by the three scenarios analyzed, a total of about 1,456 MMB of oil would be transported. Of this, 0.0000045 percent, or about 6,552 bbl would be spilled. Spills would generally be small and would occur at various locations. A significant portion would be prevented from impacting the environment because of structural and mechanical containment and cleanup capabilities.

The maximum credible spill size was estimated, based on historic data and evaluations of program operating conditions (Seaway Group FEIS, Sect. E), to be 500 bbl for transfer operations, 60,000 bbl for tanker casualty, and 10,000 bbl for pipeline operations. These values, which represent a practical upper limit to extrapolations of spills, are not changed by the Phase III expansion.

Historically, the number of tanker round trips into the Sabine Area (Sun Terminal) averaged 3 per day. Round trips through the Galveston area (OTTI and Pelican Island) and Freeport area have averaged 4 and 0.6, respectively. The worst-case increase in tanker traffic would occur during drawdown. If Sun Terminal was used for drawdown of both Big Hill and West Hackberry, traffic would increase by more than 4 trips per day. If Big Hill oil was directed to OTTI or Pelican Island, the number of transits through Sabine would decrease by 1, whereas transits through the Galveston area would increase by 1. Total transits in the Freeport area would increase by 2.

The above figures are conservative because they assume no decrease in tanker traffic as a result of foreign oil supply interruptions. Using the assumptions that tankers will be laden to 270,000 bbl (world fleet average) and only SPR tankers transit the ports during drawdown, the following estimates were made. If Sun Terminal was used for Big Hill and West Hackberry, daily transits would increase by 1. If OTTI or the Pelican Island terminal was used, traffic in the Sabine area would remain at the current average. Galveston area traffic would decrease from the average by 3. Tanker traffic into the Freeport area would increase from the average of 0.6 to 2 transits per day.

4.3.2 Pipeline Routes

The preferred crude oil pipeline route, which extends from Big Hill to Sun Terminal, is very similar to the routes described in the Texoma Group FEIS, Sect. A.7.4.1.5. Two possible alternative distribution lines to either OTTI on the Houston Ship Channel or the planned Pelican Island facility near Galveston are also evaluated. The possibility of constructing the line to Sun Terminal and one of the alternatives is also considered. The two alternative pipeline routes were selected after careful analyses of 25 possibilities. Data were collected from general land users and government agencies to determine physical features, land usage, land type, and ownership. Evaluations were based on total length, related land use patterns, ecologically sensitive areas, locations of historical and archaeological sites, water crossings, existing ROWs, and other criteria.

4.3.2.1 Land Features

Land features of the pipeline route to Sun Terminal are addressed in detail in the Texoma Group FEIS, Sect. 3.3.4.5. Construction would affect primarily agricultural lands. About 45 acres of wetlands along Taylor and Hillebrandt bayous and near Alligator Hole Marsh would be affected. By using construction techniques such as double-ditching, revegetating, and/or directional drilling, these impacts can be mitigated to a large degree.

The pipeline to OTTI would cover a distance of about 60 miles, while the route to Pelican Island would cover about 54 miles. Estimated acreages (based on a 150-ft ROW) affected by the three routes, as determined from land use maps prepared by the U.S. Geological Survey (1973), are tabulated below:

	Sun Terminal	OTTI	Pelican Island
Grassland/agricultural	330	65	490
Wetland	45	55	220
Wooded land	0	55	0
Industrial/residential	35	0	0
Open water	10	220	275

A substantial portion of the grassland/agricultural acreage for each ROW in the table is believed to be prime farmland. Construction of these lines would affect surface and subsurface soils. Soil structure, infiltration, and drainage patterns would be altered by ditching procedures. Double-ditching techniques could be used to preserve topsoil integrity to the greatest extent possible. Adjacent soils would be compacted by the weight of pipe and equipment. The ROW would be restored and allowed to revegetate. Short-term drainage problems would be avoided by leaving 50-ft (approximate) breaks every 200 ft in the dirt piles during construction and by careful restoration to original contours. By crowning the ROW (leaving a slight mound over the pipe during backfill), problems associated with future settling of the soil could be minimized. Where possible, pipelines would follow existing ROWs.

Field investigations indicate that the estimate of 220 acres of wetlands impacted by the Pelican Island pipeline route is extremely conservative. A chenier ridge, which is above wetlands elevation, extends in a northeast direction from Smith Point (see Fig. 2-6). By using this ridge and existing ROWs, wetland impacts would be greatly reduced.

After construction, the land would be restored to as close to its original state as possible. Trees growing in the ROW would be periodically cropped. The acreages subject to maintenance activities would be about half of that for construction. Although some land used for rice farming would be temporarily disturbed during construction and managed according to ROW maintenance plans during operation, it would not significantly affect productivity of this crop in Jefferson or Chambers Counties.

4.3.2.2 Water Environment

The preferred crude oil distribution pipeline route is projected to cross Taylor and Hillebrandt bayous (Fig. 2-6). At present, the volume of dredged or excavated materials to be removed from these bayous is expected to be 25,000 cubic yards for each bayou. The depth at which the pipelines would be installed in the bayous depends on the stipulations of the permitting agency [U.S. Army Corps of Engineers (USACE), Galveston District] and would be sufficiently deep to preclude interference with navigation or other activities. Neither Taylor nor Hillebrandt bayous are currently dredged for navigation channels; however, the dredging of Taylor as part of the maintenance dredging program undertaken in the Sabine-Neches Waterway (see USACE, 1975) will be addressed in an upcoming draft supplement to the project's FEIS (USACE, Galveston District, personal communication, November 1980). If maintenance dredging is initiated in Taylor Bayou, it is possible that the pipeline would have to be buried somewhat deeper than originally anticipated.

Dredging activities associated with pipeline construction would fall under the jurisdiction of the USACE as established under Sect. 10 of the Rivers and Harbors Act of 1899 and Sect. 404 of the Federal Water Pollution Control Act of 1972 as amended by the Clean Water Act of 1977. Permit requirements would be specified by the USACE. Although pipeline construction is not specifically mentioned, the USACE may determine that regulations in the new EPA Proposed Testing Requirements for Dredge or Fill Disposal Site Specification [45 FR 85360, December 24, 1980] are applicable. The new guidelines set out testing requirements that are organized by six categories of discharge:

Category 1. Discharge without potential for environmental contamination. Dredge material falls into this category when initial evaluation does not indicate the presence of contaminants above background levels.

Category 2. Open water discharge with level of contamination similar to the discharge site. Discharges should be assigned to this category when the initial evaluation indicates that contaminants may be present in the dredge material, but are not significantly greater than the disposal site.

Category 3. Contained, confined, or other disposal operations of material with potential for contamination of the water column only. This category is concerned only with return flow (runoff) from dredge material that is discharged into contained or confined disposal areas.

Category 4. Open water discharge with potential for harm. This category includes dredge material that appears to be more contaminated than the discharge site and will not be confined or contained.

Category 5. Discharge of fill material without potential for environmental harm.

Category 6. Discharge of fill material with potential for environmental contamination.

Categories 5 and 6 apply only to fill materials and are not applicable to this project. Dredging activities associated with pipeline construction include dredging the pipe ditch, temporary stockpiling of dredge material in the ROW, and backfilling the pipe ditch after laying the pipeline. Major water crossings may also require dredging a channel for the operation of a pipe barge. Depending on interpretation and location of activities, it appears that categories 1 through 3 may apply to this project; however, a final determination of the applicability of these requirements to pipeline construction in the various water bodies would be made by the permitting agency, and determinations would be adhered to by DOE.

Informal consultation with EPA suggests that Category 2 would apply to situations where sediments are known to be contaminated (Taylor and Hillebrandt bayous) and not all dredged material would be used as backfill.

Under Category 2 both the sediments and water column may be tested. For sediments, chemical extraction tests would be used to assess the potential for long-term leaching and bioavailability. Sediment extraction techniques would be selected for the specific contaminants of concern. The potential for short-term water column impact would be assessed by the standard elutriate test, or if needed, a water column bioassay would be used.

Dredging, excavation, and stockpiling of spoil materials may cause localized, temporary water quality perturbations in Taylor and Hillebrandt bayous. The alterations in ambient water quality expected to occur during these operations have been discussed in Sect. 4.2.2.2 and in the Texoma Group FEIS (Sect. 4.6.2). Of concern is the behavior of polychlorinated biphenyl (PCB) compounds which have been detected in the sediments (see Sect. 3.2.2.2). PCB compounds present in the sediments could be released during dredging and stockpiling of dredged materials. Given the strong affinity of these compounds for the particulate phase, it is likely that only a very small fraction of total PCBs would be desorbed during dredging operations. Although projected to exist in minute quantities, desorbed PCBs would be more available to human and aquatic life. PCBs sorbed to sediment particles could also be harmful as a result of entering the food web through filter-feeding organisms. In summary, it is possible that dredging of Taylor and Hillebrandt bayous could result in temporary, localized release of sediment-bound PCBs. Studies of PCB-contaminated dredge disposal conducted by Wright (1978) have demonstrated no significant uptake of PCBs or metals by organisms inhabiting the disposal areas or by caged animals that were held in proximity to the disposal site for up to 3 weeks. The redistribution of PCBs would have no long-term impacts.

The northern (OTTI) and southern (Pelican Island) routes would involve both major and minor water crossings. The northern crossing of Trinity Bay and the Houston Ship Channel is about 12 miles. The route to Pelican Island would involve about 15 miles of Galveston Bay. The impacts of dredging in Trinity Bay would be of short duration. Increased turbidity would represent the major perturbation to water quality. Studies by Hirsch et al. (1978) have shown that dredging in the bay does not generally produce increases in metal concentrations, although turbidity may increase 3 to 5 times above ambient. These effects generally last only a few hours, and no long-term impacts have been observed.

Construction of the Pelican Island pipeline across Galveston Bay would produce similar impacts. Perturbations to water quality would be of short duration. Turbidity in this region would be of greater significance because of the presence of oyster reefs and their associated sensitivity to suspended sediments. Mitigative measures would include the use of turbidity screens and the creation of oyster spat settling areas by leaving hard substrates (shell) exposed after pipeline installation. The need and scope of these actions would be determined through ongoing consultation with the local, state, and Federal authorities (see Appendix D).

Because of heavy ship traffic on the Houston Ship Channel, horizontal directional drilling techniques would be used to make the pipeline crossings if practical. Because the pipeline must pass 15 ft under the channel, no pollutants should be associated with the disturbed sediments. Impacts would be of short duration and are not considered significant.

Operation

During the operational phase of the proposed action, the bodies of water (1) transected by the preferred and both alternative crude oil distribution pipelines and (2) adjacent to the terminal facilities would probably not be adversely affected unless an accident occurs. The probability of an accident occurring and the environmental consequences are discussed in Sect. 4.3.1 and in the Texoma Group FEIS (see Appendix H).

Pipeline sectionalizing valves would be installed at the edge of each major water crossing and at approximately every 15 miles of the pipeline length. These automatic valves would close in the event of a pipeline break, thus greatly reducing the amount of oil that could be released and the magnitude of its impacts.

4.3.2.3 Climate and Air Quality

The crude oil distribution system would have no measurable impact on regional or local climatic conditions. Air quality impacts related to crude oil distribution are presented in Sect. 4.2.3. Emissions from the distribution system (valves at water crossings) are infrequent and minimal, especially compared with terminal and site operations and other petrochemical industries in the region.

4.3.2.4 Ambient Sound Levels

As described in the Texoma Group FEIS (Sect. 4.6.4), noise would contribute approximately 55 dB to the equivalent sound level (Ldn) at a distance of 500 ft from a pipeline ROW. Pipeline construction activities would be of short duration, and these impacts are considered insignificant. Noise associated with the operations of the crude oil distribution system would be related primarily to pumping activities at the site or terminal facilities. Pumps would be located within sound dampening enclosures, rendering their noise levels insignificant if necessary.

4.3.2.5 Species and Habitats

Impacts related to the construction of the preferred crude oil distribution route to Sun Terminal would be similar to those described in the Texoma Group FEIS (Sect. 4.6.5). Construction would temporarily remove 330 acres of farm-pasture habitat from production. The line would cross two major freshwater streams, Taylor Bayou and Hillebrandt

Bayou, resulting in the disruption of less than 10 acres of benthic habitat. Behavior patterns of mobile aquatic organisms would also be altered. Fish may be attracted to or may actively avoid the area, depending on the severity of turbidity associated with pipeline dredging activities. Turbidity may reduce primary productivity in the bayous by reducing light penetration. Nutrients, biochemical oxygen demand, and other chemicals would be redistributed by dredging activities. No woodland habitats would be affected by the preferred oil pipeline construction, and most disturbed habitats are expected to return to "normal" conditions within 1 to 3 years with the use of modern mitigation techniques.

Construction and operation of the alternative pipeline routes with adequate mitigative measures would have no long-term significant impacts on species and habitats in the region. Construction of the northern route to OTTI would require short-term disturbance of approximately 765 acres of agricultural/grasslands and 55 acres of wetlands. Vegetation removal would result in the loss of food and cover for wildlife, but recovery generally occurs rapidly (1 to 3 years). Maintenance of the ROW would be disruptive to woodland species and beneficial for those preferring open areas. The creation of "edge" or ecotone effects may increase diversity and density of species.

The crossing of Trinity Bay may require dredging and disruption of about 220 acres of benthic habitat. This would destroy benthic production for a short period of time. Depending on the severity of turbidity, nekton may avoid or be attracted to the area. Fish are often observed feeding on suspended benthic organisms as are many birds. Houston Ship Channel crossings would have minimal impacts on species and habitats, especially if horizontal directional drilling techniques are found to be practical.

Studies by Hirsch et al. (1978) have shown that the direct effects of dredging include death of organisms at dredging sites and burial at disposal sites. These impacts are restricted to the immediate area. Recolonization of sites generally occurs within a matter of months. However, species composition may be altered depending on the nature of the habitat involved. The release of sediment-associated chemicals and their uptake into organism tissue have been found to be the exception rather than the rule. Long-term effects of dredging and disposal would be minimal. The more naturally variable the environment, the less effect dredging would have. Organisms common to such areas are adapted to unstable conditions.

Construction of the southern alternative pipeline to Pelican Island would disrupt about 490 acres of agricultural/grass lands, 220 acres of wetlands, and 275 acres of benthic habitat. As with the other project pipelines, mitigation measures would be utilized to minimize impacts. The estimate of 220 acres of wetlands to be disturbed, based on land use maps prepared by the U.S. Geological Survey (1973), is very conservative. In actuality, much of the area considered wetlands is now rice farms. Also, a chenier ridge that is above wetlands elevation runs north from Smith Point toward the Big Hill site and would be utilized to stay out of wetlands where possible. Unlike the route to OTTI, the southern pipeline would pass through a unique habitat in the vicinity of

Hannas Reef. In this area, there are numerous oyster reefs which could be affected by pipeline construction. The pipeline route selected across Galveston Bay is very similar to the one described for the Pelican Island Terminal Expansion Project FEIS (USACE, 1979). Based on their findings, which included consultation with USFWS, National Marine Fisheries Service, and Texas Parks and Wildlife Department, this route should have minimal impacts and would avoid most of the numerous reefs in the area. Mitigative measures include leaving buried shell encountered while dredging exposed to create areas suitable for oyster spat set. Other mitigative measures available include (1) using turbidity curtains, (2) scheduling operations to avoid currents that would carry sediments toward oyster reefs, and (3) limiting operations during time of spat setting. The measures finally used would be determined in consultation with local, state, and Federal authorities during the permitting procedure.

4.3.2.6 Natural and Scenic Resources

Construction

The preferred crude oil distribution pipeline would transect some wetland areas in Jefferson County. Increased activity and noise, as well as temporary, localized alterations in the land and water resources, may disturb resident animal life. These impacts, however, are considered minor because they would be short-term and would affect only a limited area.

Wetlands, as well as the Galveston Bay complex, would be impacted by installation of either of the alternative pipeline routes. More wetlands would be transected by the southern alternative route, since it is projected to cross the northeastern corner of an area surrounding Lake Surprise, which has been identified as the site for a potential wildlife refuge (USFWS, 1977) (see Fig. 2-6). The northern route would cross a more extensive portion of the Galveston Bay complex. Impacts to the natural and scenic resources in the bay and wetlands would be short-term.

Operation

It is not anticipated that the natural and scenic resources transected by the preferred or the alternative crude oil distribution pipeline routes would be impacted during operation. Maintenance plans for the pipeline corridors have not yet been formulated. The probability of an oil spill is addressed in Sect. 4.2.

4.3.2.7 Archaeological, Historical, and Cultural Resources

Construction

A shell midden and some secondarily deposited materials have been found in the vicinity of Taylor Bayou, where the preferred crude oil distribution pipeline is projected to cross (Sect. 3.2.2.7). Although considered to be located well beyond the impact area of previously considered routes from Big Hill to Nederland (Texoma Group FEIS, Sect. 3.3.4.5), the proximity of the shell midden to the presently proposed route would be investigated before construction. Adverse impacts to this resource are not expected.

Sensitive areas exist along the projected routes for both the southern and northern alternative pipeline routes. If either option is chosen over the preferred route, then both a field survey and a more intensive records survey would be undertaken before construction to avoid potential adverse impacts to archaeological, historical, or cultural resources located in the vicinity of the route. If an archaeological site were uncovered during construction, all activities would cease and the State Historic Preservation Office would be notified immediately as required by the National Historic Preservation Act of 1966. Construction would not proceed until authorized.

Operation

It is not anticipated that archaeological, historical, or cultural resources located along the preferred or alternative routes would be impacted by facility operation.

4.3.2.8 Socioeconomics

All socioeconomic impacts related to pipeline construction are presented in Sect. 4.2.8.

4.4 EXPANSION AT BRYAN MOUND AND WEST HACKBERRY

As described in Sect. 2.0, expansion of the Bryan Mound and West Hackberry sites would require only the construction of new storage caverns and their associated piping. The new storage caverns would be connected to existing Phase II facilities. No changes are required in existing brine disposal or crude oil distribution systems.

4.4.1 Land Features

The expansion at Bryan Mound under the 40:30 alternative would result in the construction of four additional caverns within current site boundaries. This action would have no significant effect on the geological structure of the site. Additional diking and grading would be required and would directly affect about 5 to 10 acres of wetlands near Mud Lake (see Sect. 4.2.1.1). The area is already disturbed by existing site activities; however, cumulative impacts should be negligible.

The expansion at West Hackberry would require the construction of three additional caverns. Five candidate cavern locations (Fig. 2-4) are under consideration. Depending on the configuration chosen, a maximum of 34 acres of prime farmland would be affected. Potential impacts within the proposed acquisition(s) would be qualitatively similar to those predicted in the Texoma Group FEIS (Sect. 4.3.1). These include potential impacts to geologic structure, drainage patterns, erosion rate, and soil structure. Expansion of the West Hackberry site could involve the development of up to 0.03 percent (34 acres) of the estimated 103,000 acres of prime farmland (Crowley-Morey-Mowata Association) in Cameron Parish. However, none of these impacts were considered to be significant for the original project, and the proposed expansion would not augment these impacts.

The 60:10 alternative calls for six additional storage sites at Bryan Mound, compared to four additional caverns under the 40:30 alternative. All additional caverns at Bryan Mound would be located within existing project boundaries. No significant cumulative impact to land features at Bryan Mound is anticipated under this maximum storage configuration. The increase in wetland impacts as a result of this alternative would also be mitigated by the Bryan Mound wetlands creation program. Only one additional cavern would be developed at West Hackberry under this configuration. Although no significant impacts are projected for the construction of three caverns at West Hackberry, reduction of this number to one cavern would reduce the effects of such impacts. No wetlands would be affected. A detailed discussion of floodplain and wetland impacts resulting from expansion at Bryan Mound and West Hackberry is presented in Sect. 4.5.

No significant operational impacts to land features are anticipated at either Bryan Mound or West Hackberry.

4.4.2 Water Environment

Expansion at the Bryan Mound and West Hackberry sites would have no significant impacts on the water environment beyond those described in the Texoma Group FEIS (Sect. 4.3.2) and Seaway Group FEIS (Sects. 4.3.1.2 and 4.3.2.2). Any turbidity associated with construction would be of short duration and is not considered significant.

4.4.3 Climate and Air Quality

Expansion activities at Bryan Mound and West Hackberry would increase the duration of construction-related emissions in quantities proportional to the magnitude of expansion selected. These impacts are discussed in the Texoma Group FEIS (Sect. 4.3.3) and the Seaway Group FEIS (Sects. 4.3.1.3 and 4.3.2.3).

NMHC emissions for the Bryan Mound and West Hackberry sites are summarized in Table 4-12 for three cases: (1) no action, which is the Phase II baseline (included for comparison), (2) the Preferred Alternative (40:30), which is a 40 MMB increase in capacity at Bryan Mound and a 30 MMB increase in capacity at West Hackberry with integrated Phase II, Group II, and Phase III leaching, and (3) the 60:10 alternative, with a 60-MMB increase in capacity at Bryan Mound and a 10-MMB increase in capacity at West Hackberry with consecutive groups unintegrated at Bryan Mound.

Assumptions used were the same as discussed in Sect. 4.2.3 and Appendices C.2 and C.3. In addition to the brine pond and oil brine separators, the other significant emission source at Bryan Mound is four 200,000-bbl, internal floating roof tanks. Drawdown emissions are also included for both sites.

The NMHC emission levels in Table 4-12 for Bryan Mound are at a 980,000-bbl/d leach rate. With a 680,000-bbl/d leach rate, brine and surge tank operating loss emissions per unit time would decrease proportionally (30.6 percent), but total NMHC burden to the ambient atmosphere

Table 4-12. Hydrocarbon emissions for expansion sites

ALTERNATIVE	ACTIVITY/EMISSION SOURCE	BRYAN MOUND DURATION (d)	BRYAN MOUND MEAN OIL THRUPUT (MB/d)	BRYAN MOUND EMISSION RATES** (g/s)	BRYAN MOUND EMISSION RATES** (ton/y)	WEST HACKBERRY DURATION (d)	WEST HACKBERRY MEAN OIL THRUPUT (MB/d)	WEST HACKBERRY EMISSION RATES** (g/s)	WEST HACKBERRY EMISSION RATES** (ton/y)
NO ACTION (PHASE II BASELINE)	LEACH	525	2.8			459	4.4		
	BRINE EMISSIONS (.26 ppm)			0.39	13.6			0.62	21.6
	BLANKET OIL TANKAGE*								
	STANDING LOSS			.10	3.4			.03	1.2
	OPERATING LOSS			...	.1			.02	.8
	VALVES, SEALS, SLOP TANKS			.06	2.2			.06	2.2
	TOTAL			.46	19.3			.73	25.8
	LEACH/FILL	488	64			424	97		
	BRINE EMISSIONS (1.5 ppm)			2.25	78.4			3.61	125.4
	SURGE TANKAGE								
	STANDING LOSS			.10	3.4			...	...
	OPERATING LOSS			.06	2.1			...	...
	VALVES, SEALS, SLOP TANKS			.06	2.2			.06	2.2
	TOTAL			2.47	86.1			3.67	127.6
	FINAL FILL	150	180			240	155		
	BRINE EMISSIONS (2.6 ppm)			1.03	14.8			0.89	20.3
	SURGE TANKAGE								
	STANDING LOSS			.10	1.4			...	...
	OPERATING LOSS			.18	2.6			...	...
	VALVES, SEALS, SLOP TANKS			.06	2.9			.06	1.4
	TOTAL			1.37	21.7			.95	21.7
	DRAWDOWN (TOTAL SITE)	171	1,054			150	1,400		
	SURGE TANKAGE								
	STANDING LOSS			.10	1.7			...	...
	OPERATING LOSS			.99	16.1			...	...
	VALVES, SEALS, SLOP TANKS			.06	1.0			.06	1.0
	TOTAL			1.15	~~28.8~~ 19.8			.06	1.0
	REFILL (TOTAL SITE)	1,000	180			1,200	175		
	BRINE EMISSIONS (1.9 ppm)			0.76	26.3			0.73	25.4
	SURGE TANKAGE								
	STANDING LOSS			.10	3.4			...	...
	OPERATING LOSS			.18	6.5			...	...
	VALVES, SEALS, SLOP TANKS			.06	2.2			.06	2.2
	TOTAL			1.10	38.4			.79	27.6

* 4, 200,000 bbl, 225 ft. diameter, internal floating roof tanks at Bryan Mound.
1, 7,000 bbl, 40 ft. diameter, external floating roof tank at West Hackberry.

**these values include a significant percentage of ethane

Table 4-12. (continued)

		BRYAN MOUND				WEST HACKBERRY			
ALTERNATIVE	ACTIVITY/EMISSION SOURCE	DURATION (d)	MEAN OIL THRUPUT (MB/d)	EMISSION RATES** (g/s)	EMISSION RATES** (ton/y)	DURATION (d)	MEAN OIL THRUPUT (MB/d)	EMISSION RATES** (g/s)	EMISSION RATES** (ton/y)
40:30 (PREFERRED)	LEACH	617	4			613	4.5		
	BRINE EMISSIONS (.26 ppm)			0.56	19.6			0.62	21.6
	BLANKET OIL TANKAGE*								
	STANDING LOSS			.10	3.4			.03	1.2
	OPERATING LOSS			...	.1			.02	.8
	VALVES, SEALS, SLOP TANKS			.06	2.2			.06	2.2
	TOTAL			.72	25.3			.73	25.8
	LEACH/FILL	550	99			540	111		
	BRINE EMISSIONS (1.5 ppm)			3.25	112.9			3.61	125.4
	SURGE TANKAGE								
	STANDING LOSS			.10	3.4			...	...
	OPERATING LOSS			.09	3.2			...	...
	VALVES, SEALS, SLOP TANKS			.06	2.2			.06	2.2
	TOTAL			3.50	121.7			3.67	127.6
	FINAL FILL	240	180			270	175		
	BRINE EMISSIONS (2.6 ppm)			1.03	23.7			1.01	25.9
	SURGE TANKAGE								
	STANDING LOSS			.10	2.3			...	...
	OPERATING LOSS			.18	5.7			...	...
	VALVES, SEALS, SLOP TANKS			.06	1.4			.06	1.6
	TOTAL			1.37	33.1			1.07	27.5
	DRAWDOWN (TOTAL SITE)	209	1,054			172	1,400		
	SURGE TANKAGE								
	STANDING LOSS			.10	2.0			...	...
	OPERATING LOSS			.99	19.7			...	...
	VALVES, SEALS, SLOP TANKS			.06	1.2			.06	1.0
	TOTAL			1.15	22.9			.06	1.0
	REFILL (TOTAL SITE)	1,220	180			1,377	175		
	BRINE EMISSIONS (1.9 ppm)			0.76	26.3			0.73	25.4
	SURGE TANKAGE								
	STANDING LOSS			.10	3.4			...	...
	OPERATING LOSS			.18	6.5			...	...
	VALVES, SEALS, SLOP TANKS			.06	2.2			.06	2.2
	TOTAL			1.10	38.4			.79	27.6

*4, 200,000 bbl, 225 ft. diameter, internal floating roof tanks at Bryan Mound.
1, 7,000 bbl, 40 ft. diameter, external floating roof tank at West Hackberry.

**these values include a significant percentage of ethane

Table 4-12. (continued)

ALTERNATIVE	ACTIVITY/EMISSION SOURCE	BRYAN MOUND DURATION (d)	BRYAN MOUND MEAN OIL THRUPUT (MB/d)	BRYAN MOUND EMISSION RATES** (g/s)	BRYAN MOUND EMISSION RATES** (ton/y)	WEST HACKBERRY DURATION (d)	WEST HACKBERRY MEAN OIL THRUPUT (MB/d)	WEST HACKBERRY EMISSION RATES** (g/s)	WEST HACKBERRY EMISSION RATES** (ton/y)
60:10	LEACH	856	3.5			533	4.2		
	BRINE EMISSIONS (.26 ppm)			0.56	19.6			0.62	21.6
	BLANKET OIL TANKAGE*								
	STANDING LOSS			.10	3.4			.03	1.2
	OPERATING LOSS			...	.1			.02	.8
	VALVES, SEALS, SLOP TANKS			.06	2.2			.06	2.2
	TOTAL			.72	25.3			.73	25.8
	LEACH/FILL	792	85			466	107		
	BRINE EMISSIONS (1.5 ppm)			3.25	112.9			3.61	125.4
	SURGE TANKAGE								
	STANDING LOSS			.10	3.4			...	...
	OPERATING LOSS			.08	2.8			...	...
	VALVES, SEALS, SLOP TANKS			.06	2.2			.06	2.2
	TOTAL			3.49	121.3			3.67	127.6
	FINAL FILL	300	165			218	175		
	BRINE EMISSIONS (2.6 ppm)			1.03	29.6			1.01	20.9
	SURGE TANKAGE								
	STANDING LOSS			.10	2.9			...	...
	OPERATING LOSS			.15	4.6			...	...
	VALVES, SEALS, SLOP TANKS			.06	1.8			.06	1.3
	TOTAL			1.34	38.9			1.07	22.2
	DRAWDOWN (TOTAL SITE)	227	1,054			158	1,400		
	SURGE TANKAGE								
	STANDING LOSS			.10	2.2			...	...
	OPERATING LOSS			.99	21.4			...	...
	VALVES, SEALS, SLOP TANKS			.06	1.4			.06	1.0
	TOTAL			1.15	25.0			.06	1.0
	REFILL (TOTAL SITE)	1,333	180			1,263	175		
	BRINE EMISSIONS (1.9 ppm)			0.76	26.3			0.73	25.4
	SURGE TANKAGE								
	STANDING LOSS			.10	3.4			...	...
	OPERATING LOSS			.18	6.5			...	...
	VALVES, SEALS, SLOP TANKS			.06	2.2			.06	2.2
	TOTAL			1.10	38.4			.79	27.6

*4, 200,000 bbl, 225 ft. diameter, internal floating roof tanks at Bryan Mound.
1, 7,000 bbl, 40 ft. diameter, external floating roof tank at West Hackberry.

**these values include a significant percentage of ethane

would remain the same (i.e., duration would increase). Surge tank standing losses would increase proportionally at 680,000 bbl/d because of the longer duration of crude in the tanks.

The hydrocarbon losses indicated for the surge tank emissions are derived from equations (Appendix C.3) that predict "total evaporative losses" for tanks and may present an overestimate of VOC emission levels (which excludes ethane and methane).

To project ambient NMHC contributions from the West Hackberry site, the RAM computer output at 1 g/s (Appendix C.4, Table C.2-4) can again be used. The worst-case 1-h NMHC concentrations for this site are:

Significant Activity	Emission Rate (g/s)	Maximum 1-h Impact ($\mu g/m^3$)
Leach only	0.73	736.4
Leach/fill	3.67	3702.2
Final fill	0.95 (Phase II baseline	958.4
	1.07 (40:30 and 60:10 alternatives)	1079.4
Refill only	0.79	796.9

The 1-h maximum NMHC concentrations again indicate that violations of the 3-h NMHC standard of 160 $\mu g/m^3$ are likely within 3.5 km of the site. Background NMHC levels are already about 400 $\mu g/m^3$.

Figure 4-1 can again be used to convert NMHC concentrations into resulting 1-h maximum ozone levels. At typical NO_x concentrations (Level I), the worst-cast hydrocarbon concentrations would result in ozone concentrations in the range of 0.15 to 0.20 ppm in the immediate site area. At "typical" NMHC concentrations (which are at maximum about 40 percent lower than worst-case values) of 0.0 to 2200 $\mu g/m^3$ (0.0 to 3.3 ppm), ozone levels would vary from 0.0 to 0.19 ppm. During periods of extremely high ambient NO_x concentrations (Level II of Fig. 4-1), typical NMHC ambient concentrations from this source could produce ozone levels as high as 0.50 ppm (during leach/fill activity only).

Total NMHC emissions at West Hackberry would exceed 100 tons/year only during periods of significant oil flow during leach/fill. The leach/fill phase occurs during less than one half of the total leaching period. During drawdown, emissions at the site would be minimal because all surge tanks are located at Sun Terminal.

To project ambient NMHC concentrations from the Bryan Mound site, the RAM computer output at 1 g/s (Appendix C.4, Table C.2-4) is again used. The worst-case 1-h NMHC concentrations for this site are:

Significant Activity	Emission Rate (g/s)	Maximum 1-h Impact ($\mu g/m^3$)
Leach only	0.46 (Phase II baseline)	464.0
	0.72 (40:30 and 60:10 alternative)	726.3
Leach/fill	2.47 (Phase II baseline)	2491.7
	3.50 (40:30 and 60:10 alternative)	3530.8
Final fill	1.37	1382.0
Drawdown	1.15	1160.1
Refill	1.10	1109.7

The 1-h maximum NMHC concentrations again indicate that violations of the 3-h NMHC standard are very likely within 3.5 km of the site.

For quick reference of all hourly NMHC impacts during leach/fill on day 176, RAM was also run with a 3.50-g/s emission rate (Appendix C.4, Table C.4-4). This is the highest, or worst-case, emission rate for any activity. Background NMHC concentrations can be approximated from data collected at the Clute-Freeport station (Table 3-3). This value (400 $\mu g/m^3$) is low in comparison with many of the computer-projected values. Consideration of background concentrations would generally increase worst-case ambient impacts associated with Bryan Mound emissions only slightly. Background concentrations are already consistantly in violation of the NMHC guidelines.

Potential ozone ambient impacts can once again be estimated from Figure 4.1. Worst-case NMHC concentrations of 464.0 to 3530.8 $\mu g/m^3$ (0.70 to 5.30 ppm) would result in area ozone increments ranging from 0.13 to 0.20 ppm. Typical NMHC concentrations at Bryan Mound (in the range of 0.0 to 2100 $\mu g/m^3$) could result in ozone 1-h levels as high as 0.5 ppm during greatly elevated NO_x episodes (Level II of Fig. 4.1). However, such levels would only occur during leach/fill activity. Of the 50 non-zero, NMHC concentrations projected by RAM during leach/fill for day 176 (Appendix C.4, Table C.4-4), only 8 (16 percent) concentrations high enough (350 $\mu g/m^3$) to cause violations of the 0.12-ppm ozone 1-h standard during normal NO_x levels occur outside the site boundaries.

Based on currently available information and the above analysis, the level of hydrocarbon emissions is probably insufficient to have an important impact on nonlocal, regional levels of photochemical oxidants (i.e., other than in the immediate site area). It is believed that the emissions would be of minor significance to regional air quality because of their periodic nature. The use of vapor control technology (such as covering the oil brine separator and collection emissions) would help minimize impacts that occur.

In summarizing the air quality impacts, the West Hackberry and Bryan Mound facilities would be significant sources of NMHC. Additional violations of the 1-h ozone standard, immediately downwind from the facilities are predicted. If these sites are classified as major stationary sources, LAER, as defined by the Texas Air Control Board, will be implemented if the facilities are not given an exemption due to the intermittent nature of emissions. LAER for the sites would probably consist of covering the oil-brine separators, which is the major emission source, and venting collected VOC emissions to a vapor recovery system.

4.4.4 Ambient Sound Levels

Impacts of construction- and operations-related sound levels at the Bryan Mound site are addressed in the Seaway Group FEIS, Sects. 4.3.1.4 and 4.3.2.4. The creation of new storage caverns at the site, as part of Phase III expansion, would extend the duration of these impacts, but not their magnitude, which was deemed insignificant because of the industrial nature of the site.

Construction- and operations-related noise impacts at the West Hackberry site are presented in the Texoma Group FEIS, Sect. 4.3.4. Expansion of the West Hackberry site by 30 MMB would move the sources closer to existing residential structures that may remain in the area after site expansion. Significant short-term impacts to area residents could occur during construction, depending on the cavern locations selected.

4.4.5 Species and Habitats

The addition of four or six new storage caverns at the Bryan Mound site would not significantly impact species or habitats beyond the site boundaries. This action would extend the duration of impacts previously described for Phase II in the Seaway Group FEIS, Sect. 4.3.

Expansion of West Hackberry facilities by either 30 or 10 MMB could require the purchase of up to 34 acres of land to the south and west of the site. This action would remove existing pasture prairie habitats from use as well as require the removal of up to ten residences with actively maintained grounds. Removal of trees from the area would affect the species composition of birds found in the immediate vicinity. Noise and other industrial activity would keep many taxa away from the site, especially during construction. The habitats located in the impacted area are not unique to the region. Site expansion is not projected to impact any wetlands or other biologically sensitive areas.

4.4.6 Natural and Scenic Resources

Construction and operational activities involved in the Bryan Mound expansion would not affect any natural or scenic resources. Bryan Mound salt dome is located in an industrial area (Sect. 3.2.3.6) virtually lacking in these resources.

Construction and operational activities involved in the West Hackberry expansion would not affect any natural or scenic resources. The two options being considered for expansion (Sect. 2.2.1.1) are not located in wetlands.

4.4.7 Archaeological, Historical, and Cultural Resources

Although no known archaeological, historical, or cultural resources would be affected, expansion of the facilities at Bryan Mound could possibly impact resources not identified by previous studies (see Sect. 3.2.3.7). Further study of the expansion area before construction and careful monitoring during construction operations would be conducted to avoid destruction of heretofore unknown sites.

It is unlikely that the operational phase at Bryan Mound would impact any archaeological, historical, or cultural resources.

Although no known archaeological, historical, and cultural resources would be affected, it is possible that expansion of the facilities at West Hackberry could impact resources not identified by previous studies (see Sect. 3.2.4.7). Further study of the expansion area before construction and careful monitoring during construction operations would be conducted to avoid destruction of heretofore unknown sites. If an archaeological site was uncovered during construction, work would cease and the State Historic Preservation Officer would be contacted immediately as required by the National Historic Preservation Act of 1966.

It is unlikely that the operational phase at the West Hackberry expansion addressed in this document would impact any archaeological, historical, or cultural resources in the affected area.

4.4.8 Socioeconomics

Socioeconomic impacts of the proposed expansion of Bryan Mound storage capacity are likely to be undetectable for the following reasons:

- As noted in the FEIS for Phase II (Seaway Group FEIS, Sect. 3.3.8), the area was already industrially developed before Phase II.

- No further land acquisition would be required.

- Integration of the Phase III work with the Phase II work will require only a few additional workers; these workers should be on site for a very short period of time.

- With integration of Phases II and III, workers required for drilling and leaching would already be on site. No new workers would be required. Existing workers would simply stay at the site for the additional time required to drill and leach four more caverns.

- Given the industrialized nature of the site, the existing labor-shed, the relatively short increment of time required for the proposed expansion, and the probability that most workers already commute to the site, it is not likely that more of the workers currently engaged in drilling and leaching would change residences because of Phase III expansion.

The proposed Phase III expansion should require few, if any, changes in personnel required for maintenance. No significant (or even measurable) impacts are expected (Seaway Group FEIS, Sect. 4.3.2.8).

No significant local socioeconomic impacts are expected during fill or drawdown.

Phase III expansion of the West Hackberry site would cause minimal adverse socioeconomic impacts. Depending on the specific cavern locations selected up to ten residences adjacent to the existing property boundary would be removed, resulting in displacement of up to ten families.

4.5 IMPACTS TO FLOODPLAINS AND WETLANDS

On May 24, 1977, Executive Orders 11990 (Protection of Wetlands) and 11988 (Floodplain Management) were issued. Essentially, these orders require that each Federal agency issue or amend existing regulations and procedures to avoid the use of floodplain and wetland resources as sites for Federal actions unless no practicable alternative exists. In cases where no practicable alternative is available, impacts to these resources must be minimized to the greatest extent practicable. The Executive Orders and subsequent implementation guidelines and regulations promulgated by the U.S. Water Resources Council and DOE (Federal Register, February 10, 1978, and March 7, 1979, respectively) prescribed that assessment of floodplain and wetland impacts of proposed actions be included in environmental assessments or environmental impact statements prepared pursuant to the National Environmental Policy Act (NEPA).

A detailed description of the proposed and alternative actions of the Phase III SPR expansion is presented in Sect. 2.0. The approximate location of the Big Hill site in relation to the floodplain is presented in Fig. 4-10. The exact location of wellpads and the ultimate site boundary would be determined through ongoing geotechnical investigations, real estate availability, and detailed engineering design studies. All site facilities that could not withstand flooding would be located well above the 100-year flood elevation. The Big Hill storage site would cover approximately 250 acres on top of the Big Hill salt dome [elevation of 30 to 35 ft, mean sea level (msl)]. There are no wetlands associated with the Big Hill storage site. Crude oil, raw water, and brine disposal pipelines would cross floodplains and wetlands.

Expansion of the Bryan Mound site would occur within the 100-year floodplain. Site operational facilities and many of the existing wellpads are protected by a levee system designed to prevent significant overtopping from wave runup associated with a hurricane surge of 15 ft above sea level (Fig. 4-11). The levee system is a part of the Federal Flood Protection Project under construction for Freeport and vicinity and, as such, meets all Federal requirements. Construction of wellpads and wellheads in the floodplain would not alter flood elevations. Expansion at Bryan Mound would not significantly impact floodplains, but would occur in an area having wetlands.

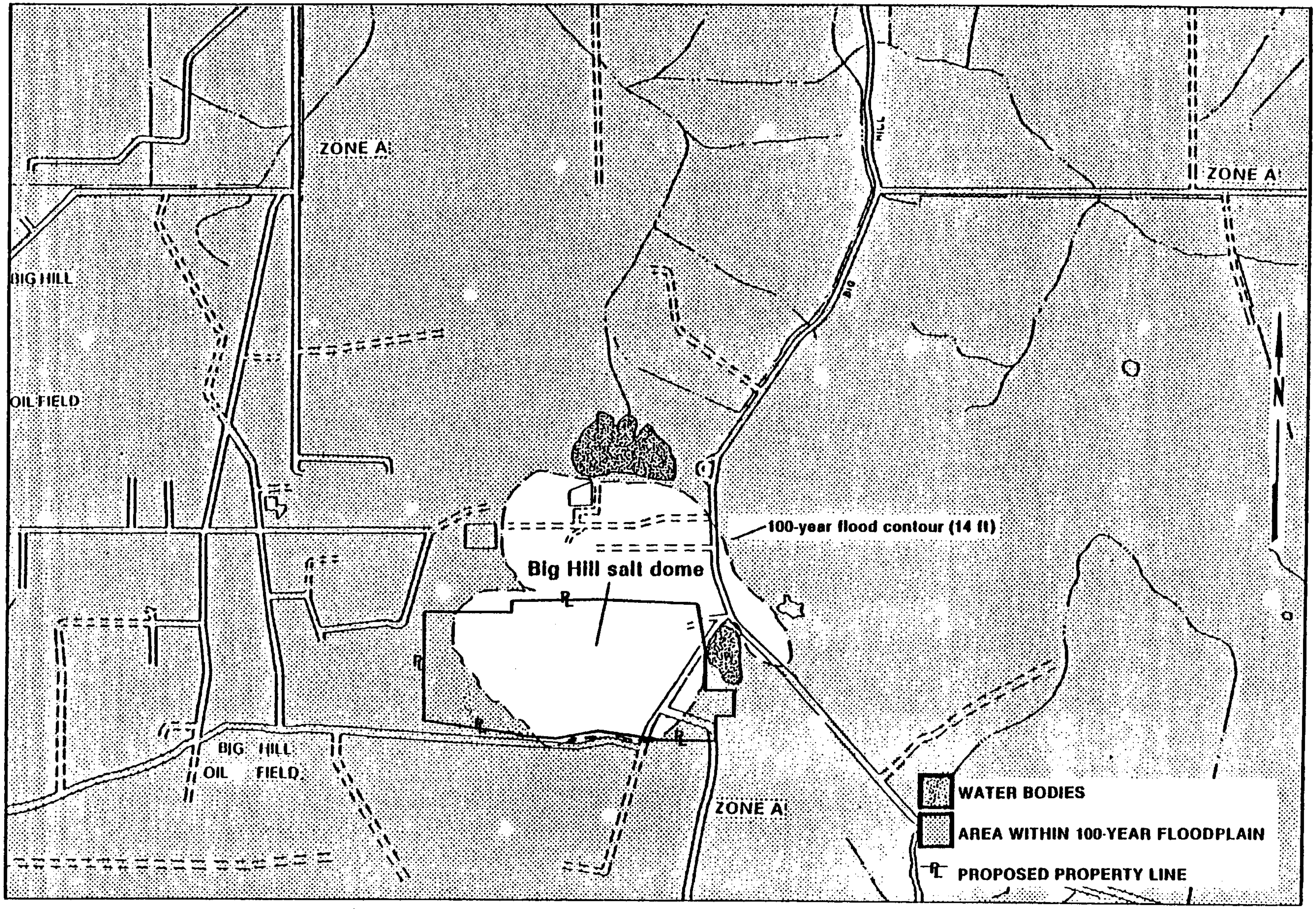


Figure 4-10. Local 100-year floodplain distribution in the vicinity of the Big Hill SPR site.

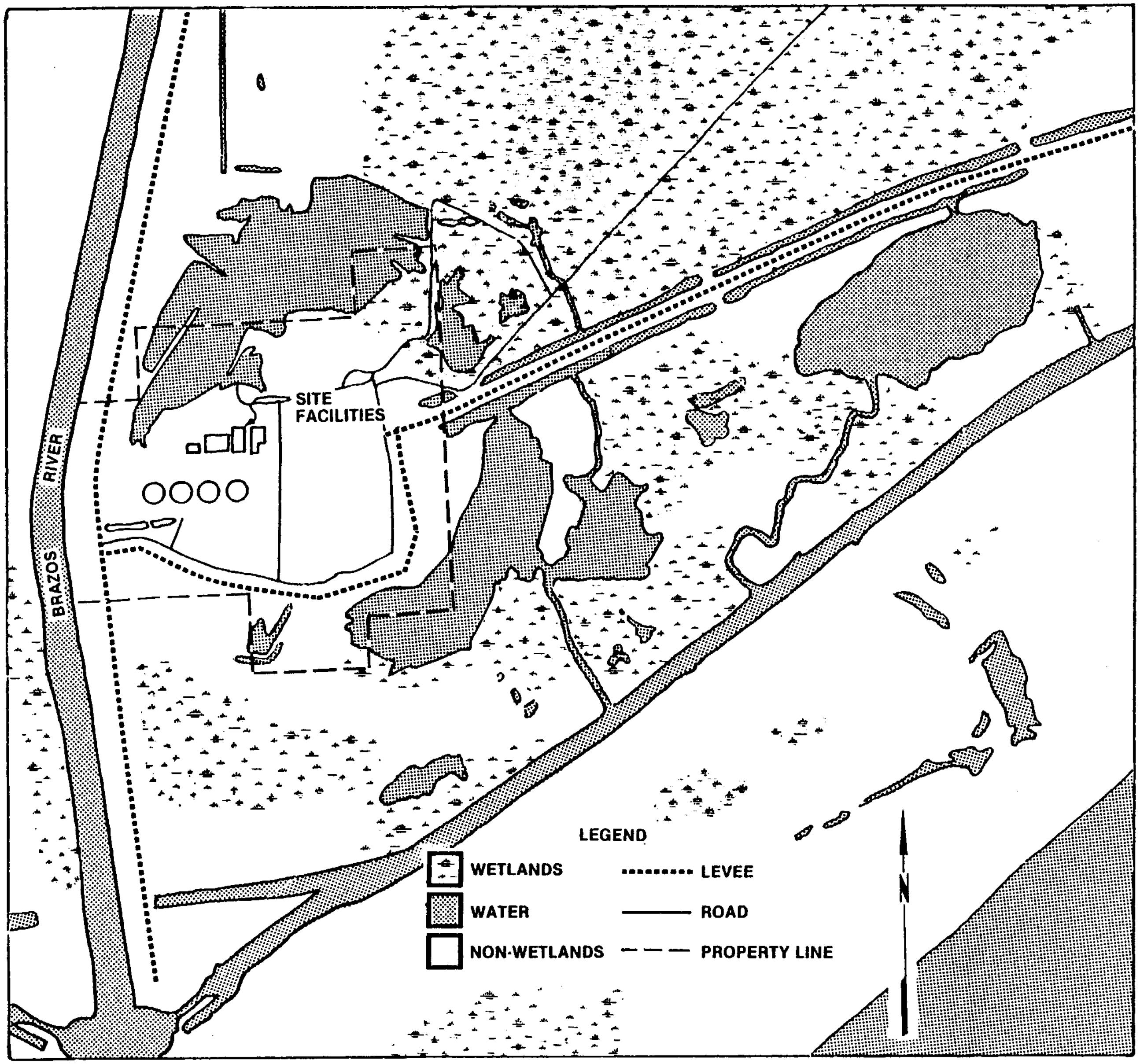


Figure 4-11. Bryan Mound SPR site hurricane flood protection system.

The expansion of the West Hackberry site would occur in the region shown in Fig. 4-12. As with the Big Hill site, this construction would occur on some of the highest ground in the area and would be above the 100-year flood elevation. There are no wetlands within the proposed expansion areas.

4.5.1 Phase III Preliminary Floodplain and Wetlands Determination

As specified by Executive Orders 11988 and 11990, a floodplain and wetlands determination for the proposed project would be made by the Secretary of DOE. The following is a preliminary determination of the practicability of locating the proposed Federal action in floodplains and wetlands.

The proposed site development at Big Hill and the expansion at West Hackberry would not be located in the 100-year floodplain or wetlands. The brine line, raw water pipeline, and oil distribution pipeline(s) for Big Hill and the expansion at Bryan Mound would impact floodplains and wetlands. Therefore, it is necessary to determine whether other sites and pipeline routes offer practicable alternatives to locating in floodplains and wetlands.

Selection of Candidate Storage Sites

This section examines only Gulf Coast salt dome storage sites. All other alternatives for Phase III were considered and rejected for various reasons, as is discussed in Sect. 2.3.1. The DOE has evaluated the feasibility of expanding the Gulf Coast sites already being used by the SPR program. Five possible domes were identified: Bryan Mound, West Hackberry, Weeks Island, Bayou Choctaw, and Sulphur Mines. Expansion of the latter three sites was not feasible (Sect. 2.3.1). The maximum practicable expansion is 60 MMB at Bryan Mound and 30 MMB at West Hackberry for a total increase of 90 MMB. At least one new site would be required to store the additional 120 MMB necessary to meet the SPR Phase III goal of 750 MMB.

The new sites were identified from the three groups of salt domes (Seaway, Texoma, and Capline) which have been under consideration for the SPR program. These were Napoleonville, Chacahoula, and Iberia of the Capline Group; Black Bayou, Vinton, and Big Hill of the Texoma Group; and Nash, Allen, Damon Mound, and West Columbia of the Seaway Group. The Big Hill dome was chosen as the preferred alternative for the reasons detailed in Sect. 2.3.

Practicability of Alternative Sites

Of the existing and new sites not proposed for expansion or development, an evaluation must be made to determine whether they would be practicable alternatives to locating in floodplains/wetlands. The three primary criteria developed to determine the practicability for Phase III development are sufficient storage capacity (for new sites), capability to dispose of brine, and avoidance of major impacts, which could not be adequately mitigated on a significant area of wetlands.

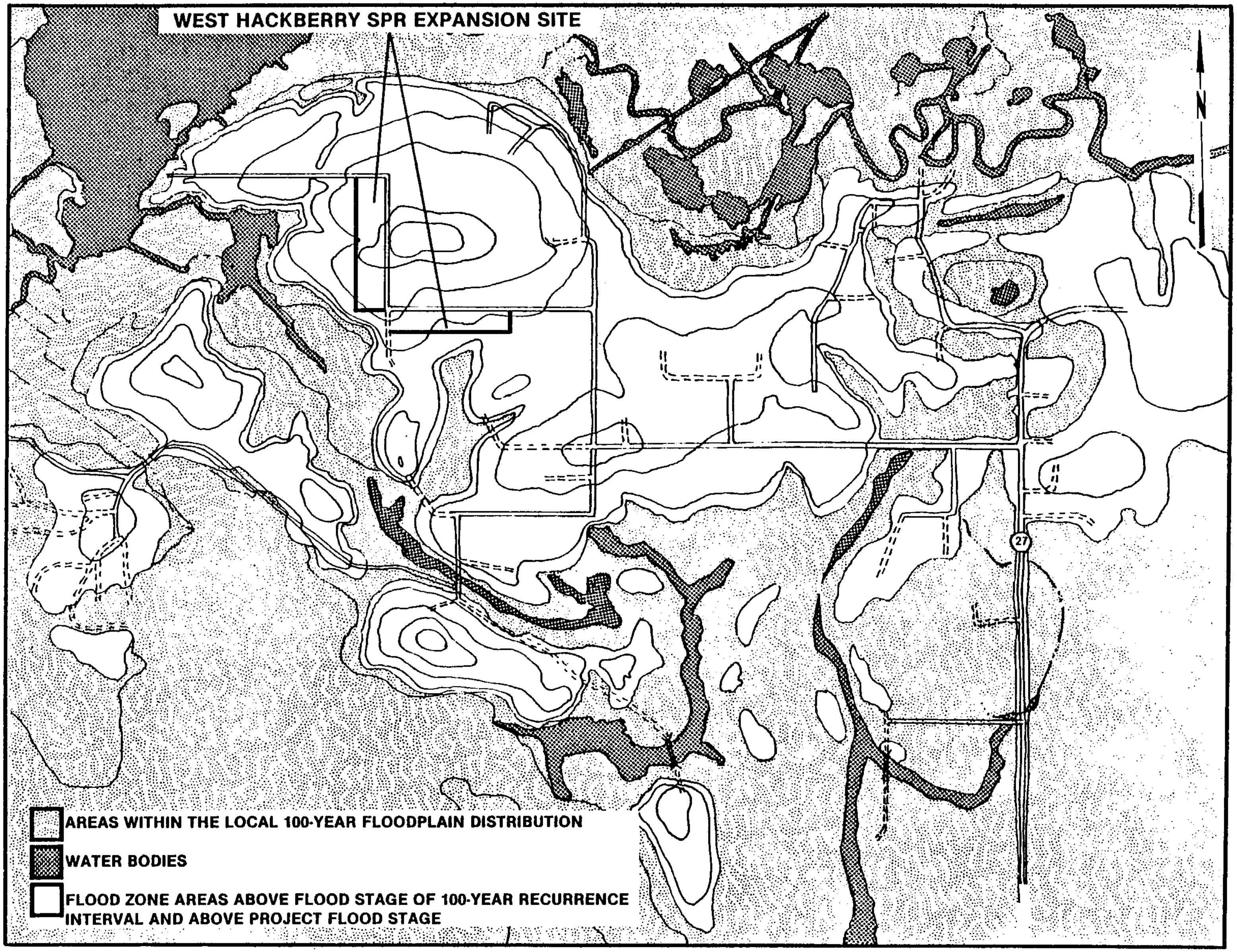


Figure 4-12. Local 100-year floodplain distribution in the vicinity of the West Hackberry SPR site.

The Iberia, Allen, and Vinton sites would not provide sufficient storage capacity. Ten sites (Iberia, Chacahoula, Napoleonville, Bayou Choctaw, Nash, Damon Mound, Weeks Island, West Columbia, Sulphur Mines, and Vinton) had major brine disposal problems. Iberia, Chacahoula, Napoleonville, and Black Bayou would have major impacts, which could not be mitigated on a significant amount of wetlands.

All these sites failed to satisfy the practicability criteria. Therefore, it is believed that there are no practicable alternative sites available for oil storage that would not be located in floodplains/wetlands.

Selection of Pipeline Routes

It is also necessary to determine whether any practicable alternatives exist to locating the Big Hill pipelines in floodplains/wetlands. Existing facilities would be used at Bryan Mound and West Hackberry.

Crude Oil Pipelines

The preferred crude oil pipeline would extend 23 miles from Big Hill to Sun Terminal. Any pipeline from the Big Hill dome will cross floodplains (see Fig. 4-10). Wetlands traversed by the proposed pipeline occur near Alligator Hole Marsh, Taylor Bayou, and Hillebrandt Bayou. It is estimated that the 150-ft ROW would impact about 45 acres of fresh marsh. Most of the land in the area is used for agriculture.

Two alternative crude oil pipeline routes were developed from 25 possible scenarios. Factors used in making the choice included total length, land use patterns, environmentally sensitive areas, presence of archaeological, historical, or cultural sites, number of water crossings, presence of existing ROWs, and construction techniques required. The two selected alternatives are the northern route to OTTI and a southern route to Pelican Island, as shown in Fig. 2-6.

The pipeline route to OTTI would temporarily impact floodplains and wetlands (including areas near Spindletop, Elm, Double, and Cedar bayous) in the area west of Big Hill and in the Trinity Bay area. The southern pipeline route would cross floodplains and wetlands (including areas near Spindletop, Elm, Oyster, and Lone Oak bayous) west and south of Big Hill and the Galveston Bay area. There are no practicable alternatives to routing the crude oil pipelines across floodplains and wetlands to transport the oil to terminal facilities.

Raw Water and Brine Disposal Systems

The proposed raw water and onshore brine disposal pipeline systems would cross a continuous floodplain/wetlands area between the Big Hill site and the Gulf of Mexico. The only practicable alternative available to construction of the brine pipeline is disposal of brine by underground injection, which would not be acceptable (Appendix H). The raw water intake facilities (electric pumps, etc.) would be located at the ICW on a spoil bank around an abandoned barge slip. The raw water intake pipe and associated protective structures would be located within the floodplain below the maximum low water level. This would ensure an uninterrupted water supply. These structures would not alter flood elevations in the area and would pose no threat to lives or property. Considering the need for a large amount of raw water located near the site, there is no practicable alternative to laying the pipeline across the floodplain and wetlands to the ICW.

4.5.2 Phase III Floodplain and Wetland Assessment

Big Hill Site

Construction of the 140-MMB Big Hill storage site would have no long- or short-term impact on floodplains or wetlands. The dome elevation, which is greater than 30 ft, places the project facilities well above the 100-year floodplain. Flooding should not occur at the site since it represents the highest elevation in the immediate region and would receive no runoff. There would be no alteration of surrounding floodplain elevations or floodplain actions as a result of site construction.

Raw Water Intake Structure at Big Hill

The raw water intake structure would be constructed on an abandoned barge slip at river mile 305 on the ICW. All components of the system (such as electric pump motors) that could not withstand flooding would be located above the 14-ft, 100-year floodplain level. These structures will not significantly alter the floodplain or floodplain action beyond those alterations caused by the presence of the ICW. Construction of the raw water intake structure would require dredging about 10,000 cubic yards of spoil from the intake channel to guarantee adequate depth and uninterrupted water supply. Spoil could be used as fill for the construction of the upland portion of the raw water facilities or could be placed in an upland spoil disposal area out of wetlands. The exact disposal techniques used will be dependent on the requirements imposed by the permitting agency. There are no expected impacts to wetlands since all construction would be on previously filled areas.

Crude Oil, Raw Water, and Brine Disposal Pipelines for Big Hill

Pipelines associated with the Big Hill SPR site development would descend from the site elevation of 30 to 35 ft to the surrounding floodplain and wetland areas described in Sect. 3.0. Pipeline construction would have minimal short-term effects on local flood drainage. Spoil would be stockpiled in a manner that would not totally inhibit natural drainage patterns. Openings of about 50 ft would be left between every 200 ft of spoil. Buried pipelines would have no long-term impacts on floodplain action and would not affect property or lives. At water crossings, shorelines would be restored as close to the original contour as practicable, reducing effects on natural overbank flood water distribution.

A major consideration in selecting pipeline routes was the avoidance of wetlands. Construction of pipelines across wetlands could involve the use of a double-ditching construction technique to preserve the topsoil. The pipeline ditch would be backfilled in reverse order, thereby ensuring that the first soil removed would be the last soil replaced. Impacts resulting from the stockpiling of spoil would be temporary and of short duration. Studies by USACE have shown that marsh flora and fauna recolonize and can even survive smothering by spoil as long as the spoil does not permanently raise elevations above limiting levels (Reimold et al., 1978). Recovery of vegetation should occur within about 1 to 3 years.

The revegetation of critical areas would be incorporated into the mitigation program if deemed necessary through ongoing consultation with local, state, and Federal authorities.

By rerouting the brine disposal pipeline, it could be possible to avoid the 73 acres of wetlands in McFaddin National Wildlife Refuge that would be affected by construction. This would affect a greater number of acres (+23) of wetlands and was therefore not considered a viable alternative. High-quality wetlands are distributed somewhat homogeneously south of the Big Hill project site from Sabine Lake to Galveston Bay between the ICW and the Gulf of Mexico. The route that would potentially impact fewer wetlands would be the more direct route across McFaddin National Wildlife Refuge. In compliance with the Rights-of-Way General Regulations (50 CFR 29.21; 34 FR 19907), the DOE would file a permit application with the Department of Interior to gain easement across the refuge. Existing pipeline ROWs would be followed where practicable, and mitigating measures (e.g., double-ditching, revegetation, and habitat creation) would be used to minimize impacts. The nature and extent of these actions would be determined through ongoing consultation with the refuge manager and other authorities.

Gosselink et al. (1979) have described the wetlands of the Sabine Basin in detail. According to their estimates of 1974, there were 250,388 acres of natural (brackish to intermediate) marsh and 101,793 acres of impounded (fresh) marsh in the basin. These marsh types have been substantially altered by man and nature since 1952, the earliest year of reliable data. Between 1952 and 1974 there was a 16.8 percent decrease in natural marsh and a 29.4 percent increase in impounded marsh. Because of the lack of adequate historical data, the impacts of these changes on ecosystem productivity cannot be quantified (Gosselink et al., 1979). Construction of the raw water and brine lines to the ICW would disrupt about 96 acres of primarily impounded marsh based on a worst-case 150-ft ROW. This represents a 0.09 percent reduction in this habitat type within the Sabine Basin. Construction of the brine line from the ICW to the Gulf of Mexico would involve 73 acres of natural marsh, assuming no existing ROW could be practicably utilized. This would represent 0.03 percent reduction in habitat. Mitigation programs implemented in coordination with local authorities and experts during the permitting procedure would be used to minimize impacts to the extent practicable.

Bryan Mound Site

Expansion at Bryan Mound would occur within the 100-year floodplain and in an area having some wetlands. Construction of wellpads would not alter floodplain action or affect the extent or severity of floods. Construction of the wellpads would require disruption of about 5 to 10 acres of wetland habitat under the 40:30 scenario. Between 7 and 15 acres of wetlands could be disrupted if the 60:10 alternative is developed. The wetland mitigation program at Bryan Mound, which includes the physical creation of new wetland habitat, would be amended to compensate for new construction.

West Hackberry Site

Examination of Fig. 4-3 reveals that all of the site expansion would occur above the 100-year flood elevation. Construction of wellpads would not significantly affect local runoff or floodplain action. There would be no effects on lives or on surrounding property. As with the Big Hill site, the West Hackberry dome surface represents the highest elevation in the immediate vicinity. No wetlands would be affected by expansion of the West Hackberry SPR site.

4.6 IMPACT DUE TO TERMINATION

After termination of the SPR program, facilities would be disposed of in accordance with applicable laws and regulations. If no future use is found for the storage sites, lands would be returned to conditions as close to original as is reasonably practicable.

4.7 RELATIONSHIP OF THE PROPOSED ACTION TO LAND AND WATER USE PLANS, POLICIES, AND CONTROLS

All of the sites discussed have been previously used for mineral extraction (salt, oil, gas) or storage. SPR operations would be compatible with continued production of oil and gas from fields adjacent to the domes.

Wherever pipelines cross state or Federally owned lands or sensitive areas, such as near oyster reefs, efforts would be made to minimize and mitigate impacts through coordination with the proper regulatory agencies.

Water withdrawal from the ICW would have no impact on current utilizations for transportation and recreation. This brackish water is not suitable for agricultural usage. Replenishment of water in the ICW from East Bay and Sabine Lake, which open directly into the Gulf of Mexico, and through local watershed drainage would preclude any possibility of adverse effects on water level or quality beyond those variations that naturally occur in the region.

Expansion of the SPR at Bryan Mound and Big Hill would be coordinated with the Texas Coastal Management Program, as maintained by the state's various natural resource agencies. This would ensure continued balance among future economic, environmental, and social needs along the Texas coast. The state of Texas is now in the process of developing a comprehensive Coastal Zone Management Plan pursuant to the Federal Coastal Zone Management Act of 1972. The state of Louisiana recently gained approval for their Coastal Zone Management Plan. Consultation would be made with the appropriate authorities to ensure that expansion of the SPR would not be in conflict with their goals.

Expansion of the SPR under Phase III would have no impact on any estuarine or marine sanctuaries. The Flower Garden reefs, located over 100 miles off shore from the Big Hill disposal site, is the only proposed marine sanctuary in the region. Rapid dilution of brine in sea water and distance would prevent any possible impacts to this natural resource.

4.8 NO ACTION

There are several significant impacts associated with the no-action option of the proposed Phase III SPR expansion. The SPR would be limited to the 538 MMB storage now under development in Phase I and II and therefore would not provide the United States with sufficient petroleum reserves to adequately minimize the effects of a future oil supply interruption. No action would also be in direct violation of the Energy Policy and Conservation Act (EPCA) of 1975 as amended by the Omnibus Reconciliation Act of August 13, 1981, Section 1033 (P.L. 97-35). A more detailed discussion is presented in Sect. 2.3.2.

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5.0 ENVIRONMENTAL MONITORING

5.1 INTRODUCTION

Since the inception of the SPR project with Public Law 94-163, the Department of Energy (DOE) has recognized the importance of baseline characterization and monitoring for environmental impact assessment. In accordance with the National Environmental Policy Act of 1969 (NEPA), the National Pollutant Discharge Elimination System (NPDES) regulations, Executive Order 11752, Sect. 10 of the 1899 Rivers and Harbors Act and Sect. 404 of P.L. 92-500, as well as numerous other Federal and state laws and regulations (see Sect. 9.0), the DOE has conducted environmental studies related to all phases of facility construction and methods of brine disposal, including discharge to the Gulf of Mexico (Table 5-1). Throughout these studies, brine disposal has been recognized as one of the most sensitive environmental issues.

5.2 BASELINE CHARACTERIZATION

A 1-year oceanographic survey of baseline conditions was conducted in the area of the proposed Big Hill diffuser from September 1977 to October 1978 (see Appendix F). This study, which was part of a larger regional Texoma survey, included detailed documentation of physical oceanography, trace chemistry, sediment texture and distribution, macro- and meio-benthos, phytoplankton, zooplankton, and demersal nekton populations. Results of this survey provided much of the information pertaining to the marine environment in the Texoma Final Environmental Impact Statement (FEIS).

Baseline characterization of the West Hackberry site has been conducted in three phases. As part of the Texoma regional survey, monthly sampling identical to that performed at the Big Hill site was conducted between September 1977 and May 1978. Beginning in June 1978, sampling shifted to a National Oceanic and Atmospheric Administration/National Marine Fisheries Service (NOAA/NMFS) multidisciplinary program that sampled sediment and microorganisms, benthos, demersal nekton, macrocrustaceans, and zooplankton on a quarterly basis. Physical oceanographic parameters were collected over a 1-year cycle. Brine pit monitoring, shrimp studies, and other tasks are now being extended to the West Hackberry site.

The third phase of offshore monitoring at West Hackberry will follow closely the plan developed at Bryan Mound. This program will consist of an initial intensive predischarge characterization, followed by continued surveillance during the startup of brine discharge.

Baseline environmental surveys at the proposed Bryan Mound 5.8-mile and the current 12.5-mile disposal sites began in September 1977 and November 1977, respectively. These multidisciplinary investigations included numerous aspects of the near-shore environment in the region of the proposed brine diffuser sites. Intensive sampling at the 5.8-mile site was reduced in scope when the 12.5-mile brine line and diffuser was selected and constructed. Environmental characterization of the offshore site continued throughout the period of construction of the diffuser. With the commencement of brine disposal in March 1980,

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efforts shifted from a characterization mode to a discharge phase monitoring mode. To date, no substantive, unexpected findings have been obtained (see Sect. 4.2.5.2).

5.3 PRE- AND POST-DISCHARGE MONITORING

Briefly, the rationale for conducting a monitoring program is to satisfy legal requirements of legislative and regulatory policies, to determine any short- or long-term irreversible commitments of resources to the project, to provide policymakers with sufficient information to aid in making future decisions on similar projects, and to provide regulatory agencies with enough information about impacts that alternatives or mitigative measures could be taken. Both temporary and long-term impacts must be addressed. Monitoring programs should cover all project features that have a reasonable probability of resulting in detectable impacts, especially where impacts may be considered long-term (USACE, 1979). In general, monitoring programs would consist of two basic actions: (1) the development of a data base containing information on preproject baseline conditions and (2) an ongoing data gathering program designed to detect the trend of environmental impacts before the impact reaches a critical or unacceptable level.

In response to a stipulation in Part III of EPA NPDES Permit No. TX 0074012 that states "discharge shall not be authorized until the permittee has provided the (comprehensive) monitoring plan, has received the Regional Administrator's approval of the plan, and has provided for implementation of the plan," the DOE developed a monitoring plan for Bryan Mound brine disposal to the Gulf of Mexico (DOE, 1979). The duration of this plan is expected to be 67 months or for as long as leach-fill operations continue. Modifications of the plan may occur at the discretion of EPA, although for planning purposes 17 to 18 months of observations are expected to be made before any major changes are incorporated. The developed monitoring plan consisted of five major tasks. These are presented in DOE (1979) as:

Task 1. Oceanographic Monitoring

Purpose

- o To observe the physical environmental factors that disperse the effluent and govern the structure and dynamics of the ecosystem.
- o To determine the orientation and extent of the plume and its spatial-temporal variation.
- o To determine the nature and spatial extent of impacts on the receptor communities, plankton, benthos, and demersal nekton.

Task 2. Brine Pit Monitoring

Purpose

- To monitor chemical and physical characteristics of the discharge from the brine surge pit as specified in the NPDES permit.

Task 3. Shrimp Studies

Purpose

- To determine the proportion of the spawners in the total population with a secondary objective of identifying spawning grounds.

- To determine recruitment in adjacent bays of postlarvae and juveniles to the fishery (to be done in conjunction with the Texas Department of Parks and Wildlife).

- To conduct white and brown shrimp tagging, in shore and off shore.

- To perform statistical analysis of commercial catch data.

Task 4. Numerical Modeling of Energy Transfer Through the Food Web

Purpose

- To develop a numerical model of energy transfer through trophic levels of a shrimp community.

- To identify and quantify where possible subtle-nonlethal impacts, offsetting impacts, or net positive impacts.

Task 5. Red Drum Bioassay

Purpose

- To evaluate the possible effects of brine on eggs, larvae, and postlarvae of red drum.

The detailed and site-specific aspects of the ongoing monitoring programs are discussed in detail in DOE (1979) and other documents related to the project (see Table 5-1). Offshore environmental data base development at the Big Hill, Bryan Mound, and West Hackberry sites began in the fall of 1977.

5.4 PHASE III, OFFSHORE MONITORING

Through its commitment to permit requirements and to public concerns, DOE would continue to monitor the environmental effects of offshore brine disposal for Phase III development. Although a specific monitoring design has not been approved, results from the intensive Bryan Mound and West Hackberry programs are expected to lead to decreases in the scope of required monitoring as an understanding of the consequence of offshore brine disposal increases and environmentally acceptable bounds are defined. All standards for determining startup, curtailment, shutdown, or alteration of process procedures would be left to the informed judgment of the EPA Administrator, as established by the terms and conditions of all applicable permits.

5.5 PHASE III, ONSHORE MONITORING

Onshore environmental characterization of the Big Hill, Bryan Mound, and West Hackberry SPR sites was conducted as a part of the development of project-related environmental impact statements. These documents addressed numerous aspects of the local affected environment and attempted to predict the nature and severity of SPR construction- and operation-related impacts. To comply with Executive Order 11752 and Draft DOE Order 5400, the DOE plans to initiate onshore monitoring programs in association with their SPR facilities. These surveys will update the onshore data base by sampling and evaluating the following parameters:

- Meteorology, air quality, and noise
- Hydrology and water quality
- Soils
- Vegetation
- Aquatic ecology
- Wildlife

Some measurements, such as meteorology, will be made continuously with onsite recording equipment. Biological sampling may be conducted periodically.

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6.0 SUMMARY OF IMPACTS AND MITIGATION MEASURES

This section summarizes the primary environmental impacts and mitigative measures described in Sect. 4.0. Most impacts would result from the construction and operation of a new 140-million-barrel (MMB) storage facility at Big Hill, Texas. The possible construction of a similar 100-MMB facility was previously addressed in the Texoma Group FEIS.

The expansion of the Bryan Mound site by either 40- or 60-MMB capacity would incrementally increase the impacts described in the Seaway Group Final Environmental Impact Statement (FEIS). These increases are not considered significant. All proposed expansion would occur on existing DOE property.

The expansion of the West Hackberry site by either 10 or 30 MMB would also incrementally increase the impacts described in the Texoma Group FEIS. A total of 34 acres of prime farmland may be required, depending on the sites selected for storage caverns. Up to ten residential units could be displaced if parts of both the southern and western land areas are selected.

The preferred leach rate of 980,000 bbl/d at Bryan Mound would use and produce the same amounts of raw water and of brine as would the 680,000-bbl/d alternative. As leach rate increases, duration of leaching decreases. The higher leach rate would allow a net savings of 14 months and lead to earlier attainment of oil storage capacity. The daily air emissions (nonmethane hydrocarbons) would be proportionately greater at the higher leach rate.

Table 6-1. Cumulative summary of proposed Phase III environmental impacts and mitigative measures

Action	Primary impact	Mitigative measures	Unavoidable impact
A. Land features			
Big Hill storage site, 140 MMB	Removal of 250 acres of prime farmland soils from potential production	Landscaping and soil conservation	Same as primary
West Hackberry site, 30 or 10 MMB	Removal of up to 34 acres of prime farmland and ten residences in addition to the 160 acres removed in Phase II (Texoma FEIS)	Same as above	Same as primary
Bryan Mound site, 40 or 60 MMB	All construction would occur within existing facility boundaries; possible destruction of 15 acres of wetlands	Same as above; create new wetlands	Same as primary; reduced overall loss of productivity
Road construction off site	Destruction of natural vegetation	Revegetate where practical	Changes in vegetation, species composition
	Disruption of natural drainage	Install culverts to maintain natural flow regime	Some alteration of natural watershed; borrow ditches, creation of areas with open water
Big Hill raw water/brine disposal pipeline	90,000 yd^3 will be dredged from the pipeline route, then used as backfill; an additional 10,000 yd^3 will be dredged from an abandoned barge slip on the ICW for construction of the raw water intake structure; 9.2-mile ROW; 5.3 miles to ICW; 3.9 miles to Gulf of Mexico	Close supervision of dredging; operators use most advanced dredging/pipe-laying techniques; double ditching in wetlands; directional drilling at water crossings where practical; revegetation after 1 year if not naturally occurring	Increased water turbidity, sedimentation, spoil bank creation
Crude oil distribution system			
Preferred route, Big Hill to Sun Terminal	23-mile ROW for duration of project 18 miles cropland/pasture 2.5 miles wetland 0.5 miles open water 2 miles industrial/residential	Same as above	Loss of trees on ROW for duration of project, reduced primary impact
Alternative route, Big Hill to OTTI	60-mile ROW 42 miles cropland/pasture 3 miles wetland 12 miles open water 3 miles forested land	Same as above	Same as above
Alternative route, Big Hill to Pelican Island	54-mile ROW 27 miles cropland/pasture 12 miles wetland 15 miles open water	Same as above	Same as above

Table 6-1 (continued)

ction	Primary impact	Mitigative measures	Unavoidable impact
. Water environment			
Big Hill raw water/brine disposal system (on shore)	Dredging in the ICW and Star Lake will result in increased turbidity, elimination of benthic habitat, desorption of toxic chemicals, lowered water quality	Follow most recent technological advance; remove contaminated spoil	Reduce effects of primary impact
Big Hill site	Alteration of natural watershed, siltation, oil and grease, toxic chemicals, brine spill	Oil brine separator; containment dikes; revegetation	Reduced effects of primary impact
Grading, excavation, and filling	~1400 yd³ of sediment washed into surface water system by erosion during 5 months of activity will increase suspended solids in Spindletop Marsh, Salt Bayou Marsh, Willow Slough, and Mayhaw Bayou	Use soil conservation procedures, revegetate, contour	Reduced primary impact
Miscellaneous construction activities	Spillage of oil and fuels during equipment operations	Train and supervise operators	Reduced primary impact
	Improper use of herbicides, pesticides, and fertilizers (i.e., excessive use, improper waste disposal of materials, etc.)	Train and supervise operators	Reduced primary impact
	Biological pollutants entering water system (bacteria, fungi, worms, viruses, etc.)	Proper design, maintenance, and inspection of sanitary disposal facilities	None
Dredging in Taylor Bayou	Removal of 25,000 yd³ of dredged material	Follow most recent technological advances; directional drilling turbidity screens	Reduced primary impact
	Released pollution from channel beds into stream	Same as above	Reduced primary impact
	Increased BOD	Same as above	Reduced primary impact
	Increased nutrient(s) concentration	Same as above	Reduced primary impact
	Increased sulfides from petroleum pollutants	Decrease by combining with heavy metal ions	Decreased augmentation of sulfides
Dredging in Hillebrandt Bayou	Removal of 25,000 yd³ of dredged material with impacts similar to Taylor Bayou	Follow most recent technological advances; directional drilling turbidity screens	Reduced primary impact

Table 6-1 (continued)

Action	Primary impact	Mitigative measures	Unavoidable impact
B. (continued)			
Dredging in the ICW	Removal of 62,500-70,000 yd^3 of dredged material with impacts similar to Taylor Bayou	Follow most recent technological advances; directional drilling turbidity screens	Reduced primary impact
Dredging in the Gulf of Mexico	Estimated offshore pipeline construction impacts covering 21 acres for the 3.5-mile site, 76 acres for the 12.5-mile site; turbidity increase	None	Reduced primary impact
	Hazard of trench to commercial trawling	Backfill, if not naturally occurring	Reduced primary impact
Withdrawal of water for displacement and leaching	Altered flow velocities increased by 0.06 ft/s in the ICW	None	Induced flows are negligible
	Maximum salinity increase in the withdrawal point of less than 0.20 ppt	None	Same as primary impact
	Maximum salinity increase in the ICW of less than 2 ppt	None	Same as primary impact
Brine disposal in Gulf of Mexico	During both leaching and refill processes, bottom areas of up to 2,575 acres around the diffuser have salinities in excess of 1 ppt above ambient	None	Same as primary impact
	Leaks would damage biota in vicinity	Monitor and repair	Same as primary
Bryan Mound site brine disposal, 980,000 bbl/d (preferred)	During leaching bottom area with salinities in excess of 1 ppt above ambient around the diffuser would increase to ~1,800 acres	Monitor	Same as primary
680,000 bbl/d (alternative)	+1,000 acres of sea bottom with nominal salinities in excess of 1 ppt	Monitor	Same as primary
C. Air quality impact			
Construction activities at Big Hill storage facility	Annual pollutant emission rate of particulates = 13,000 tons/year	Use most advanced dust suppression techniques	Reduced particulate emissions
Leach/fill at Big Hill, 1.4 MMB/d	Annual pollutant emission rate of NMHC = 163 tons/year	Use vapor control technology with oil brine separators	Reduced NMHC emissions
Bryan Mound, 980,000 bbl/d, 680,000 bbl/d	NMHC = 121 tons/year NMHC = 86 tons/year	Same as above	Same as above
West Hackberry, 1,088,000 bbl/d	NMHC = 128 tons/year	Same as above	Same as above

Table 6-1 (continued)

Action	Primary impact	Mitigative measures	Unavoidable impact
C. (continued)			
Tanker loading (preferred alternative)	Annual pollutant emission rate of NMHC = 2,426 tons/year	Use vapor control technology with shipboard activities	Reduced NMHC emissions
Tanker loading (alternative pipeline)	Annual pollutant emission rate of NMHC = 1,372 tons/year	Use vapor control technology with shipboard activities	Same as above
D. Noise impacts			
Construction at site	At 2,000 ft from center of site, noise levels of L_{eq} < 55 dB and L_{dn} < 55 dB	None	Same as primary impact
Pipeline construction	At 500 ft from center of construction, noise level of L_{eq} < 55 dB	None	Same as primary impact
Terminal and dock	At 2,000 feet from dock site, noise level of 65 dB	None	Same as primary impact
Petroleum transfer operations	Increased noise from pumping machinery (localized), tanker engines, and electrical generation equipment	None	Same as primary impact
E. Biological impact			
Road construction	Decreased production of beef cattle dependent on pasture forage	Partially regained after reestablishment of pasturage in construction areas	Net decrease in production locally
Brine pipeline construction off shore	Destruction of immobile organisms in path of pipelines	Recolonization after about one growing season would occur	Species diversity would probably decrease
	Interference with life cycles of and mortality to shellfish and finfish by increased sediment load	None	Same as primary impact
	Loss of productivity by increased light attenuation in water column due to turbidity	Reduce turbidity by using best available technology; turbidity screens where practical	Some increase in later productivity due to increased nutrient concentration
	Destruction of benthic organisms by settling of sediments	None	Temporary decrease in benthic populations
Onshore construction of oil, raw water, and brine pipelines	Destruction of vegetation and immobile organisms in path of pipeline	Revegetate after about one growing season would occur; this may be enhanced by good construction techniques such as double ditching, reseeding if not naturally occurring, directional drilling at water crossings where practical	Species diversity would probably decrease

Table 6-1 (continued)

Action	Primary impact	Mitigative measures	Unavoidable impact
E. (continued)			
Petroleum handling operations	Spills can be directly toxic to flora and fauna and can render soils unable to support vegetation	Rapidly contain and clean up spilled oil	Reduced toxic effects
	Spills at the site could enter watershed, causing serious damage and toxic effects to resident flora and fauna	Provide permanent, large-volume dikes around wellheads for containment	Greatly reduced impact to local ecology
Withdrawal of water for leaching and displacement	Entrainment of planktonic organisms	Reduce velocity and alter intake structure design to reduce entrainment	Small, less mobile organisms entrained
Brine disposal	Salinity of 1 ppt above ambient would cover 2,575 acres under worst-case conditions in the Gulf	None	Same as primary impact
F. Socioeconomic impacts			
Construction surface facilities	Construction of surface facilities would impact local residence with noise and traffic	Schedule operations to avoid certain time periods (night)	Reduced primary impact
Construction of pipeline	Short-term disruption of grazing due to pipeline construction	None	Same as primary impact
Traffic due to construction	Short-term disruption of traffic due to construction	None	Same as primary impact
Use of public services	Potential injuries of workers laying pipelines	Helicopter ambulance service	None

7.0 RELATIONSHIP BETWEEN LOCAL SHORT-TERM USE OF THE ENVIRONMENT AND MAINTENANCE AND ENHANCEMENT OF LONG-TERM PRODUCTIVITY

7.1 INTRODUCTION

In this section the short-term uses of the local environment implicit in the proposed action are discussed in terms of the expected effects on maintenance and enhancement of long-term productivity. Effects on the natural and regional economic productivity and adverse impacts on environmental resources are considered.

7.2 EFFECT ON NATIONAL AND REGIONAL ECONOMIC PRODUCTIVITY

The primary long-term effect of the proposed actions would be to help offset the impacts of an oil supply interruption on both the regional and national economies. In this regard, the proposed actions do not differ from those described in the Texoma and Seaway Group Final Environmental Impact Statements (FEISs).

The construction and operation of the Strategic Petroleum Reserve (SPR) facility at Big Hill, together with the expansion of the Bryan Mound and West Hackberry facilities, would most likely not significantly impact the long-term economic productivity of the regional or national economy.

7.3 ADVERSE IMPACTS ON ENVIRONMENTAL PRODUCTIVITY

Adverse impacts on environmental productivity would differ little at the Bryan Mound and West Hackberry sites from those described in the Seaway and Texoma Group FEISs. The primary difference would be the possible acquisition of an additional 34 acres of land at West Hackberry, which would remove that amount of land from residential and pasture usage. The following discussion will therefore be restricted to the impacts at Big Hill.

7.3.1 Impacts on Land

In general, the impacts on the land occurring during construction would include road construction, well drilling, site preparation, dredging, temporary spoil deposition, and pipeline burial. Except for the grading of the site, retention dikes built around onsite wells and ponds, and the dredged area created at the raw-water intake structure, no long-term alteration of the topography would occur. Temporary alteration of drainage patterns from pipeline construction activities (spoil disposal) would constitute the only short-term effects on the environment. Construction of the 250-acre site would preclude the use of approximately 0.05 percent of the prime or potential prime farmland soils in Jefferson County during the life of the project.

7.3.2 Impacts on Water

Construction activities associated with the raw water and brine pipelines would result in only short-term impacts to various water bodies.

Long-term effects on the aquatic environment resulting from water withdrawal from surface water bodies would be negligible. Although the quantities of water are large, the induced currents and altered salinities are too small to produce noticeable effects on aquatic biota.

The operation of the brine diffusers would produce impacts during the leaching of the caverns and during the periods when the caverns are being filled with oil. Any significant effects of increased salinities would be localized. From preliminary brine disposal data obtained at the Bryan Mound diffuser, no significant long-term effects are anticipated because of the high diffusion rate of the brine and the overall low induced salinities at distances beyond the 330-ft (100-m) release zone.

7.3.3 Impacts on Air

Nonmethane hydrocarbon emissions at the storage sites may be in excess of 100 tons/year during leach/fill operations, which would release worst-case emissions. Offsite, nonmethane hydrocarbon and ozone concentrations would be in excess of the 160 $\mu g/m^3$ and 0.12-ppm standard respectively, under certain meteorological conditions. These emissions would occur for short periods (2 years or less) and would not significantly impact long-term regional air quality. When oil is taken out of storage and loaded onto vessels at the Sun Terminal, the standards could also be exceeded. Hydrocarbon emissions from SPR operations at the terminal would be temporary and would replace emissions from foreign crude during a supply interruption.

Particulate levels would be moderately high during construction because of airborne dust. Particulate suppressors, such as water-spraying and chemicals, would help reduce the short-term impact.

8.0 IRREVERSIBLE AND IRRETRIEVABLE COMMITMENT OF RESOURCES

8.1 INTRODUCTION

During Phase III development and subsequent operation of Strategic Petroleum Reserves (SPR) facilities at West Hackberry, Big Hill, and Bryan Mound, a number of resources would be irreversibly committed to the project in addition to those committed during Phases I and II. These resources cannot be restored to their original value and, once consumed, are not recoverable for subsequent use.

The types of resources affected by underground storage of crude oil are (1) material resources (e.g., renewable and nonrenewable materials consumed in construction and operation) and (2) natural resources, including any other recognized beneficial uses of the environment.

Resources that may be irreversibly committed are (1) plants and animals destroyed or displaced on or near the site; (2) construction materials and energy that cannot be recovered or recycled; and (3) materials consumed or reduced to waste products.

The sections below identify and quantify the resources that would be irreversibly committed in the Phase III expansion of the SPR program. The preferred actions providing a basis for the determination of resource commitments were:

- 140-million-barrels (MMB) development at Big Hill with all systems as discussed in Sect. 2.0, including the preferred crude oil pipeline route.
- 30-MMB additional capacity at West Hackberry on newly purchased land using the systems existing for the Phase I and II operations.
- 40-MMB additional capacity at Bryan Mound on existing land using the systems existing for the Phase I and II operations.
- 980,000-bbl/d leach rate at Bryan Mound for Phase III and remaining Phase II leach operations.

Alternative actions at these three sites for which resource commitments were also determined are:

- 10-MMB additional capacity at West Hackberry (instead of 30 MMB).
- 60-MMB additional capacity at Bryan Mound (instead of 40 MMB).
- An alternative 60-mile crude oil pipeline from Big Hill to the Oil Tanking of Texas, Inc., Terminal (OTTI) instead of to Sun Terminal.

- o An alternative 54-mile crude oil pipeline from Big Hill to the Pelican Island Terminal tank farm instead of to Sun Terminal.

- o Two combinations of crude oil pipelines from Big Hill.

  - Pipelines to Sun Terminal as well as to OTTI.

  - Pipelines to Sun Terminal as well as to the Pelican Island Terminal tank farm.

- o An alternative location of the brine diffuser for the Big Hill site that would be up to 12.5 miles off shore (total possible length of 22.2 miles) instead of 3.5 miles off shore.

- o 680,000-bbl/d leach rate at Bryan Mound.

Resource commitments for the preferred and alternative actions are summarized in Table 8-1.

8.2 LAND

During construction and operation of the preferred facilities, irretrievable loss of land and its potential uses would be sustained from a maximum number of acres for each site as follows:

	System Pipeline Rights-of Way (ROWs)[1]				
	Onsite	Oil	Brine[2]	Raw Water[3]	Total
Big Hill, 140 MMB	250	209	36	48	543
West Hackberry, 30 MMB	34	N/C[4]	N/C[4]	N/C[4]	34
Bryan Mound, 40 MMB	N/C[2]	N/C[4]	N/C[4]	N/C[4]	0

For the alternative actions, the maximum commitment of acres, including the land for the preferred action not affected by the alternative, would be:

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[1]Impacts to pipeline ROWs are short-term, except in wooded areas, where trees would be removed for the duration of the project.

[2]Big Hill to ICW raw water and brine line share a common ROW.

[3]ICW to coast brine line ROW.

[4]No change in land use from Phase I and II activities at the site.

Table 8-1. Summary of resource commitments for SPR Phase III development

Resource	Units	West Hackberry[1]		Bryan Mound[2]		Big Hill[3]			
		Preferred	Alternative	Preferred	Alternative	Preferred	Pipeline 1	Pipeline 2	Pipeline 3
Land									
Land removed from present use	acres	34	0	0	0	543	879	825	+0
Water									
Water used during project lifetime	MMB	400	135	520	785	1,830	1,830	1,830	N/A
Material									
Construction materials									
Steel	tons	640	135	520	1,270	47,000	76,700	71,200	+7,900
Concrete	ft^3	4,800	1,600	6,400	9,600	200,000	392,400	362,000	+46,100
Salt	10^6 tons	11	4	15	23	53	53	53	N/A
Oil losses during operation	MB	45	15	60	90	210	210	210	N/A
Energy									
Construction	kWh	6.0×10^7	2.0×10^7	8.0×10^7	1.2×10^8	8.0×10^8	9.3×10^8	8.5×10^8	$+1.1 \times 10^8$
Fill/withdrawal (five cycles)	kWh	4.3×10^8	1.4×10^8	5.7×10^8	8.5×10^8	2.0×10^9	2.0×10^9	2.0×10^9	N/A
Energy equivalents									
Construction	bbl	36,100	11,900	50,000	75,000	520,000	581,800	533,800	+65,000
Fill/withdrawal (five cycles)	bbl	270,000	90,000	357,000	530,000	1,250,000	1,250,000	1,250,000	N/A
Oil losses	bbl	45,000	15,000	60,000	90,000	210,000	210,000	210,000	N/A
Percent of potential storage capacity	%	0.23	0.23	0.23	0.23	0.28	0.28	0.28	N/A
Potential storage capacity (five cycles)	MMB	150	50	200	300	700	700	700	N/A
Labor									
Manpower for construction	man years	30	10	30	30	415	465	465	+30
Manpower for operation	man years	10	0	10	10	450	450	450	N/A
Capital									
Construction	(1980 $)	25×10^6	10×10^6	30×10^6	35×10^6	245×10^6	250×10^6	250×10^6	$+2 \times 10^6$
Operation (range/year)	(1980 $)	No additional cost		No additional cost		$1.7\text{-}8.8 \times 10^6$	$2.1\text{-}11 \times 10^6$	$2.1\text{-}11 \times 10^6$	+25%

[1]West Hackberry alternatives - Preferred - Additional 30 MMB of storage capacity.
Alternative - Additional 10 MMB of storage capacity.

[2]Bryan Mound alternatives - Preferred - Additional 40 MMB of storage capacity.
Alternative - Additional 60 MMB of storage capacity.

[3]Big Hill alternatives - Preferred - 140 MMB storage with oil pipeline to Sun Terminal, diffuser to 3.5-mile site.
Pipeline 1 - 60-mile crude oil pipeline to OTTI (preferred site with this pipeline only).
Pipeline 2 - 54-mile crude oil pipeline to Pelican Island Terminal (preferred site with this pipeline only).
Pipeline 3 - Extended diffuser location (9 miles further off shore) (additional on preferred site).

	System Pipeline ROWs				
	Onsite	Oil	Brine	Raw water	Total
Big Hill, pipeline to OTTI	250[1]	545	36[1]	48[1]	879
Big Hill, pipeline to Pelican Island Terminal tank farm	250[1]	491	36[1]	48[1]	825
Big Hill, pipeline to Sun Terminal and OTTI	250[1]	754	36[1]	48[1]	1,088

	System Pipeline ROWs				
	Onsite	Oil	Brine	Raw Water	Total
Big Hill, pipeline to Sun Terminal and Pelican Island Terminal tank farm	250[1]	700	36[1]	48[1]	1,034
Big Hill, alternative diffuser location	No change in land commitment				
West Hackberry, 10-MMB addition	N/C	N/C	N/C	N/C	0
Bryan Mound, 60-MMB addition	N/C	N/C	N/C	N/C	0

Losses in biological and agricultural production resulting from construction would be short-term, generally lasting less than 3 years. Permanent production losses would occur at the facility site where buildings, tanks, and other permanent structures would be erected. Spoil banks and other "filled" areas created in wetland-aquatic habitats would alter the habitat. Biological productivity would be temporarily reduced, and different life forms would eventually recolonize and contribute to the land's productivity.

Along pipeline routes, land would be returned to former uses after construction, except for routes through wooded areas where the ROW would be maintained. A large portion of acreage at the sites would not be disturbed beyond the construction period.

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[1]Same as preferred action.

8.3 AIR

During construction and operation of the three proposed Phase III sites, the commitment of air resources would be intermittent and would result in temporary lowering of air quality. Uncontrolled venting from the oil-brine separators during leaching and oil fill and from the terminals during the transfer of oil would result in sizable releases of hydrocarbon vapors. Other minor emissions include fugitive dust from site preparation and the use of unpaved roads; diesel exhaust (CO, NO_x, and aldehydes) from construction equipment; and hydrocarbon emissions from light-duty vehicles, drilling rigs, painting operations, and ship ballasting. Any reduction in air quality would cease when the project was terminated; therefore, no irreversible commitments of air resources in the region would occur from the proposed Phase III expansion.

8.4 WATER

Expansion of the Bryan Mound and West Hackberry sites and the development of the Big Hill site to a Phase III capacity of 212 MMB would require a commitment of water resources approximately eight times the volume of the caverns. During withdrawal operations, additional water resources would be required for the displacement of crude oil. Displacement water requirements are about 5 percent greater than the volume of the displaced oil. A summary of water requirements for the preferred action (including five fill/withdrawal cycles) is:

Phase III Water Use (MMB)

Site	Leaching	Displacement	Source
Big Hill	1,120	735	ICW
West Hackberry	240	158	ICW
Bryan Mound	320	210	Brazos River Diversion Channel
Total	1,680	1,103	

Water requirements for the Phase III alternative actions vary only because of storage capacity differences (i.e., no difference at the Big Hill site). These requirements are:

Site	Water Use (MMB) Leaching	Displacement
West Hackberry	80	53
Bryan Mound	480	315
Total	560	368

After the water is drawn from the original source and used for either leaching or displacement, it would be transported to the Gulf of Mexico for disposal. Because water "cycles" through the environment, it is not permanently lost from the system. Thus, disposing of water saturated with salt in the Gulf of Mexico would not constitute either an irreversible or irretrievable commitment of resources. The water would simply be unavailable for other purposes until it was "cycled" back to its present state.

8.5 SPECIES AND ECOSYSTEMS

Construction of the proposed Phase III crude oil storage facilities and the associated pipelines would result in some habitat alterations. During construction, there would be a temporary displacement and/or loss of plants and animals from onshore and offshore pipeline ROWs and on the sites, which are currently used for pasture. Oil-fill operations and resulting brine disposal would also temporarily affect marine biota. Effects during standby operation would be minimal.

The cumulative effects of facility construction and operation on the biotic community would be minimal to insignificant, in light of the total productivity of the area. No endangered, threatened, or unique wildlife or vegetation species would be adversely affected by the proposed action.

8.6 MATERIAL

8.6.1 Construction Materials

Most of the concrete, steel, and other construction materials may be physically, although not economically, salvageable. However, for this project, these materials are considered an irretrievable commitment of resources. Estimates of construction materials for the preferred Phase III development and the alternatives are:

Site	Steel (tons)	Concrete (ft^3)
Big Hill, 140 MMB	24,200	85,000
Big Hill, oil pipeline to Sun Terminal	22,800	115,000
Bryan Mound, 40 MMB	850	6,400
West Hackberry, 30 MMB	640	4,800

Site	Steel (tons)	Concrete (ft^3)
Big Hill, pipeline to OTTI	52,500	307,400
Big Hill, pipeline to Pelican Island Terminal	47,000	277,000
Big Hill, oil pipeline to Sun Terminal and OTTI	75,300	422,400
Big Hill, oil pipelines to Sun Terminal and Pelican Island Terminal tank farm	69,800	392,000
Big Hill, alternative diffuser location	+7,900[1]	+46,100[1]
West Hackberry, 10 MMB	220	1,600
Bryan Mound, 60 MMB	1,270	9,600

[1]Additional material in conjunction with the preferred site development.

8.6.2 Salt

Offshore disposal of brine from solution mining irreversibly commits the salt dome and the solid salt resource. However, many other salt domes and layered deposits are available throughout the country, and the salt committed in the proposed action would not significantly impact total availability. The irreversible commitment of salt for the Phase III development is shown below:

Site	Salt (tons)
West Hackberry, 30 MMB	11×10^6
Big Hill, 140 MMB	53×10^6
Bryan Mound, 40 MMB	15×10^6
West Hackberry, 10 MMB	4×10^6
Bryan Mound, 60 MMB	23×10^6

8.6.3 Oil

For each fill/withdrawal cycle planned for the SPR program, about 0.03 percent of the total oil stored would be lost because of incomplete recovery (0.0046 percent), evaporation (0.023 percent), and spills (0.0006 percent). This loss must be considered an irretrievable commitment of oil resources. The extent of this commitment for five storage cycles is shown below:

Site	Oil Lost (10^3 bbl) (five cycles)
West Hackberry, 30 MMB	45
Big Hill, 140 MMB	210
Bryan Mound, 40 MMB	60
West Hackberry, 10 MMB	15
Bryan Mound, 60 MMB	90

8.7 ENERGY

The energy consumed during site construction and operation includes the energy required to supply materials, prepare and operate the site, and transport the crude oil. The energy used is irretrievable. The commitment of energy and the equivalent volume of oil that it represents are shown below:

West Hackberry, Preferred (30-MMB Addition)

Usage	Energy (kWh)	Equivalent Oil (bbl)[1]
Leaching	4.9×10^7	30,600
Fill/withdrawal (five cycles)	4.3×10^8	270,000
Concrete[2]	1.3×10^6	800
Steel[3]	7.5×10^6	4,700
Total	4.9×10^8	306,100

[1]1600 kWh/bbl.

[2]Concrete production requires 9×10^5 Btu/ft^3 for manufacture.

[3]Steel production requires 40×10^6 Btu/ton for manufacture.

Big Hill, Preferred

Usage	Energy (kWh)	Equivalent Oil (bbl)[1]
Leaching	2.3×10^8	143,800
Fill/withdrawal (five cycles)	2.0×10^9	1,250,000
Concrete[2]	5.3×10^7	33,000
Steel[3]	5.5×10^8	344,000
Total	2.8×10^9	1,770,800

Bryan Mound, Preferred (40-MMB addition)

Usage	Energy (kWh)	Equivalent Oil (bbl)[1]
Leaching	6.8×10^7	42,500
Fill/withdrawal (five cycles)	5.7×10^8	357,000
Concrete[2]	1.7×10^6	1,000
Steel[3]	1.0×10^7	6,500
Total	6.5×10^8	407,000

West Hackberry, Alternative (10-MMB addition)

Usage	Energy (kWh)	Equivalent Oil (bbl)[1]
Leaching	1.6×10^7	10,000
Fill/withdrawal (five cycles)	1.4×10^8	90,000
Concrete[2]	4.2×10^5	300
Steel[3]	2.5×10^6	1,600
Total	1.6×10^8	101,900

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[1]1600 kWh/bbl.

[2]Concrete production requires 9×10^5 Btu/ft^3 for manufacture.

[3]Steel production requires 40×10^6 Btu/ton for manufacture.

Bryan Mound, Alternative (60-MMB addition)

Usage	Energy (kWh)	Equivalent Oil (bbl)[1]
Leaching	1.0×10^8	63,800
Fill/withdrawal (five cycles)	8.6×10^8	537,000
Concrete[2]	2.5×10^6	1,600
Steel[3]	1.5×10^7	9,500
Total	9.8×10^8	611,900

Big Hill, Alternative

The alternative pipelines at Big Hill would mainly affect the energy requirements for concrete and steel production. The following additions of irreversible energy commitments would be realized if the alternative actions are taken:

Action	Energy (kWh)	Equivalent Oil (bbl)[1]
Pipeline to OTTI	7.0×10^8	438,000
Pipeline to Pelican Island Terminal	6.2×10^8	390,000
Extended brine diffuser location	1.1×10^8	65,500
Combination pipelines to Sun Terminal and OTTI	9.9×10^8	619,000
Combination pipelines to Sun Terminal and the Pelican Island Terminal	9.2×10^8	575,000

These tabulations indicate that about 9.4×10^8 kWh would be used in the construction of the preferred Phase III SPR expansion, and 3.0×10^9 kWh would be expended in handling the oil through five storage cycles. In terms of crude oil equivalence (1,600 kWh/bbl), the potential oil resource commitment as a percentage of the 1,050-MMB (five cycles @ 210 MMB) Phase III capacity is:

11600 kWh/bbl.

2Concrete production requires 9 x 105 Btu/ft3 for manufacture.

3Steel production requires 40 x 106 Btu/ton for manufacture.

Construction	0.06% of potential cavern capacity	625,000 bbl
Operation (5 cycles)	0.18% of potential cavern capacity	1,877,000 bbl
Oil lost (5 cycles)	0.03% of potential cavern capacity	315,000 bbl
Total	0.27% of 1,050 MMB capacity	2,817,000 bbl

8.8 LABOR

To construct the Phase III portion of the SPR facilities and to operate them for 20 years would require the following amounts of labor (over the Phase I and II labor), measured in man-years of effort:

Site	Total	Construction	Operation[1]
West Hackberry, 30 MMB	40	30	10
West Hackberry, 10 MMB	30	30	5
Big Hill, 140 MMB	865	415	450
Big Hill, with alternative pipelines	915	465	450
Bryan Mound, 40 MMB	40	30	10
Bryan Mound, 60 MMB	40	30	10

The use of this labor represents an irretrievable resource commitment since the labor services consumed would not be available for other activities.

8.9 CAPITAL

The cost incurred during construction and operation of the Phase III SPR facilities (in millions of 1980 dollars) is shown below:

Site	Construction	Operation (range/year)
West Hackberry, 30 MMB	25	No additional cost[2]
West Hackberry, 10 MMB	10	No additional cost[2]
Big Hill, 140 MMB	245	1.7 - 8.8
Big Hill, with alternative pipelines	250	+ 25%
Bryan Mound, 40 MMB	30	No additional cost[2]
Bryan Mound, 60 MMB	35	No additional cost[2]

These figures do not include the value of the stored oil, the costs associated with oil transport, or the cost of land. These capital costs are irretrievable since material costs, energy costs, and labor costs are essentially irretrievable.

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[1]Assumes 38-month fill and five cycles over 20 years.

[2]Same cost incurred in operating the Phase I and II portions of the site.

8.10 SUMMARY

Irreversible or irretrievable commitments of resources, resulting from the construction and operation of the proposed Phase III additions, include the loss of environmental productivity along pipeline ROWs, on and off shore, and at the site; destruction of organisms and marsh and terrestrial vegetation; the commitment of steel and concrete, which has limited secondary-use potential; consumption of energy and labor services; and the use of capital resources.

9.0 CONSULTATION AND COORDINATION

9.1 AGENCIES INVOLVED IN REVIEW AND ISSUANCE OF ENVIRONMENTAL PERMITS, LICENSES, OR APPROVALS

A number of Federal, state, and other agencies must be consulted about the proposed action. The Department of Energy (DOE) is coordinating planning efforts with various agencies to avoid adverse impacts to the environment potentially affected by the project. Agencies involved in consultation and coordination efforts and a brief summary of their jurisdictional concerns relevant to the proposed action are presented in Table 9-1. As required under Sect. 7 of the Endangered Species Act of 1973, formal consultation was initiated with the U.S. Fish and Wildlife Service and the National Marine Fisheries Service for the review of DOE's biological assessment of the proposed project. Letter responses are presented in Appendix D.

9.2 DISTRIBUTION OF DRAFT SUPPLEMENT ENVIRONMENTAL IMPACT STATEMENT

Comments on the Draft Supplement Environmental Impact Statement were requested from the Federal, state, and local agencies and organizations listed in Table 9-2. Notice of availability and a request for comments from interested parties were published in the Federal Register on May 8, 1981. Copies of this document were also sent to libraries and organizations and individuals on DOE's Technical Information Center standard distribution list. Property owners adjacent to Big Hill and West Hackberry were sent copies of the draft.

9.3 PARTIES FROM WHOM COMMENTS WERE RECEIVED

Comments received on the Draft Supplement Environmental Impact Statement are addressed herein. Copies of the letters of comment are presented in Appendix J.

9.3.1 Advisory Council on Historic Preservation

Comment 1: The environmental statement must demonstrate that either of the following conditions exists:

- No properties included in or that may be eligible for inclusion in the National Register of Historic Places are located within the area of environmental impact and the undertaking will not affect any such property.

- Properties included in or that may be eligible for inclusion in the National Register of Historic Places are located within the area of environmental impact, and the undertaking will or will not affect any such property. If there will be an effect, compliance with Sect. 106 of the National Historic Preservation Act must be evidenced in the Final Impact Statement.

Table 9-1. Federal, state, and other agencies involved in consultation for the development of SPR facilities at Big Hill (140 MMB) and the expansion of existing SPR facilities at West Hackberry and Bryan Mound (70 MMB, collectively).

Agency	Executive administrator	Site under jurisdiction	Brief summary of jurisdictional concerns applicable to project
FEDERAL			
U.S. Environmental Protection Agency Region VI, Dallas, Texas	Regional Administrator	All three sites	Protection of the nation's air, water, and land resources. Certify state programs for the environmental control of waste discharges or emissions. In proposed action, involved in the following: --Certifies compliance with Sect. 402 of the Federal Water Pollution Control Act, as amended by the Clean Water Act of 1977 and the Ocean Discharge Criteria of 1980. --Certifies compliance with Sect. 403 required by same. This section is concerned with NPDES permits for ocean discharge --Reviews Sect. 404 permits required by same. This section is concerned with the discharge of dredged or fill material into navigable waters --Certifies compliance with the Clean Air Act Amendments of 1977 through a state agency with approved State Implementation Plan (SIP) --Reviews Spill Prevention, Control, and Countermeasure Plan (SPCC) for each oil handling facility --Certifies compliance with the Resource Conservation and Recovery Act of 1976, as amended through 1980
U.S. Department of the Army U.S. Army Corps of Engineers, Galveston District, Galveston, Texas New Orleans District, New Orleans, Louisiana	District Engineer	Big Hill, Bryan Mound West Hackberry	Jurisdiction over navigable waters. Issues permits for activities affecting navigable waters. In proposed action, involved in the following: --Discharge of dredged or fill material (Sect. 404 of the Water Pollution Control Act, as amended by the Clean Water Act of 1977) --Construction in wetlands and on floodplains --Construction of fixed structures on the continental shelf --Review of floodplain/wetland assessments prepared in response to Executive Orders 11988 and 11990 --Issues permit for Sect. 10 of Rivers and Harbors Act, 33 USC 1344
U.S. Department of Transportation Materials Transportation Bureau, Office of Pipeline Safety Operations, Southwest Region, Houston, Texas	Regional Chief	All three sites	Establishes and provides for enforcement of safety standards for the transportation of hazardous materials by pipeline that is either in or affects interstate commerce
U.S. Coast Guard, 8th Coast Guard District, New Orleans, Louisiana	District Commander	All three sites	Jurisdiction over all oil transfer operations. Receives notification of occurrence of oil spills and delegates responsibility for cleanup

Table 9-1. (continued)

Agency	Executive administrator	Site under jurisdiction	Brief summary of jurisdictional concerns applicable to project
FEDERAL (continued)			
U.S. Department of the Interior U.S. Fish and Wildlife Service (USFWS), Region II, Albuquerque, New Mexico	Regional Director	Big Hill, Bryan Mound	Protection of fish and wildlife. The involvement of the USFWS in this project is summarized below: --Under the Fish and Wildlife Coordination Act, DOE must discuss the proposed action with the USFWS. Wetland protection is an important issue in this project --Under the Endangered Species Act of 1973, the project must not impact habitat critical to the continued existence of Federally protected (threatened or endangered) species --Under the Migratory Bird Treaty Acts, actions that harm or disturb the behavior patterns of migratory birds (important in wetlands) are not permitted --Involved in review of Sect. 402 and 404 permits --Reviews floodplain/wetland assessments prepared in response to Executive Orders 11988 and 11990 --Reviews Sect. 10 obstruction to navigation permits, as specified in the Rivers and Harbors Act 33, USC 1344.
Region IV, Altanta, Georgia		West Hackberry	
USFWS, Region II, National Wildlife Refuge Area office, Austin, Texas --and-- Refuge Management Office, Anahuac, Texas	Area Manager Refuge Manager	Big Hill (nearby McFaddin National Wildlife Refuge)	A national wildlife refuge program has been established under the Federal Land Policy and Management Act. Refuge use permit must be obtained for crossing McFaddin with the brine disposal pipeline
USFWS, Region IV, National Wildlife Refuge Area Office, Jackson, Mississippi --and-- Refuge Management Office, Hackberry, Louisiana	Area Manager Refuge Manager	West Hackberry (nearby Sabine National Wildlife Refuge)	
Bureau of Land Management, Gulf of Mexico and Florida Outer Continental Shelf Office, New Orleans, Louisiana		All sites	Jurisdiction over offshore activities, primarily oil and gas leasing on the Outer Continental Shelf
Heritage Conservation and Recreation Service (HCRS), Texas Parks and Wildlife Department, Austin, Texas	HCRS State Liaison Officer	Big Hill, Bryan Mound	Protection of archaeological, historical, cultural, and natural resources. The National Historic Preservation Act of 1966, 30 other laws, executive orders and agreements are designed to assure historic preservation, natural resource conservation, and adequate opportunities for recreation. Consulted about the existence of wild and scenic rivers according to the Wild and Scenic Rivers Act, as amended 1978
Louisiana Department of Culture, Recreation and Tourism, Baton Rouge, Louisiana	HCRS State Liaison Officer	West Hackberry	

Table 9-1. (continued)

Agency	Executive administrator	Site under jurisdiction	Brief summary of jurisdictional concerns applicable to project
FEDERAL (continued)			
U.S. Department of Agriculture Soil Conservation Service Temple, Texas	State Conservationist	Big Hill, Bryan Mound	Can provide information on prime farmland in the impacted area. Policy statement made by the Council on Environmental Quality (CEQ) requires DOE to preserve prime farmlands during construction and operation of project
Soil Conservation Service, Alexandria, Louisiana	State Conservationist	West Hackberry	
U.S. Department of Commerce National Oceanic and Atmospheric Administration (NOAA), National Marine Fisheries Service, Southeast Region, St. Petersburg, Florida	Regional Director	All three sites	Protection of marine fisheries as directed by the Marine Mammals Protection Act of 1972; the Marine Protection, Research and Sanctuaries Act of 1972; the Endangered Species Act of 1973; the Offshore Shrimp Fisheries Act of 1973; and the Fish and Wildlife Coordination Act of 1973
NOAA Office of Coastal Zone Management, Louisiana State Program in Department of Natural Resources, Baton Rouge, Louisiana	Unit Director	West Hackberry	Planning and management of coastal areas according to the Coastal Zone Management Act of 1972
U.S. Department of Labor Occupational Safety and Health Administration, Region VI, Dallas, Texas	Regional Administrator	All three sites	Jurisdiction over the development, promulgation, and compliance of health and safety regulations of the Occupational Safety and Health Act of 1970
U.S. Department of Housing and Urban Development Federal Insurance Administration, Region VI, Dallas, Texas	Regional Director	All three sites	Administers the National Flood Insurance Program as specified by the National Flood Insurance Act of 1968, as amended, and Flood Disaster Protection Act of 1973
Area Office, Dallas, Texas	Area Director	Big Hill, Bryan Mound	Provides information on extent of floodplains useful in preparing floodplain/wetland assessment
Area Office, New Orleans, Louisiana	Area Director	West Hackberry	
National Advisory Council on Historic Preservation, Western States Office, Denver, Colorado	Executive Secretary		Must be consulted by DOE to ensure that proposed action will not adversely affect historical or cultural resources. Consultation is required by the National Preservation Act of 1966

Table 9-1. (continued)

Agency	Executive administrator	Site under jurisdiction	Brief summary of jurisdictional concerns applicable to project
STATE			
Texas (Austin)		Big Hill, Bryan Mound	
Texas Department of Water Resources,	Executive Director		Protection of state's water resources; implement the rules, regulations and laws relating to water. Specific to the proposed action are the following: --Issues NPDES permits for discharge of wastes --Issues permit for water appropriation --Issues regulations or control measures for activities that are inherently capable of causing spillage or accidental discharge of polluting substances. Must be informed of any spills or accidents that occur --Reviews Sect. 404 permit applications --Administers an industrial solid waste program --Administers national flood insurance laws
Texas Water Development Board	Chairperson (judicial functions)		
--and--			
Texas Water Commission	Chairperson (administrative and legislative functions)		
Texas Air Control Board	Executive Director		Administers state's clean air laws to control and abate air pollution. Specific to the proposed action is the issuance of permits for construction and operation of onsite and offsite facilities that emit air contaminants
Texas Department of Health, Bureau of Environmental Health	Commissioner of Health		Administers the state's solid waste management program and implements safety and health programs for places of employment
Texas General Land Office	Commissioner		Issues easements required to use state-owned lands for pipeline installation. Approves rights-of-way (ROWs) for pipelines crossing public lands
Texas Parks and Wildlife Department	Executive Director		Protection of recreational areas within the state; protection of wildlife and their habitats. Specific to the proposed action are the following: --Protection of animals and plants not listed as threatened or endangered on the Federal list --Protection of beaches --Review of Sect. 404 permit applications
Texas Railroad Commission, Oil and Gas Division	Commissioner		Issues permits for drilling. Issues permits for oil pipelines. Receives reports on oil storage and pipeline operations from agencies with permits.
Texas State Department of Highways and Public Transportation, Right-of-Way Division	Director		Involved with policies and procedures for ROWs for pipelines crossing highways
Texas Historical Commission			
Affiliates of Commission:			
Texas Antiquities Committee	Chairperson		Issues permits for salvage excavation on study of archaeological resources within the state
--and--			
Texas Historical Development Council	Chairperson		Coordinates efforts of member agencies; develops resources within the state

Table 9-1. (continued)

Agency	Executive administrator	Site under jurisdiction	Brief summary of jurisdictional concerns applicable to project
STATE (continued)			
Texas Coastal and Marine Council	Chairperson		Assists in comprehensive assessment and planning for coastal resources management and other marine-related affairs affecting the state
Texas State Board of Insurance, Office of the State Fire Marshall	Fire Marshall		Involved in a variety of functions regarding fire prevention
Louisiana (Baton Rouge)		West Hackberry	
Louisiana Department of Natural Resources	Assistant Secretary		Will assume authority when such authority is delegated for administration of permit programs for the regulation of air quality, water pollution control, solid waste disposal, hazardous waste management, and coastal zone management.
Office of Environmental Affairs--	Assistant Secretary		
(1) Air Quality Control Division	Administrator		
(2) Water Pollution Control Division	Administrator		
(3) Solid Waste Division	Administrator		
(4) Hazardous Waste Division	Administrator		
Office of Conservation--	Assistant Secretary		Issues permits for drilling operations
Permits Section	Administrator		
Office of the Secretary--	Assistant Secretary		Jurisdiction over any state lands affected by the project
Division of State Lands	Administrator		
Louisiana Department of Wildlife and Fisheries, New Orleans	Secretary		Jurisdiction over state's natural resources; mandated to protect, conserve, and replenish wildlife and fishery resources; consulted for operations such as dredging
Louisiana Department of Transportation and Development, Office of Public Works	Assistant Secretary		Issues additional construction permits as necessary
Louisiana Department of Culture, Tourism and Recreation, Office of Program Development, Division of Archaeology and Historical Preservation	State Historical Preservation Officer		Responsible for historical, cultural, and archaeological resource preservation
Louisiana Department of Public Safety, Office of Fire Protection	Assistant Secretary		Administers state laws for fire protection

Table 9-1. (continued)

Agency	Executive administrator	Site under jurisdiction	Brief summary of jurisdictional concerns applicable to project
REGIONAL			
Texas			
Planning Councils			
Southeast Texas Regional Planning Commission, Nederland	Executive Director	Big Hill	Involved in environmental quality planning, land resource management planning, transportation planning, and other functions
Houston/Galveston Area Council, Houston	Executive Director	Bryan Mound	
River Authorities			
Lower Neches Valley Authority, Beaumont	Executive Director	Big Hill	Functions and serves in the area of water conservation and supply
Sabine River Authority, Orange	Executive Director	Big Hill	Functions and serves in the areas of water conservation and supply, water quality control, data collection, recreation and hydro-electric power
Brazos River Authority, Waco	Executive Director	Bryan Mound	Functions and serves in the areas of flood control, water conservation and supply, water quality control, data collection, recreation, and hydroelectric power
Louisiana			
Imperial Calcasieu Regional Planning and Development Commission, Lake Charles		West Hackberry	Involved in resource and transportation planning
LOCAL			
Texas			
Jefferson County Commissioners Court, Beaumont		Big Hill	Issues permits for crossings of county roads and property
Jefferson County Drainage District 7		Big Hill	Issues permits for crossing drainage ditches
Jefferson County Department of Environmental Control, Beaumont		Big Hill	Reviews and approves location and design of septic system
Brazoria County Commissioners Court, Angleton		Bryan Mound	Issues additional construction permits or modifications of existing ones as necessary

Table 9-1. (continued)

Agency	Executive administrator	Site under jurisdiction	Brief summary of jurisdictional concerns applicable to project
LOCAL (continued)			
Velasco Drainage District		Bryan Mound	Issues additional construction permits or modifications of existing ones as necessary
Brazoria County Health Department, Angleton		Bryan Mound	Approves additional septic systems as necessary
Louisiana			
Cameron Parish Police Jury, Cameron	Secretary	West Hackberry	Issues additional construction permits as necessary
OTHER - INTERSTATE			
Sabine River Compact Commission, c/o Texas Department of Water Resources, Austin, Texas	Commissioners	Big Hill	Involved in planning, appropriation, and development of Sabine River and its tributaries
Gulf States Marine Fisheries Commission, Ocean Springs, Mississippi	Commissioners	All three sites	Involved in interstate pact for proper utilization of Gulf's fishery resources
Gulf of Mexico Fishery Management Council, Tampa, Florida	Executive Director	All three sites	Involved in management of fishery resources within the Gulf of Mexico
Migratory Bird Conservation Commission, Washington, D.C.	Commissioners	All three sites	Involved in selection of lands for migratory bird refuges in the National Wildlife Refuge System according to the Migratory Bird Conservation Act of 1929
OTHER - INTERNATIONAL			
Marine Mammal Commission, Washington, D.C.	Chairperson	All three sites	Reviews status of and makes recommendations for marine mammal populations; established by the Marine Mammal Protection Act of 1972
Inter-Governmental Maritime Consultive Organization, London, England	Director General	All three sites	Develops regulations for oil discharges

Table 9-2. Federal, state and local agencies and organizations from whom comments on the Draft Supplement Environmental Impact Statement were requested.

GOVERNMENT AGENCIES AND OFFICIALS

Council on Environmental Quality
Department of Agriculture
Department of the Army, Corps of Engineers
Department of Commerce
Department of Defense
Department of Education
Department of Health and Human Resources
Department of Housing and Urban Development
Department of Interior
Department of Labor
Department of State
Department of Transportation
Department of Treasury
Environmental Protection Agency
Federal Energy Regulatory Commission
Interstate Commerce Commission
National Oceanic and Atmospheric Administration
National Science Foundation
Nuclear Regulatory Commission
Tennessee Valley Authority
U.S. Coast Guard
U.S. Senate Appropriations Committee,
   Subcommittee on Interior and Related Agencies
U.S. Senate Committee on Energy and Mineral Resources,
   Subcommittee on Energy and Natural Resources
U.S. House of Representatives Appropriations Committee,
   Subcommittee on Interior and Related Agencies
U.S. House of Representatives Energy and Commerce Committee,
   Subcommittee on Fossil and Synthetic Fuels
Governor, State of Louisiana
Governor, State of Texas
U.S. Senators, State of Louisiana
U.S. Senators, State of Texas
U.S. Congressional Delegation from affected districts, State of Louisiana
U.S. Congressional Delegation from affected districts, State of Texas
State Clearinghouses of: Alabama, Arkansas, Florida, Kentucky,
   Louisiana, Mississippi, Ohio, Oklahoma, and Texas
Brazoria County, Texas
Cameron Parish, Louisiana
Chambers County, Texas
Galveston County, Texas
Harris County, Texas
Jefferson County, Texas
Louisiana Department of Health and Human Resources
Louisiana Department of Natural Resources

Table 9-2 (continued)

Louisiana Department of Wildlife and Fisheries
Texas Department of Health
Texas Department of Parks and Wildlife
Texas Department of Water Resources
Texas Historical Commission

ORGANIZATIONS AND INTERESTED PARTIES

American Fisheries Society
American Industrial Hygiene Association
American Littoral Society
American Petroleum Institute
Appalachian Regional Commission
Audubon Naturalist Society of the Central Atlantic States
Center for Law and Social Policy
Center for Natural Areas
Center for Urban Environmental Studies
Center for Wetlands Resources
Chamber of Commerce of the United States of America
Clean Water Action Project
Consumer Action Now, Inc.
Council on Economic Priorities
Defenders of Wildlife
Dow Chemical
Ecology Center of Louisiana, Inc.
Electric Power Research Institute
Environmental Action Foundation, Inc.
Environmental Action, Inc.
Environmental Defense Fund, Inc.
Environmental Fund, Inc.
Environmental Law Institute
Environmental Policy Center
For the People, Inc.
Friends of the Earth
Funds for Animals, Inc.
Gulf States Marine Fisheries Commission
Institute of Gas Technology
Institute of Medicine
International Association of Fish and Wildlife Agencies
International Institute for Environment
Interstate Natural Gas Association
Izaak Walton League of America
League of Conservation Voters
League of Women Voters
Louisiana Offshore Terminal Authority
National Academy of Engineering
National Academy of Sciences
National Association of Counties
National Audubon Society
National League of Cities

Table 9-2 (continued)

National Parks and Conservation Association
National Research Council
National Water Resources Association
National Wetlands Technical Council
National Wildlife Federation
Natural Resources Defense Council, Inc.
Nature Conservancy
North American Wildlife Foundation
Public Interest Research Group
Renewable Natural Resources Foundation
Resources for the Future
Scientist's Institute for Public Information
Seadock, Inc.
Sierra Club
Sport Fishing Institute
Standard Oil Company of California
Texas Environmental Coalition
Texas Offshore Port
U.S. Conference of Mayors
Water Pollution Control Federation
Water Resources Council
Wilderness Society
Wildfowl Foundation
Wildlife Society
World Wildlife Fund
Zero Population Growth, Inc.

Response: Sections of the document (3.2.1.7, 3.2.2.7, 3.2.3.7, 3.2.4.7, 4.2.7, 4.3.2.7, and 4.4.7) dealing with the presence or absence of properties eligible for the National Register of Historic Places have been amended to include statements emphasizing DOE's commitment to compliance with the National Historic Preservation Act of 1966 (16 USC Sect. 470f, as amended, 90 Stat. 1320). No sites listed or proposed for inclusion in the National Register of Historic Places were identified.

9.3.2 U.S. Department of Agriculture, Farmers Home Administration

Comment 1: The Oyster Creek Municipal Utility District derives its water from a freshwater formation 250 to 300 ft deep located about 3 miles north of Bryan Mound. Extreme care should be taken to ensure the purity of this freshwater aquifer.

Response: All waters used in developing caverns of the Bryan Mound SPR site would be derived from the Brazos River and would not influence groundwaters (see Sect. 2.2.1.1 and Appendix J, letter from the Texas Department of Water Resources). No fresh groundwaters would be utilized for oil recovery. All caverns are monitored and pressure-tested to ensure integrity before they are filled with oil. Caverns would be below the depth of the aquifer (separated by an aquaclude) being used by the Oyster Creek Municipal Utility District.

9.3.3 U.S. Department of the Air Force

Comment 1: There is no apparent environmental interaction between the Phase III expansion of the SPR and any Air Force activities in the project area.

Response: Comment noted.

9.3.4 Texas Historical Commission

Comment 1: The document does not indicate which properties, if any, are eligible for inclusion in the National Register for Historic Places. Statements regarding the National Register of Historic Places must be contained in the document.

Response: Statements concerning the National Register of Historic Places have been added to the appropriate sections of the document (see also Sect. 9.3.1).

9.3.5 U.S. Department of Transportation, Federal Highway Administration

Comment 1: The proposed project would not significantly affect any projects or programs under the Department of Transportation's jurisdiction.

Response: Comment noted.

9.3.6 U.S. Department of Housing and Urban Development

Comment 1: The Department has no specific comments on the Draft Supplement.

Response: Comment noted.

9.3.7 U.S. Department of Agriculture, Soil Conservation Service

Comment 1: Conversion of up to 34 acres of prime farmland at the West Hackberry site should be addressed by the impact statement.

Response: Statements regarding the conversion of prime farmlands at the West Hackberry site have been included in Sects. 3.2.4.1 and 4.4.1 and in Table 6-1.

9.3.8 Gulf of Mexico Fishery Management Council

Comment 1: Our principal comments concern the effect of the brine discharge on penaeid shrimp populations and the shrimp fishery in the affected areas. In particular, the generalities (8-11) on page 3-20 appear misleading in their implications. While there is little spawner-recruit relationship, long or short-term destruction of shrimp habitat (estuarine or spawning areas) should be minimized. The draft supplement should at least acknowledge this habitat alteration. Generalities 9 and 10, which appear to justify such alteration, are quite contradictory in relating the overcapacity of the environment (#9) to the oversupply of postlarvae (#10). Furthermore, a review of the references in Appendix G (Berry and Baxter, 1969; Truesdale, 1970) does not substantiate generality #8 that all stages of the penaeid life cycle can tolerate wide ranges of salinty, which is the key issue of the brine discharge.

Response: Most of these concerns are addressed in responses to National Marine Fisheries Service (NMFS) concerns (see Sect. 9.3.17). No long-term habitat alteration is expected from brine discharge, especially beyond the 100-m release zone. Most commercially important species of the northwest Gulf of Mexico can tolerate the salinity increases expected, as indicated by the Bryan Mound plume monitoring results.

The impact statement did not intend to imply a relationship between generality 9 and generality 10. Generality 9 refers to impacts on catch, whereas generality 10 refers to lack of importance of site-specific impacts on the supply of postlarvae produced by the brood stock.

The study by Berry and Baxter (1969) deals with the prediction of shrimp landings based on postlarval catch. It was not referenced in the discussion of salinity relationships presented in Appendix G. Truesdale (1970) discusses the relationship between shrimp occurrence and salinity in Trinity Bay ranging from freshwater to 15.6 ppt. There are numerous references in Appendix G to the occurrence of penaeid shrimp in salinities varying from fresh to hypersaline water. The section was reorganized to help clarify any misunderstandings.

Comment 2: The section on environmental impacts on penaeid shrimp (Section 4.2.5.2, page 4-25) again uses the faulty generalizations cited above to conclude that actual catches will not decrease, but will be made up from adjacent areas. The same "heavy commercial exploitation of shrimp stocks" cited on the bottom of page 4-25 may well invalidate this conclusion. The shift in fishing effort from the affected discharge areas to adjacent areas with existing "heavy exploitation" will either divide up the limited resources or result in proportionately less increase in catch for the same increase in effort.

Response: Penaeid shrimp are very mobile organisms, with their offshore distribution determined as much by ambient salinity levels as any other factor. They are not tied to any particular local area of the Gulf. As such, it is erroneous to attempt to relate decreases in shrimp production to a particular area.

Comment 3: The section on socioeconomic impacts on penaeid shrimp (Section 4.2.8, page 4-33) describes the potential costs in terms of lost revenue to the shrimp industry under various cases. This section should be very helpful to decisionmakers; however, a question arises as to the purpose of this section. Since all other entities will be compensated for direct impacts of the SPR project, does this section develop a basis for compensation to affected fishermen?

Response: The reason for Sect. 4.2.8, page 4-33, was to explain various possible economic impacts, but not to provide a quantified basis for compensation. Much of any impact statement deals with several scenarios and expected or potential consequences, so that, as noted, decisionmakers are better aware of the potential consequences of their actions. Every consequence, however, of a Government project is not compensable. Compensation to individuals or other entities from any Federal project is governed by the United States Constitution and Federal statutes. Each case is considered on its own merits and based on the applicable laws.

9.3.9 U.S. Department of Commerce, Maritime Administration

Comment 1: The discussion in Sect. 4.3.1, Oil Spill Risk, should be updated to reflect present U.S. Coast Guard regulations and Intergovernmental Maritime Consultative Organization conventions.

Response: The section has been updated to include the most recent U.S. Coast Guard regulations (33 CFR 157). These regulations cover all ships entering U.S. territorial waters and were based in part on the conventions of the Intergovernmental Maritime Consultative Organization.

Comment 2: The discussion in Sect. 4.3.1.3, Related Risk, should be updated to include the most recent U.S. Coast Guard regulations (46 CFR part 32) concerning inert gas systems.

Response: The discussion in Sect. 4.3.1.3 has been updated to include the most recent U.S. Coast Guard regulations concerning inert gas systems.

9.3.10 Wallace Menhaden Products, Inc.

Comment 1: The Phase III Supplement almost ignores the menhaden fishery, and where it is recognized, unsupported generalizations are made. For example, p. 3-20 #8 states that "All literature reviewed indicated that all stages of the ... life cycle ... for the Gulf menhaden, *Brevoortia patronus*, can tolerate wide ranges of salinity." A more careful review of the literature would indicate that different life stages are collected in Gulf waters, at different times, in different areas, in different salinities. Eggs may be hatched in a very narrow range and immediate survival might be critically related to salinity. Page 4-18 states that "impacts (of the brine plume at Bryan Mound) should be restricted to the bottom communities." A recent study by Randall and Hann indicates, however, that the plume on occasion was as high as 25 feet. At the proposed Big Hill site, this could place the plume near the surface which could have a large impact on the fishery, if indeed those eggs, or larvae, cannot tolerate the change in salinity.

Response: A detailed review of the menhaden literature has been added to Appendix G. Results of this review do not alter any of our conclusions regarding impacts on menhaden. No literature was found indicating that any stage of the menhaden life cycle is not euryhaline. Christmas and Waller (1975) found eggs at salinities ranging from 6.0 to 36.6 ppt. The Hann and Randall data (1981) refer to the maximum vertical rise of detectable salinity increase (1 ppt above ambient) above the diffuser nozzle. The plume rapidly descends to the bottom and spreads, such that at 100 m from the diffuser, the plume is within the bottom 3 ft of the water column. Even if 1-ppt salinity increases in the upper water column at the diffuser did prove harmful, a point source impact in such a small area would not have large impacts on a fishery that occupies most of the northern Gulf Coast.

Comment 2: Task 5 described on page 5-4 indicates that the effects of brine on red drum eggs, larvae, and postlarvae will be evaluated. Certainly the economics of the menhaden warrant a similar evaluation.

Response: Red drum bioassays were performed as required by the Environmental Protection Agency (EPA). Economics of the red drum fishery were not a major point included in EPA's determination of which species to evaluate. Factors utilized included availability and ease of handling.

Comment 3: Another concern is that the effects of multiple sites along the shoreline may have an impact on a species which passes through all those areas. Adult shrimp and menhaden may be able to circumnavigate individual areas of altered salinities but the menhaden spawned off lower Texas, in following their natural migration pattern, must now pass through Bryan Mound, Big Hill, and the almost immediately adjacent site, West Hackberry. This could significantly alter or reduce the range of the fish.

Response: From the detailed review of the literature presented in Appendix G there appears to be no evidence that appreciable numbers of menhaden migrate from central Texas to Louisiana during their life history. Major areas of spawning occur off the Mississippi delta. If longshore transport does occur, it would be east to west with the prevailing currents. The literature which was reviewed suggests only the occurrence of onshore-offshore migrations as a recurring trend. The statement that adult shrimp and menhaden may be able to circumnavigate individual areas of altered salinities is probably true. However, it should also be noted that postlarval and juvenile menhaden are capable of avoiding hostile environments, as seen in net avoidance problems (Fore and Baxter 1972).

Because of the euryhaline nature of the species (0 to 60 ppt), one or more point sources of brine disposal should not limit the range of a fish which occurs around the Gulf from southern Florida to Mexico. This is especially true when considered in the context of the natural variability of salinity in the nearshore zone, the low (+5 ppt) salinity overages being recorded at Bryan Mound, and the expected predominance of eggs, larvae and postlarvae in upper portions of the water column.

9.3.11 The State of Texas, Office of the Governor

Comment 1: Cover letter transmitting Texas Department of Health and Texas Department of Water Resources comments.

Response: No response required.

9.3.12 Texas Department of Health

Comment 1: Based on the information supplied it is believed that no adverse public or environmental health conditions should arise if proper construction and operation techniques are followed.

Response: Comment noted. It is DOE's intent to abide by all required health, safety, and environmental regulations during construction and operation of the SPR facilities.

9.3.13 Railroad Commission of Texas

Comment 1: No comment.

Response: No response required.

9.3.14 Texas Department of Water Resources

Comment 1: The Texas Department of Water Resources believes that the final report should contain accurate and complete data regarding the present and proposed water rights permits for both leaching and displacement at the Bryan Mound site.

Response: Sections of the document (2.2.1.1 and Appendix B) related to water requirements have been expanded to include the information requested by the Texas Department of Water Resources.

Comment 2: The Texas Department of Water Resources believes the final report should contain data and explanation about additional permitting requirements and actions.

Response: A brief discussion of the required water rights permitting actions has been incorporated into Appendix B. This information, however, is based on the conceptual design specifications and may not be identical to final design requirements and actual permit applications.

9.3.15 U.S. Department of Commerce (The Assistant Secretary for Policy)

Comment 1: Cover letter for enclosed comments (9.3.15 and 9.3.16).

Response: No response required.

9.3.16 U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Survey

Comment 1: The National Ocean Survey has no specific comments, although the final report should incorporate three documents listed by the National Ocean Survey.

Response: The three referenced reports relate to a baseline oceanographic study conducted by NOS for DOE. Two of the three reports have recently been made available to DOE; however, the data of this study were previously validated and archived and were taken into account in the assessments presented in this EIS. The list of related studies presented in Table 5-1 has been updated and expanded to include a broader coverage of relevant subject areas.

9.3.17 U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service

Comment 1: The impact statement should contain as detailed discussions of menhaden ecology (Section 3.0) and expected project impacts (Section 4.0) to the menhaden fishery as presented for brown and white shrimp. It should also discuss the relative importance of the proposed Big Hill diffuser location to menhaden spawning activities.

Response: We have added appropriate comments to Sections 3.0 and 4.0. A detailed discussion of the menhaden life cycle, including spatial and temporal distribution of spawning, salinity relationships, and characteristics of the fishery have been added to Appendix G. Results of this literature review do not alter any of our conclusions regarding impacts on menhaden. Menhaden are perhaps one of the most euryhaline organisms in the Gulf of Mexico. We disagree with the characterization by NMFS of the work of Fore (1970). In our opinion, Fore's results for the northwestern Gulf showed that, off western Louisiana and eastern Texas, eggs and larvae of Gulf menhaden are found much further offshore as compared with the area off the Mississippi Delta region. However, our evaluation of this NMFS work (Fore, 1970) is that not nearly enough samples were collected in the nearshore area to adequately characterize the nearshore distribution of menhaden eggs and larvae. Christmas and Waller (1975), however, found that most spawning takes place in the region of the Mississippi Delta, not off southwest Louisiana and southwest Texas.

Comment 2: The DEIS contains an inadequate analysis of alternative offshore brine disposal locations. Two potential locations, one each at 3.5 miles offshore and 12.5 miles offshore were discussed, but justification for selection of these sites or for elimination of alternative sites at other depths is lacking or weak. We suggest that the discussion of alternative discharge sites be expanded to include at least an alternative location between the white and brown shrimp communities (water depth of approximately 60 ft and over) and a location which would be preferred if all known environmental conditions were taken into consideration.

Response: Although the preferred site, based on environmental considerations, is the 3.5-mile (30-ft-depth) site, alternatives out to 12.5 miles are under consideration. The document has been modified to clarify this point (see Fig. 2-6). Justification for preferring the 3.5-mile site is presented in Sects. 3 and 4.

DOE believes that evaluation of a site at the 60-ft-depth contour would be impractical. The 60-ft contour off Big Hill is approximately 38 miles from shore and does not necessarily represent the "transition zone" between the white and brown shrimp ground communities in this region of the Gulf continental shelf. Depth is not the only controlling factor influencing community distributions. Other factors include temperature, distance from shore (nursery areas) and freshwater inflow. For example, near the Mississippi Delta, in a region where the continental shelf is steep and narrow, near-shore fauna (e.g., *M. undulatus*, *A. felis*) commonly dominate the catch at 60 ft and are collected consistently at 300 ft (Moore et al., 1970; Ragan et al., 1980). The brown shrimp ground community is poorly represented in this region.

As one proceeds westward, the distributions and abundances of species vary with changes in the structure (substrate and topography) of the continental shelf and the overlying hydrographic regime. Off Weeks Island the 30-ft-depth contour is approximately 20 miles from shore, at which point the shelf becomes steeper, dropping quickly to 60 ft depth. Landry and Armstrong (1980) reported inshore recruitment of brown shrimp ground fauna (e.g., *S. caprinus*) during late summer, further indicating that the transition zone between communities is not solely depth-dependent, but occurs across a range of depths.

Off the Chenier plain of western Louisiana and eastern Texas, the continental shelf is at its widest, becoming more constricted southwest of Galveston. Water depth 12.5 miles offshore at Big Hill is approximately 40 ft and, because of the distance and depth, is within the transition zone between communities. Because of the shallow nature of the near-shore Gulf and high estuarine production of near-shore fauna, winter intrusions of these taxa into the offshore grounds are not uncommon (Moore et al., 1970). At Bryan Mound the 60-ft depth is at approximately 12.5 miles offshore and is within the transition zone between communities (Chittenden and McEachran, 1976; Comiskey et al., 1980). As one proceeds west from the Mississippi Delta to the Rio Grande, estuarine-dependent, near-shore species play a reduced role in the dynamics of the continental shelf fauna. This may be directly attributed to the reduction in estuarine nursery habitat and freshwater inflow occurring along this gradient (Gulf of Mexico Fishery Management Council, 1980). Based on the above, the results of the Bryan Mound and West Hackberry experiences, the euryhaline nature of the near-shore fauna, and cost considerations, DOE believes a near-shore site is the most practicable.

The offshore distance to be traversed to reach a depth of 60 ft would produce a greater environmental burden than a location near shore.

Comment 3: Most of the discussion of salinity impacts to shrimp in the DEIS covers tolerance and occurrence with little or no coverage of salinity or temperature ranges for optimum growth and survival.

Response: Texas Department of Water Resources (1981) presents a table of salinity limits, preferences, and optima. The results of that table show a wide range of optimum salinities reported in the literature, further substantiating the euryhaline nature of penaeid shrimp. However, as noted in Appendix G, investigations into those factors responsible for success or failure of a particular year class for brown shrimp have shown that both temperature and salinity of the estuaries are important. Results generally indicated a negative impact on the brown shrimp year class, by reducing the size of the estuarine nursery area. Whether this is a result of a direct negative effect from low salinity or of some other factor that varies with salinity has not been conclusively shown.

Comment 4: DOE has apparently misunderstood the design of facilities at Pelican Island. We believe that the proposed Virginia Point facility, rather than Pelican Island, would have the appropriate storage and distribution facilities necessary for the SPR.

Response: During the development of the conceptual design for Phase III expansion of the SPR, DOE contacted the Pelican Island Terminal Corporation to discuss and verify possible scenarios for the utilization of their proposed port facilities and tank farm. SPR crude oil would pass through metering facilities at the terminal, at which point the Pelican Island Terminal Corporation would assume control of the oil and distribute it, as required, to commercial customers. This distribution would include transfer to both local refineries and to oil tankers for transport to East Coast and Caribbean refineries. Virginia Point is one of several candidate sites for a Pelican Island Terminal Tank farm.

Comment 5: The rationale for selecting only two alternative offshore brine disposal sites should be presented. If the 12.5 mile alternative was selected to coincide with the distance offshore of the brine disposal site at Bryan Mound, there should be environmental justification provided similar to that developed for Bryan Mound (i.e., the Bryan Mound 12.5 mile site was selected to be at a depth intermediate between the major brown and white shrimp grounds). The section also should include a presentation of an alternative site of 10 or more fathoms [between the brown and white shrimp ground communities, as described by Chittenden and McEachran (1976), and nearly the same depth as the Bryan Mound brine discharge] and the environmentally most desirable offshore brine discharge location, if it is either of these sites.

Response: See response to NMFS comment 2.

On a broad scale [as shown by the Bureau of Land Management's South Texas Outer Continental Shelf (OCS) and Mississippi Alabama and Florida OCS data], the major trends in distribution of biota in the northern Gulf correspond to distance off shore (or depth). In the near-shore zone, depth is an important factor, but the situation is somewhat more complex than a white shrimp grounds versus brown shrimp ground fauna. Multivariate analyses conducted by Comiskey et al. (1980) on the baseline nekton data (14 species) collected off Freeport Texas in depths of 3.5 to 25 fathoms have shown that what is commonly called the "white shrimp grounds" community is made up of a number of components that exhibit unique spatial and temporal trends. Factor analyses of these data identified five major trends in the data over all depths for the period July 1978 to April 1979. These are:

(1) *Stenotomus caprinus* behaved uniquely with respect to both space and time, with peak populations occurring in July and at Stations 16 to 18 (15 to 25 fathoms).

(2) An inshore group, generally restricted to the <10-fathom stations, consisted of *Stellifer lanceolatus* and *Menticirrhus americanus*. *Penaeus setiferus* was closely related to this group (temporally and spatially), except that it occurred somewhat further off shore.

(3) A group closely related to the inshore group, including *P. setiferus*, *Cynoscion nothus*, and *C. arenarius*, had a seasonal distribution, with peak numbers in December and lowest numbers in July. Species belonging to this group generally had higher numbers at the near-shore stations and no representation at Stations 17 to 19 (20 and 25 fathoms). Thus, the greatest difference in this group and the one with *S. lanceolatus* and *M. americanus* (defined by Factor 2) appeared to be the onshore-offshore constriction of the latter group. This group was defined by the same factor as was *S. caprinus* (bipolar factor), and these species showed distributions in space and time that were negatively correlated with those of *S. caprinus*.

(4) The Micropogon- Polydactylus- Penaeus aztecus group was spread widely over the study area, occurring mainly in July and October, and with low populations in February.

(5) Trichiurus lepturus and Peprilus burti formed a distinct group characterized by peak numbers in April, and except for the absence of T. lepturus at the 20- and 25-fathom-depth stations, both species were distributed over the entire study area. This group defines a factor in virtually all our analyses in which March-April data are used.

As can be seen, gradient from shore is an important trend in the distribution of most species, but the situation is much more complex than simply the presence of two communities. Depth is an expression of the myriad of environmental factors that change with depth, including temperature, salinity, and the variability of these hydrographic parameters. Cluster and ordination analyses of these same data (Comiskey et al., 1980) have shown shoreward migration of members of the more offshore fauna in summer as high-salinity water encroaches on the coastal zone. Perhaps the major problem with the concept of a brown shrimp grounds community is that brown shrimp are themselves estuarine-dependent, unlike most of the other members of the "brown shrimp ground" community.

Comment 6: Substantiation should be provided for the statement that, "...It may be postulated that biotic communities at the 3.5 mile site are better suited to withstand the effects of brine discharge than communities at a 12.5 mile site...", or this statement should be deleted.

Response: Numerous workers (see Gunter, 1967 for an excellent summary) have called attention to the euryhaline nature of the nekton community of the near-shore Gulf. Euryhaline organisms, having been originally derived from the euryhaline component of the marine fauna, are tolerant of both low and high salinities. As one proceeds off shore, stenohaline marine forms become more abundant. These organisms are less tolerant of both increases and decreases in salinity and, as such, are less able to tolerate discharge-related alteration of the salinity regime of the near-bottom waters. The more near-shore the diffuser is placed, the more euryhaline is the fauna.

Comment 7: The eleven generalizations and comparisons based on Appendices F and G are overly simplistic and often provide misleading information on shrimp and fish ecology. Therefore, we suggest that each of the listed items presented on pages 3-19 and 20 be carefully reviewed and adequate substantiation be provided. In particular need of correction, clarification and/or documentation are items numbered 5 and 7 through 11, as briefly detailed below.

Response: We have modified these generalizations to some degree for clarification. The generalizations were based on a thorough review of the literature and the results of the Big Hill sampling, although the Big Hill study was not aimed specifically at assessing impacts on the shrimp populations. We have compared the literature review in Appendix G with those presented in the Management Plan for the Gulf Shrimp Fishery (GMFMC, 1980). Our conclusions are quite consistent with the results presented in the Shrimp Fishery Management Plan.

Comment 8: Although the statement that euryhaline organisms are tolerant of both high and low salinities is generally correct, paragraph 5, page 3-19 should point out that certain life stages of euryhaline organisms may have a narrow range of prolonged salinity tolerance, preference, optimal growth, and optimal survival.

Response: We are not aware of any published report involving penaeid shrimp or menhaden that reaches this conclusion. The Texas Water Development Board (TDWR, 1981) summarized the salinity relationships for penaeid shrimp, including optima, and showed that the salinity optima reported for various stages of the penaeid life cycle are very broad indeed.

Comment 9: The seventh paragraph on page 3-19 should present available information on the chronic or sublethal impacts of increased salinities which might be encountered at the diffusers to shrimp, Gulf menhaden, and other important species.

Response: Given the motility of adult shrimp, the pelagic nature of the adult menhaden, and the transient nature of the eggs or larvae in the area of the diffuser (as they pass through), a consideration of chronic exposures does not appear to be justified. This is especially true given the euryhaline nature of the life stages of both groups that might enter the area of the diffuser and the small salinity increases that are expected from brine discharge. A worst-case scenario based on the assumption that all shrimp within an area of 3 ppt above ambient salinity were destroyed (which is highly unlikely) would not represent a significant impact, given the large area of the near-shore Gulf of Mexico.

Comment 10: The DEIS states that "... all literature reviewed indicated that all stages of the penaeid life cycle and also those for the Gulf menhaden, Brevoortia patronus, can tolerate wide ranges of salinity ..." However, much of the literature on shrimp that DOE cited in Appendix G, Shrimp Ecology, does not indicate that all stages of the penaeid life cycle can tolerate wide ranges of salinity. At least one study that was cited as indicating a wide range of salinity tolerance only surveyed brackish to fresh salinity. In addition, we are unaware of any literature cited in the DEIS that indicates that all stages of the Gulf menhaden life cycle can tolerate wide ranges of salinity. As noted in our General Comments, a review of menhaden ecology should be just as appropriate as shrimp ecology.

Response: We have conducted an extensive review of all relevant aspects of the menhaden life cycle, including salinity relationships, and these are presented in Appendix G. As discussed above, TDWR (1981) summarized the salinity relationships for penaeid shrimp, including optima. We disagree with the NMFS comment that the literature discussed and cited in Appendix G does not clearly establish the euryhaline nature of all stages of the penaeid life cycle. There are numerous references in Appendix G.1 to the occurrence of penaeid shrimp in salinities varying from fresh to hypersaline.

Comment 11: The degree of heavy exploitation of each species of fish and shrimp in the Big Hill area should be provided, to substantiate, or refute, the first sentence. If data are available which describe the "carrying capacity of the environment" in the vicinity of the Big Hill diffuser site, they should be provided for each species, or the last sentence deleted or modified.

Response: The text has been modified to remove reference to carrying capacity of the environment. With regard to the degree of heavy exploitation, Gunter (1967) presents a detailed description of the intensity of the fishery in the "Fertile Crescent." Catches of menhaden in the general area of the southeastern Texas Coast are obviously large since Cameron is a major part of menhaden landings, often leading the U.S. in total tonnage of fish landed.

Results of analyses of historical Gulf Coast Shrimp Data (Comiskey et al., 1981) have shown that the 0- to 10-fathom depths in statistical areas 18 and 19 yield the highest catches of white shrimp of any statistical area by 10-fathom-depth stratum on the Texas coast. There is also a heavy fishery in Calcasieu Lake for white and brown shrimp (TDWR, 1981).

An adequate method for documenting the spatial distribution of catch of finfish species has not been established. However, our review of menhaden ecology (see Appendix G) shows that highest catches occur near shore. This is further substantiated by the fact that the offshore menhaden fishing season (spring through fall) essentially ends when the menhaden stocks move further off shore for the fall through spring spawning season.

Comment 12: The statement that there, "appears to be a general oversupply of penaeid shrimp postlarvae" is ecologically incorrect.

Response: The text has been modified to remove the semantic problem with the word "oversupply." The ecological basis for the original statement now contained in generality 9 is correct.

Comment 13: The last sentence of this item should be modified to indicate penaeid populations do not necessarily "rebound quickly" in a year following one of poor production.

Response: We have modified the statement on the penaeid populations "rebounding quickly," but the basic concept is correct. The success of a year class of shrimp will depend primarily on factors inside the estuary. If the factors inside the estuary are not adequate, the populations will not do well. Our statement referred to the "potential" for shrimp populations to rebound based on this high reproductive potential. According to GMFMC (1980), "... Although annual catches appear somewhat cyclical, they are caused by environmental conditions. A poor year can be followed by an exceptionally good year for any of these (brown, white, and pink shrimp) species. Catch for a given year appears to be independent of the preceding year's catch, and no spawner-recruit relationship suggests itself ..." The clear indication is that recruitment is independent of the density of the spawning stock. Quoting again from the Fishery Management Plan for the Shrimp Fishery of the Gulf of Mexico (GMFMC, 1980), "... The biological characteristics which affect sustainable yields for penaeid shrimp are unusual. They are an annual crop. Very few individuals live a year and the majority harvested are less than six months old. There is no demonstrable stock-recruitment relation and recruitment overfishing, given present technology, is essentially impossible. That is, it is not economically or technically feasible to take so many shrimp that there are too few survivors to provide an adequate supply for the following year. Because of these characteristics, fishing mortality and yield in one year do not affect yield in the following year. The maximum yield in number for a given year is essentially all the shrimp available to harvest, using current technology."

Comment 14: Concerning the second sentence on page 3-29, paragraph 4, studies in Galveston Bay and entrance channel by Baxter (1963) and Berry and Baxter (1969) indicate that the postlarval shrimp catch can be used to project adult production for a particular year - class. It, therefore, appears that it is the abundance of postlarvae entering the estuaries from the Gulf, along with the environmental factors inside the estuaries, that determine the size of the harvestable shrimp.

Response: Berry and Baxter (1969) found that postlarval abundance was very variable from year to year, and of all the indices which they attempted to use to predict shrimp catch, postlarval catches were least useful. There were some modest correlations between commercial catch and postlarval catch, but the trends were not consistent. Berry and Baxter (1969) did not utilize any statistical techniques (e.g., regression) to relate postlarval abundance to offshore catch.

Comment 15: The statement that Sabine Lake is "no longer conducive to shrimp production" should be substantiated. In addition, this section should be expanded to differentiate between harvest and nursery utilization in Sabine Lake when referring to production. We are unaware of any recent data on early life stages in Sabine Lake which would indicate whether it is no longer conducive to production of shrimp harvested in the Gulf.

Response: At one time Sabine Lake exhibited characteristics of a freshwater body, including very low salinities and populations of freshwater fish species. Channelization of Sabine Lake began in the 1870s, and by 1880, a 15-ft channel and the outer bar to the estuary had been dredged. By 1967, there was a 40-ft channel to Beaumont. This channelization of the lake increased the saltwater intrusion and actually enhanced the area as a nursery to many commercial species of shellfish and finfishes.

Sam Rayburn Reservoir on the Neches River came on line in 1965, followed closely by completion of the Toledo Bend Reservoir on the Sabine River in 1966. Toledo Bend Reservoir affects the seasonal hydrographic pattern of Sabine Lake by decreasing the flow in winter and early spring and increasing the flow in late spring and summer. TDWR (1981) reported that, even though a reduction in the quantity of inflow to the Sabine-Neches estuary may be beneficial to production of estuarine-dependent fishes, the reservoir construction in the mid-60s appeared to have had just the opposite effect.

This emphasis on the hydrologic balance of Sabine Lake and the effect of its disruption on the shrimp fishery of the lake should not be taken to mean that this is the only aspect of the lake environment that is being disrupted. A major industrial (mainly petrochemical) complex lines much of the lake's western shore and is probably contributing to the degradation of the water quality in the area. In 1966, there was construction of spoil levees across Little Keith Lake, eliminating the major natural channel to the Keith Lake system. This leveeing and the construction of the Gulf Intracoastal Waterway across the southern portion of Jefferson County destroyed the viability of the area as a shrimp nursery. The Keith Lake complex, encompassing 54,340 acres of marsh area, had previously been one of the best areas for shrimp production on the Texas Coast. Shrimp harvest dropped an order of magnitude, and effort declined 58 percent from the previous year. In 1968, the South Disposal Area (3,081 acres) in Sabine Lake was leveed, followed by the leveeing of the North Disposal Area (1,975 acres) in 1968, further reducing estuary nursery area. TDWR (1981) concluded that "... the effects of estuary modification and seasonal fresh water inflow levels, acting together, appear to have resulted in the decline of the Sabine-Neches fishery, primarily through reduced habitat availability and unfavorable conditions for growth and survival of juvenile penaeid shrimp ..."

Gosselink et al. 1979 (page 42) note that "... The shrimp fishery offshore of Sabine (Lake) is a thriving one, but in recent years the Sabine estuary has produced no commercial landings of shrimp (National Marine Fisheries Service). Therefore, most of the shrimp caught offshore of the Sabine Basin use other inshore areas as nurseries." This assessment was made based on Louisiana landings and not Gulf Coast Shrimp Data. Examination of Gulf Coast Shrimp Data for the period 1973-1976 showed 6,937 lb of white shrimp, with a value of $12,113, being caught in 21 days of effort (vessel days) in Sabine Lake in 1976. This was the highest catch in Sabine Lake in the 1972-1976 period. In 1975, 232 lb of white shrimp worth $704 were taken, while in 1973 and 1974 no shrimp of any kind were harvested commercially. In 1977, the first appreciable catch of white shrimp was made in a number of years, but only 20,688 lb were taken (worth $35,035). When this catch is compared with the catches in the 1960s, the decline in the shrimp fishery of Sabine Lake is most evident. During the 1962-1965 period, white shrimp catch from Sabine Lake varied from 160,506 lb in 1964 to 747,803 lb in 1963.

TDWR (1981) compared the penaeid shrimp fishery production trends in Sabine and Calcasieu Lakes. By 1960 the commercial fishery was established in both lakes. The annual shrimp landings showed a similar trend until 1966, when annual harvest and effort began to show divergent trends. While the Calcasieu fishery expanded to an annual harvest of 2 million pounds (1972-1976), the Sabine Lake shrimp fishery began a decade of decline that resulted in essentially no harvest from 1970 to 1973. Commercial finfish harvest in Sabine Lake averaged only 20,000 lb annually for the 1972-1976 period and has been poor to nonexistent since 1970 (TDWR 1981). Breuer et al. (1976) report that sport fish harvest accounts for about 99 percent of the total fish harvested in Sabine Lake for the September 1975-August 1976 period. TDWR (1981) reports that, for the 1972-1976 period, the Sabine-Neches estuary produced 0.1 percent of Texas finfish landings and 4.6 percent of shellfish landings, these being mainly the blue crab.

Some improvements have recently been made in the viability of the estuary, including construction of a permanent opening (Keith Lake Exchange Pass) from the Port Arthur Channel to Keith Lake in 1977 to allow passage of small shrimp and finfish into this sizable nursery area (TDWR 1981). Because some increase occurred in white shrimp catch in 1977, the reestablishment of the nursery area may be having measurable effects.

Comment 16: This section (page 3-20, paragraph 5) should document any endangered species consultations that the DOE has had with the NMFS regarding sea turtles and marine mammals.

Response: Documentation of DOE's consultation with NMFS regarding threatened and endangered species is presented in Appendix D.

Comment 17: This section (3.2.1.8 Socioeconomics) should document Gulf menhaden economics to the same degree as was documented for shrimp in the subsection Offshore Shrimp Fisheries Economics. Gulf menhaden represent the greatest landings by weight of any Gulf fishery, and the vicinity of the proposed Big Hill diffuser site may serve as an important spawning ground in the region.

Response: Menhaden economics and spawning are discussed in Appendix G-2 and Sects. 3.2.1.8 and 4.2.5.2. No impacts to the menhaden fishery are expected. The literature does not support the conclusion that the area is a menhaden spawning ground. Menhaden move further off shore in the fall before spawning begins.

Comment 18: All Galveston Bay oyster reef crossings of the southern pipeline to Pelican Island (or Virginia Point) should be documented.

Response: The route of the southern pipeline crossing of Galveston Bay is depicted in Figure 3-7. This base map, with reef locations, was provided by the Texas Parks and Wildlife Department.

Comment 19: To avoid confusion or misunderstanding, the 2nd paragraph on page 4-3 should state that double-ditching and other available mitigation techniques would be used during pipeline crossing of wetlands.

Response: Statements in the text have been modified to indicate that DOE would utilize double-ditching techniques as required by the permitting agency.

Comment 20: The last sentence on page 4-4 of paragraph 3 should state when the agency consultation would be initiated to develop mitigation measures for waterway crossings.

Response: The sentence referenced (now page 4-5) was modified to state that consultation would begin during the permitting process.

Comment 21: Although, by extrapolation from other studies, plume thickness has been computed to be less than 3 ft, these data should be compared to Bryan Mound monitoring studies which found the plume to have a vertical extent of up to 25 ft under less than maximum discharge levels (Hann and Randall, 1981). The implication of such a large vertical extent of the plume should be discussed in terms of impacts to the Gulf fishery at the Big Hill site which has a total depth of only 30 ft.

Response: The prediction of a brine plume thickness of less than 3 ft was in reference to the brine plume on the bottom at distances beyond the release zone (i.e., at distances greater than 100 m from the diffuser). Hann and Randall data (1981) refer to the maximum vertical extent of detectable salinity increase (1 ppt above ambient) above the diffuser nozzles. It should be noted that these data do not refer to the jet centerline or vertical extent of turbulence. For the case of a diffuser at the 30-ft contour, the salinity overage above the nozzle would be essentially indistinguishable in the upper half of the water column from the natural variation in ambient salinity and, therefore, would not result in significant impacts. For a discussion of effects and impact assessment of the plume immediately adjacent to the diffuser, see Sect. 4.2.5.2.

Comment 22: The DOE's definition of an "unreasonable buildup of brine" should be provided.

Response: An unreasonable buildup of brine is one that causes an unreasonable degradation of the environment. The precise definition of unreasonable degradation is given in 40 CFR Part 125. No such degradation is anticipated from the SPR brine discharge.

Comment 23: Assessment of bioassay results should also consider chronic or sublethal effects of salt dome brine on various life stages of penaeid shrimp.

Response: This is discussed above in the response to Comment 9.

Comment 24: The extent to which shrimp larvae could avoid the brine plume in an oceanic environment should be discussed and documented.

Response: The text has been modified in Sect. 4.2.5.2 and Appendix G.1 to reflect the fact that the motility of shrimp larvae and postlarvae are not well known.

Comment 25: The statement that shrimp stocks and those of many demersal fish species in the northwestern Gulf are below carrying capacity as a result of commercial harvest should be documented.

Response: The text has been modified in Sects. 3.2.1.5 and 4.2.5.2 to clarify this point.

Comment 26: As noted in our General Comments, a subsection on impacts on menhaden should be added.

Response: Menhaden life history is discussed in Appendix G.2, and impacts are discussed in Sect. 4.2.5.2.

Comment 27: In the event that ship channel crossings are not completed by horizontal directional drilling techniques, the document should discuss the impacts of storage of large volumes of spoil from the channel crossings and means to mitigate those impacts (e.g., upland disposal, temporary barge storage).

Response: The impact of dredging activities are discussed in Sect. 4.3.2.2. As stated, dredging activities would fall under the jurisdiction of the USACE, as established under Sect. 404 of the Federal Water Pollution Control Act of 1972. During the permitting period DOE would be required to evaluate dredge materials under EPA requirement [45 CFR 85360, December 24, 1980]. On the basis of the results of these studies, the USACE would determine permit requirements that would be followed by DOE.

Comment 28: The 4th paragraph on page 4-69 should discuss under what conditions double-ditching techniques for wetlands crossings for pipeline installation would be used and details of additional mitigation measures being proposed (e.g., revegetation, avoidance of alterations of marsh hydrology).

Response: As stated in Comment ~~18,~~ 19 double-ditching techniques would be utilized as required by the permitting agency. Mitigative measures for possible pipeline construction impacts are presented in Sect. 4.3.2.1 and Table 6-1. These include crowning the ROW to reduce problems related to soil settling, reseeding in critical areas, and careful restoration to original contours in upland areas.

Comment 29: The first paragraph on page 4-70 of the Draft Impact Statement should document correspondence with Federal and State fish and wildlife agencies for the purpose of determining the need for a wetlands revegetation program.

Response: Documentation of correspondence with Federal and state fish and wildlife agencies regarding this project is presented in Appendix D. The need for a wetland revegetation program would be determined during the permitting process after exact pipeline routes are determined.

Comment 30: Section 5.0 should be expanded to discuss what corrective measures would be taken if the monitoring program documents significant environmental impacts to the Gulf fishery from Big Hill brine discharges.

Response: As stipulated in the Marine Discharge Guidelines (40 CFR Part 125) and in the discharge permit,"...if impacts are occurring and are determined to be significant and unacceptable by the Regional Administrator, EPA would issue an administrative order under Section 309 of the Clean Water Act to cause immediate cessation, regulation, or modification of the rate and manner of this discharge to eliminate or minimize any adverse effects to the marine environment. If impacts continued, the permit would be revoked..." The department will take whatever steps are necessary to comply with the permit.

Comment 31: Under item B on Table 6-1, "Water environment, dredging in the Gulf of Mexico," it is stated that the Gulf pipeline trench would be backfilled "if practical." We suggest that the potential impacts to commercial trawlers and their gear of exposed pipelines be discussed in Section 4.0 and the parameters for determining backfill practicality be presented. To avoid personal injury and vessel and gear destruction, we believe that mandatory backfilling should be an essential mitigation measure. The only time no backfilling would be a viable alternative would be where self burial has already occurred.

Response: The statement on Table 6-1 has been modified. The pipeline ditch would be backfilled if self burial does not occur. USACE guidelines require pipelines in less than 200 ft of water to be covered. Based on this information, a discussion of the potential impacts of exposed pipelines is unwarranted.

Comment 32: Under the heading U.S. Department of Commerce on Table 9-1, the National Marine Fisheries Service's jurisdiction and responsibility under the Fish and Wildlife Coordination Act should be summarized.

Response: The National Marine Fisheries Services involvement in the Fish and Wildlife Coordination Act has been noted. A letter of communication regarding this subject is presented in Appendix D.

Comment 33: Although we have not thoroughly reviewed the accuracy of the conclusions drawn from the numerous publications cited in this appendix (Appendix G), inaccuracies in references to Berry and Baxter (1969) and Truesdale (1970) lead us to suggest that each be carefully reviewed. For example, the DEIS references to Truesdale (1970) indicated that this scientist concluded that salinity does not influence shrimp distribution in the estuary, and although unclear in the text, he presumably corroborated the euryhaline nature of shrimp and their tolerance of high and low salinity. In our review of this reference, we found that the mean salinity for all stations sampled by Truesdale from March 1966 through May 1968 was only 2.3 ppt (the highest individual salinity was only 15.6 ppt; well below oceanic salinities) and that he reported freshwater inflow (a major factor affecting salinity) did influence shrimp distribution. Therefore, this publication did not corroborate shrimp tolerance of high salinity. It did, however, confirm the occurrence of the early life stages of shrimp in low salinity estuarine waters and the influence of high river flows and very low salinities on shrimp distribution during the major nursery season.

Response: It was not intended that each study which was presented show tolerance to the entire range of salinities. What was intended was that, when all the studies are considered together, the euryhaline nature of all stages of penaeid shrimp becomes obvious. Also, "euryhaline" must be taken in the context of the natural salinity variability in the area and the expected overages. It is our conclusion that, when taken in this context, the salinity tolerances of the various stages of penaeid shrimp are great. Appendix G provides adequate examples of the ability of penaeid shrimp to tolerate both high and low salinities. For brown shrimp, low salinities may be a problem in the spring by limiting the size of the nursery area of the estuary.

Comment 34: The comment that Sabine Lake no longer produces a fishable stock of brown shrimp is misleading since we are unaware of changes of brown shrimp catches (which were never a significant portion of the total shrimp landings) since closure of Toledo Bend Dam and subsequent inflow alterations.

Response: The text has been modified to clarify the situation regarding Sabine Lake. See response to Comment ~~14~~. 15

Comment 35: The first sentence on page G-4, paragraph 2 and the figure cited on page G.5 should be clarified to indicate that the reference is only to white shrimp.

Response: The text and figure have been modified.

Comment 36: Documentation should be provided for the discussion of proteins and lipids (last 3 lines, page 8, and first 3 lines, page 10).

Response: Documentation has been added to the text of Appendix G.1.

Comment 37: This section should discuss past study findings on optimal salinity as thoroughly as salinity ranges are discussed. In consideration of data developed on optimal salinity conditions during various shrimp life stages, adverse impacts of salinity alterations expected (e.g., feeding rates, metabolism, disorientation, predator avoidance) should be discussed.

Response: A discussion of optima does not appear warranted or relevant to the discussion of offshore impacts. Optimal conditions, which are quite wide for euryhaline organisms, may never occur in the natural environment, especially an environment as variable as the near-shore Gulf of Mexico.

Comment 38: Examination of Table 1 presented by Berry and Baxter (1969) indicates that postlarval collections in 1969 and 1962-66 were not very similar.

Response: The text has been revised to clarify the issue. Reference was to Figure 7 of Berry and Baxter (1969), not to Table 1. These concerns are discussed further in the response to Comment 13.

Comment 39: This paragraph (page G-14, paragraph 2) and the following paragraph should discuss and reference studies on the importance of marsh vegetation to shrimp production (e.g., Turner, 1977).

Response: Turner (1977) and GMFMC (1980) have been referenced in Appendix G.

Comment 40: This section should be expanded to discuss both historical trends in fishing effort and in the average size of shrimp landed in the northwestern Gulf of Mexico.

Response: A discussion of effort and average size is not pertinent to the impact analysis. According to GMFMC (1980),"...Although effort is expected to increase, there is no reason to believe that recruitment overfishing will occur. Growth overfishing could occur and decrease the total yield if effort in inshore areas continues to increase..." Growth overfishing (a decrease in average size) could result in a decrease in yield (pounds, heads off) and dollar value per pound.

9.3.18 U.S. Department of the Army, Galveston District Corps of Engineers

Comment 1: The 100-year floodplain level of 14.0 ft mean sea level for the Big Hill site is still water and does not account for wave runup.

Response: As discussed in detail in the previous Texoma FEIS (DOE/EIS-0029), all facilities would be designed to withstand the effects of storm surge or wave runup. This would be accomplished by the design and construction of levee systems and the implementation of a severe storm countermeasure plan. The plan would allow safe shutdown, tiedown, or removal of objects that could be blown or washed against facility structures if the levee system were breached during a storm event.

Comment 2: Projects are within the purview of Sect. 10 of the 1899 River and Harbor Act.

Response: Comment noted (see Table 9-1).

Comment 3: Projects are within the purview of Sect. 404 of the Federal Water Pollution Control Act, as amended.

Response: Comment noted (see Table 9-1).

Comment 4: Coordination regarding Department of Army permits should continue with both the Galveston and New Orleans Districts.

Response: DOE personnel have been maintaining, and will continue to maintain, close coordination with the Corps of Engineers offices in New Orleans and Galveston regarding permit requirements.

9.3.19 U.S. Department of the Interior, Office of the Secretary

Comment 1: The disposal of PCB-contaminated dredge spoils should be carefully controlled and monitored to reduce the possibility of toxic effects on fish and wildlife.

Response: As stated in Sect. 4.3.2.2, DOE would abide by the stipulations of the permitting agency (U.S. Army Corps of Engineers) regarding the disposition of all dredged materials. Chemical surveys of dredge sites would be conducted as part of the permitting process where required.

Comment 2: It is suggested that a brief evaluation of in-situ mineral resources within the project boundaries be made, along with an analysis of the project's effects on such resources.

Response: As stated in Sect. 4.2.1, Land Features, future salt production in the area of the new storage caverns and mineral extraction from the caprock would be incompatible with the SPR program.

Comment 3: Project effects, if any, on the stand of live oak trees at the Big Hill site should be clearly stated.

Response: The document has been revised to include a discussion of the project effects on the live oak trees at Big Hill (see Sect. 4.2.1).

Comment 4: Since the near-shore brine disposal site has lower ambient salinities than the far-shore site, it would be subject to more salinity change from brine disposal. Although the salinity change may not exceed the tolerances of any species in the area, it would change the habitat.

Response: The statement that brine discharge would change the habitat in the vicinity of the diffuser is incorrect. If the brine is disposed of at the near-shore site, salinity increases above ambient would be less than natural variation in ambient salinities based upon Appendix F and the observed Bryan Mound results. Salinity overages are generally less than +5 ppt. Natural salinity gradients in the near-shore region may at times be more variable than those predicted and observed for brine disposal.

Comment 5: Physical factors (temperature and salinity) in the Gulf generally do not control shrimp populations because these factors are relatively constant. If these factors in the Gulf start to fluctuate, as proposed with brine disposal, they could become controlling factors on shrimp populations as much as estuarine conditions.

Response: It should be noted that hydrographic parameters in the near-shore Gulf are extremely variable (see Appendix F). The region is often referred to as an extended estuary. Salinity fluctuations of 10 ppt and temperature variations of 20°C are not uncommon at a 3.5-mile site. Offshore, in deeper water, however, salinity and temperature become more constant because of a reduction in vertical mixing. This major trend, along with distance from estuarine nursery grounds, is primarily responsible for development of the distinct faunal assemblages commonly referred to as the white and brown shrimp ground communities. Near-shore fauna have evolved in a dynamic environment and are generally broadly eurytolerant to environmental perturbations. Brine disposal in the nearshore zone would produce fluctuations smaller than those naturally occurring outside the 100-m release zone.

Comment 6: The best facility design would place all well sites in upland areas.

Response: DOE will comply with Executive Order 11990 regarding location of Federal facilities in wetlands. Geotechnical and engineering constraints as well as environmental concerns have been used in the development of SPR site facilities. Safety and environmental considerations require that oil storage wells be placed directly above caverns in the salt domes (i.e., directional drilling is thus foreclosed). No deep injection wells for brine disposal are planned.

9.3.20 Federal Energy Regulatory Commission

Comment 1: It does not appear that there would be any significant impact or serious conflicts with this agency's responsibilities should this action be undertaken.

Response: Comment noted.

9.3.21 U.S. Environmental Protection Agency

Comment 1: DOE should be advised to substantiate the claim that impacts on the shrimp fishery will be minimal. Of concern is the location of brine discharge for Big Hill in the Gulf of Mexico.

Response: See responses to National Marine Fisheries Service comments presented in Sect. 9.3.17.

Comment 2: DOE should recognize that the brine discharge from Big Hill will be subject to the Ocean Discharge Criteria (40 CFR 125 M) promulgated on October 3, 1980, under Sect. 403(c) of the Clean Water Act, as amended.

Response: This information has been added to Sect. 4.2.5.2, Brine Disposal.

Comment 3: The EPA does not expect any long-term significant impacts resulting from the expansion of Bryan Mound and West Hackberry SPR sites. However, we request that prior to initating Phase III related brine discharges, the completed comprehensive monitoring plan be submitted to EPA for final review and approval.

Response: DOE would submit to EPA comprehensive monitoring plans as required by the permit application procedure. These would apply specifically to the Big Hill permit for new discharges and the Bryan Mound permit amendment for an increased leach rate. Operations at West Hackberry are expected to require a permit amendment for increasing brine disposal duration. The current West Hackberry permit expires in 1986.

Comment 4: The Final Supplement should recognize that the volatile organic compound (VOC) emissions resulting form the Texoma and Seaway Group Salt Domes would be subject to the Federal offset policy or non-attainment provisions of the applicable State Implementation Plan (SIP).

Response: These subjects have been included in the revised text of Sect. 4.2.3. Special consideration has been given to the subject of ozone formation as related to VOC emissions.

Comment 5: The Final Supplement should recognize that the NMHC standard was used only as a guide in developing SIPs to achieve the ozone standard and since has been revoked.

Response: Since the NMHC standard has been proposed for revocation, discussion and analyses in Sect. 4.2.3 have been revised to reflect increased attention to the ozone standard.

Comment 6: In order to minimize air emissions and their associated impacts we urge DOE to provide, whenever possible, lowest achievable emission rate (LAER) technology such as vapor recovery systems.

Response: Statements concerning DOE's commitment to LAER have been incorporated into Sect. 4.2.3.

Comment 7: The Final Supplement would be strengthened if the socioeconomic impacts could be more accurately defined. Further evaluation should be exercised to more definitively assess which of the two scenarios would most likely occur. Mitigation measures should be identified.

Response: A discussion of socioeconomic mitigation measures has been added to the text (Sect. 4.2.9). This discussion of possible mitigation scenarios suggests that with minimal effort the projected impacts would be minimized. Because of the large number of variables involved and the uncertainties of future population and labor projections for the region, two scenarios were presented. Mitigation would reduce the possibility of severe impacts.

Comment 8: The Supplement would be substantially strengthened if Appendix I included addtional information identifying measures to control impacts resulting from possible oil spills. Specifically, assurances should be presented that a Spill Prevention Control and Countermeasures (SPCC) plan would be developed.

Response: A brief discussion of an SPCC plan for Big Hill has been added to Appendix I, ensuring that operations of the site would not commence until the plan is approved. The detailed SPCC plan will be developed as part of the final design and permitting procedure. The terminals and both Bryan Mound and West Hackberry have existing SPCC plans approved by the appropriate state and Federal agencies.

9.3.22 U.S. Nuclear Regulatory Commission

Comment 1: We have determined that the proposed action has no significant radiological health and safety impact, nor will it adversely affect any activities subject to regulation by the Nuclear Regulatory Commission.

Response: Comment noted.

9.3.23 Ohio State Clearinghouse, Office of Budget and Management

Comment 1: No reviewer has stated concerns related to this report.

Response: Comment noted.

9.3.24 Olin Corporation

Comment 1: Please note that in our previous correspondence of May 13, 1981, Olin Corporation expressed to you its opposition to the use of additional Olin-controlled salt dome property at the Hackberry location for the Strategic Petroleum Reserve.

Response: Olin Corporation refers to a correspondence of May 13, 1981, which preceded their receipt of the publication of the Draft Supplement Environmental Impact Statement.

Comment 2: In our review of this 500-page Impact Statement, we have found no mention of industrial use of the salt dome property which the Department of Energy proposes to acquire. The land which is owned by Olin and valued as an important business asset is referred to as "pasture land." While the surface of this land is leased for pasture use, the Department of Energy well knows that the true value lies beneath the surface in the salt.

Response: The subsurface or salt potential is recognized in discussions of the regional and site-specific geology in the Federal Energy Administration West Hackberry Salt Dome Final Environmental Impact Statement, FES/76/77-4, V.2, Sect. 3 and Appendices H and I, and in the Texoma Group Final EIS, 1978, DOE/EIS-0029, Sects. 13.2.1 and B.3.1.1.5. It is accurate to state that parts of the West Hackberry salt dome are presently being used for industrial purposes; however, no brining or subsurface storage is presently being undertaken on the Olin tract proposed for possible use in Phase III development.

Comment 3: We now treasure the remaining 80 usable acres out of the original 480 acres, believing that it may still have significant commercial utility. However, the proposed Phase III expansion would remove more than 25 percent of that remainder. We believe the government should identify another route for the Phase III expansion.

Response: Alternatives to the preferred action at West Hackberry are discussed in Sect. 2.3 of this document.

Comment 4: It is noted that fair valuation of property upon which future business opportunities may be based has proven to be difficult. In addition to the potential for future underground storage development, Olin values the salt properties as a raw material reserve for chlorine manufacture. The company is a significant factor in the chlorine business in the United States, with manufacturing facilities at four locations and an on-going expansion program. Because of market opportunities in the area and internal chlorine consumption at Lake Charles, that location has important potential for future chlorine plant construction.

Response: The irreversible commitment of salt for Phase III development at West Hackberry for the preferred action is estimated to be eleven million tons and is discussed in Sect. 8.6.2. Olin will be justly compensated for salt acreage acquired by the Government, and as large salt deposits occur frequently throughout the Gulf Coast region, Olin could acquire substitute salt acreage to continue to expand their Lake Charles plant. Agreements to provide brine to private industry have been arranged at other SPR sites. Should Olin desire additional brine for their Lake Charles plant, a sales contract could possibly be negotiated with the Government.

Comment 5: These possibilities offer important socio-economic advantages for the area not mentioned in the Impact Statement, Section 3.2.4.8 (page 3-53). In Section 4.4.8 (page 4-63), the report refers to a possible adverse socio-economic impact in the "taking of existing properties and houses for the proposed expansion." We suggest that existing properties and houses can readily be replaced in the immediate area and that the community would likely prefer to retain the possibility of future expanded job opportunities.

Response: Comment noted.

Comment 6: We suggest as alternate courses of action to retain the original time schedule, utilize the land to the south of the original taking, and leave the Olin property to the west for future Olin commercial development.

Response: Both alternatives remain under consideration. However, there are geological structure concerns in the area south of the original taking that may be relevant to this decision.

Comment 7: Accept a compromise in timing, as suggested in an alternate proposal on page VIII (Section 2.5) and page 2-18 so that only 10 million barrels of the expansion occur at West Hackberry and 60 million barrels at Bryan Mound.

Response: This action would prevent the complete integration of solution mining Phase III caverns at Bryan Mound, resulting in a 6-month delay in completion of Phase III site expansion and increasing costs appreciably. The preferred alternative is still believed to be valid in terms of programmatic and environmental considerations and constraints.

Comment 8: Simply enlarge the caverns currently under construction, or enlarge the caverns under construction as well as the original existing caverns. A 30 million barrel expansion could be accomplished in this fashion by adding less than two million barrels to each of the 16 caverns, a 19 percent expansion, which would require only slightly over a 4 percent change in cavern diameter.

Response: The pre-existing caverns were the result of leaching for petrochemical feedstock; their size and geometry were not designed specifically for oil storage. DOE believes it would not be prudent to enlarge these caverns beyond that which will occur during cycling. Expansion of the other caverns also is not desirable as we wish to maintain the designed cavern web thickness, which provides for the stability necessary for five drawdown cycles. Further, the storage caverns at West Hackberry are permitted by the State of Louisiana and a decision to allow cavern expansion would rest with the State of Louisiana.

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Education:

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B.S.	1970	Biology	Wake Forest University
M.S.	1972	Ecology	University of Tennessee
Ph.D.	1976	Ecology	University of Tennessee

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M.S.	1976	Nuclear Engineering	Georgia Institute of Technology

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Diploma	1964	Engineering Management	Technology Center & Systems Design

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M.S.	1975	Chemical Engineering	University of Tennessee

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M.S.	1967	Aeronautical Engineering	Aachen Technical University
Ph.D.	1972	Aerospace Engineering	University of Tennessee

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M.S.	1972	Biological Oceanography	Old Dominion University
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Education:

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10.6 TERRESTRIAL BIOLOGY AND SCENIC FEATURES

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APPENDIX A

SCOPING CONSIDERATIONS

APPENDIX A

SCOPING CONSIDERATIONS

A Notice of Intent to publish a supplemental draft Environmental Impact Statement (EIS) was published in the Federal Register, Volume 45, Number 196, on Tuesday, October 7, 1980, soliciting comments on the proposed Phase III expansion of the Strategic Petroleum Reserve (SPR) from interested Federal, state, and local agencies; public and private organizations; and individuals. A single response was received from the Bureau of Land Management (BLM), requesting maps and supportive information to ascertain whether the proposed expansion would affect any BLM interests or programs.

Letters requesting identification of specific items of environmental concern regarding the Phase III expansion were sent to various regulatory and advisory Federal agencies, state agencies in Texas and Louisiana, and several special interest groups. Replies sent to the Department of Energy (DOE) identified several areas of concern, including (1) ensured availability of data from the current monitoring program at Bryan Mound; (2) need for an up-to-date evaluation of the effects of brine discharge into the marine environment; (3) identification of environmentally sensitive areas both on and off shore; (4) in-depth discussion of alternative pipeline routes for the various pipelines; (5) projections of air and water quality impacts; and (6) review of the necessary permits needed for project implementation. This draft supplemental Final Environmental Impact Statement (FEIS) contains the information requested above.

Additionally, several meetings were held to introduce the proposed expansion and to discuss specific problems that could arise with the project. Attendees included representatives from the Environmental Protection Agency, U.S. Fish and Wildlife Service, National Marine Fisheries Service, Texas Parks and Wildlife Department, Texas Water Resources Department, Louisiana Department of Wildlife and Fisheries, Louisiana Department of Natural Resources, and the Gulf of Mexico Fishery Management Council.

Table A-1 lists a preliminary analysis of environmental issues associated with the SPR Phase III expansion. These issues are ranked (remote, low, moderate, and high) according to their projected potential for occurrence and relative severity of impact. The contents of Table A-1 are arranged by subject areas considered within the text of this supplement. The identification, categorization, and summarization of issues herein constitute a preliminary scoping effort. Certain issues have been recategorized on the basis of additional information. Initially, wetlands destruction, brine disposal, and oil spill pollution emerged as major issues of discussion and resolution.

Table A-1. Summary of environmental issues relevant to the development of Big Hill (140 MMB) and expansion of West Hackberry and Bryan Mound (70 MMB, collectively)

Subject area	Source of impact	Area affected	Anticipated impact	Potential for occurrence	Relative severity of impact	Focus of analysis
Land environment	Construction - earthmoving operations	Site storage facilities and pipeline corridors	Disturbance of soils, leaching, erosion, and alteration of drainage patterns	High; unavoidable consequence of construction	Low; limited areal extent affected and numerous mitigation measures available to stabilize disturbed land	Determination of the areal extent of disturbed land, any significant changes in land use, length of time land would be disturbed, and efficacy of mitigation measures
		Pipeline corridors	Disturbance of wetlands	High; unavoidable consequence of construction	Low-moderate; pipeline routes chosen to avoid wetlands when possible; potential need for land acquisition of dredged or excavated spoil disposal	Determination of areal extent of wetlands and land acquisition for spoil material disposal
	Operation - cavern leaching operations and fill/withdrawal operations	Site storage facilities	Cavern collapse or other structural failure, possibly causing surface subsidence	Remote with appropriate construction safeguards	High; major damage to local water and ecosystems, depending on the presence of oil stored at the time of failure	Risk assessment
		Pipeline corridors	Maintenance of permanent corridors may preempt other uses for land	High; some permanent corridors will be maintained	Low; relatively small amount of land resources involved	
Water environment	Construction - earthmoving operations	Site storage facilities, raw water intake structure, and pipeline corridors	Water quality alterations due to (1) runoff and erosion from affected areas, (2) elutriation of dredged sediments, and (3) changes in drainage patterns	High; unavoidable consequence of construction	Low-moderate; impacts will be short term and localized, and appropriate mitigation measures exist. However, some sediments may contain chemical contaminants such as PCB compounds	Determination of water quality perturbations likely to occur and if water quality standards will be violated; available data will be analyzed

Table A-1 (continued)

Subject area	Source of impact	Area affected	Anticipated impact	Potential for occurrence	Relative severity of impact	Focus of analysis
Water environment (continued)	Operation - cavern leaching and drawdown operations	Areas hydrologically connected to the raw water intake	Drawdown of complex surface water and groundwater system due to removal of water from ICW for cavern leaching purposes; may increase salinity in the ICW	High; Gulf Intracoastal Waterway (ICW) to be used as source of raw water	Low; withdrawal of water from ICW for Big Hill operations minor in comparison to entire volume of water in ICW	Predictive modeling (MIT Water Quality Network Model) of hydrologic regime at the ICW intake location
	Operation - onshore disposal of wastes	Spindletop Marsh and evapotranspiration field near septic system	Surface water and groundwater quality alterations due to (1) discharge of precipitation runoff to Spindletop Marsh and (2) wastewater from septic system	Low-moderate; discharge from site drainage system will occur when precipitation exceeds the 25-year, 24-h rainfall event; wastewater from septic system will be discharged during entire time that the facilities are operating	Low; site drainage will be monitored; septic system will be designed and operated according to good sanitary engineering practices	
	Operation - offshore disposal of wastes (brine, heat)	Brine disposal area (Gulf of Mexico; 3.5 to 12.5 miles off shore)	Localized areas of the Gulf of Mexico may be impacted by high salinity, contaminant hydrocarbons, and higher temperature of the discharge. In addition, leach water from the ICW may contain pesticides and metals (agricultural and industrial pollutants) which are also discharged to the Gulf	High; Gulf will receive continuous discharge during the course of cavern leaching operations	Low-high; dependent on site-specific conditions	Evaluation of discharge locations; application of dispersion model results from 3.5- to 12.5-mile discharge points

Table A-1 (continued)

Subject area	Source of impact	Area affected	Anticipated impact	Potential for occurrence	Relative severity of impact	Focus of analysis
Climatology and air quality	Construction - earthmoving operations	Site storage facilities and pipeline corridors	Localized alteration in air quality as a result of fugitive dust and miscellaneous construction emissions	High; unavoidable consequence of construction	Low; short-term and localized	
	Operation - fill and drawdown operations	Site storage facilities and crude oil distribution system	Oil transportation and storage are anticipated to increase emissions of hydrocarbons and, more importantly, photochemical oxidants; this region is already a nonattainment area for photochemical oxidants	High; some degree of release (from storage tanks, pipelines, pump seals and valves, tanker transit and loading/unloading operations, engines, pump stations) appears inevitable	Moderate; potentially significant but short-term	Calculation of emission rates and modeling; quantification of additional impacts when projected photochemical oxidant levels are exceeded
	Operation - cavern leaching operations and drawdown of post-oil-storage displacement water	Site storage facilities	Agitation of brine, causing salt particles to become airborne	Moderate; some degree of salt emission probable	Moderate; local corrosive effects on metals could occur	Calculation of emission rates
Ambient sound levels	Construction - earthmoving operations	Site storage facilities and pipeline corridors	Increased noise levels due to operation of construction equipment (drilling rigs, pumps, bulldozers, etc.)	High; increased noise levels unavoidable	Low-moderate; short-term increases in noise levels in rural corridors	Consideration of people affected (workers and area residents), OSHA regulations, and efficacy of mitigation measures
	Operation - cavern leaching operations and fill/withdrawal operations	Site storage facilities, raw water intake, and brine disposal pipeline	Increased noise levels due to pump operation	High; pump noise unavoidable	Low; not anticipated to be significantly higher than ambient sound levels	

Table A-1 (continued)

Subject area	Source of impact	Area affected	Anticipated impact	Potential for occurrence	Relative severity of impact	Focus of analysis
Ambient sound levels (continued)	Operation - fill and drawdown operations	Site storage facilities and crude oil distribution system	Increased noise levels due to pump operation	High; pump noise unavoidable	Low; not anticipated to be significantly higher than ambient sound levels	
Species and habitats	Construction - earthmoving operations	Site storage facilities, raw water intake structure, and pipeline corridors	May impact habitat of Federally protected, threatened, or endangered species	Low; unlikely that any species would be affected at the site storage facilities; some chance of encountering American alligator in the wetlands along pipeline corridors	Remote; no critical habitat in area	An assessment of threatened or endangered species has been made to delineate the proximity of these habitats to the pipeline corridors
			Habitat destruction (removal of vegetation and other modifications) by grading, excavation, and dredging; habitat destruction or modification by dredge spoil deposition; habitat alteration in areas near the disturbances, resulting in disruption of animal movements and reproductive cycles; habitat destruction by siltation and erosion; creation of an edge	High; temporary loss of some terrestrial and aquatic habitat unavoidable	Low-moderate; depends upon habitat type affected; wetland habitat the most sensitive to be impacted	Determination of the areal extent of potentially impacted area and what percentage it represents of a certain type of ecosystem; determination of the types of organisms (e.g., oyster reefs) which will be eliminated; determination of any seasonal differences in projected construction impacts
	Operation - cavern leaching operations and fill/withdrawal operations	Raw water withdrawal systems	Entrainment/ impingement of aquatic organisms in the raw water intake system, resulting in losses of these organisms to the ICW	High; some entrainment and impingement losses unavoidable	Low; not considered to be significant losses	Evaluation of the nature and magnitude of losses; evaluation of efficacy of mitigation measures

Table A-1 (continued)

Subject area	Source of impact	Area affected	Anticipated impact	Potential for occurrence	Relative severity of impact	Focus of analysis
Species and habitats (continued)	Operation - cavern leaching operations and drawdown of post-oil-displacement water	Site storage facilities	Emission of salt from brine pond could impact onsite and near-site vegetation	Moderate; depends on sensitivity of vegetation	Moderate; potentially significant but localized	Evaluation of emission rates, dispersion, and sensitivity of nearby vegetation
	Operation - cavern leaching operations and fill/withdrawal operations	Pipeline corridors	Maintenance of permanently established rights-of-way (ROWs) does not permit return of original habitat; maintained habitat may have reduced productivity and diversity	High; some permanent ROWs will exist	Low-moderate; although permanent, maintained ROWs will be relatively small areas; can be potentially significant if ROW destroys ecosystem integrity	Evaluation of what "edge" effects may result; consideration of proximity of ROW to migration routes or diel movement routes
Natural and scenic resources	Construction - earthmoving operations and pipeline installation	Pipeline corridors, especially brine disposal through McFaddin National Wildlife Refuge	Temporary disturbance to wetland resources; unaesthetic aspects of construction and temporary living conditions of workers	High; some wetlands will be unavoidably transected by pipeline corridors	Low-moderate; potentially significant, but short-term and very localized	Consideration of areal extent of disturbed resources and efficacy of mitigation measures
	Operation - cavern leaching operations and fill/withdrawal operations	Pipeline corridors	Maintenance of permanently established ROWs may cause periodic disturbances to resources located along the routes	High; likely that some disturbances will occur	Low-moderate; although permanent, maintained ROWs will be relatively small areas; can be potentially significant if ROW destroys ecosystem integrity	Analysis of long-term impacts and efficacy of mitigation measures
Archaeological, historical, and cultural resources	Construction - earthmoving operations	Site storage facilities, raw water intake structure, brine diffuser, and pipeline corridors	Disturbance or destruction of resources	Low-high; depends on proximity of resources to affected areas	Low; records and field surveys should identify sensitive areas; monitoring during construction should eliminate adverse impacts to unknown resources	Analysis of proximity of operations to sensitive areas; evaluation of uniqueness of resources potentially impacted

Table A-1 (continued)

Subject area	Source of impact	Area affected	Anticipated impact	Potential for occurrence	Relative severity of impact	Focus of analysis
Socioeconomic environment	Construction - all phases	Site storage facilities and pipeline distribution systems	Stress placed on goods, housing, and services in impacted areas; increased traffic volume; preemption of land uses at storage site	High; some small communities in rural locations will be unavoidably affected	Low-high; depends on the availability of goods, housing, and services and highway/road usage before impact	Analysis of what occurred at West Hackberry and Bryan Mound and extrapolation of these results, if possible, to the Big Hill situation; consideration of the efficacy of mitigation measures
	Operation - all phases	Site storage facilities	Some stress placed on goods, services, and housing in small communities near site storage facilities; some increase in traffic volume for the lifetime of the operations	Moderate; lower numbers of workers present at site, but likelihood that at least some permanent employees will not commute but will seek local residences; hence, will depend on local goods, housing, and services and will contribute to increased traffic volume	Low-moderate; depends on availability of goods, housing, and services and highway/road usage before impact	See above
Accidents, oil spills	Operation - fill and drawdown pipelines	Site storage facilities, terminal, and crude oil distribution pipeline	Greatest concern would be possibility of harm from explosion or fire; other impacts would include contamination of surface water and/or groundwater near an oil spill	Low-high; depends on nature (chronic or acute) and extent of spill; low potential for explosion or fire with proper safeguards	High; impacts ranging from relatively minor chronic spills to major spills, all considered significant	Risk assessment
		Tanker route	Accidental spills during marine transfers, marine transport, and berth operations	High-low; high for chronic or operational spills; low for large or maximum credible spills	High-moderate; high for the incoastal waters or sensitive areas; moderate in open seas	Risk assessment

Table A-1 (continued)

Subject area	Source of impact	Area affected	Anticipated impact	Potential for occurrence	Relative severity of impact	Focus of analysis
Accidents, oil spills (continued)		Terminal facilities and site storage facilities	Accidental spills during pumping and standby storage	Moderate, given available control measures	Moderate, given appropriate mitigation measures	Risk assessment
		Crude oil distribution pipeline	Accidental spills due to pipeline rupture, operator errors, or interference by third party	Moderate-low; moderate for chronic or operational spills, low for maximum credible spills	Moderate-high; depends on area impacted and size of spill	Risk assessment
Accidents, tanker traffic	Operation - fill and draw-down operations	Terminal facilities and areas located downstream (for Sun Terminal, the Neches River, and Sabine Lake)	Congestion of areas below Sun Terminal	Moderate	Moderate	Tanker logistics
Accidents, brine spills	Operation - cavern leaching operations and drawdown of post-oil-storage displacement water	Onshore and offshore brine discharge pipeline route	Contamination of aquatic and terrestrial areas along pipeline route; potential for impacting groundwater quality; potential for impacting McFaddin National Wildlife Refuge; potential for impacting off-shore marine environments	Moderate for an operational spill	Low-moderate; depends on the area affected and size of spill	Risk assessment
		Site storage facilities	Contamination of nearby surface waters or ground-waters from brine pond or from pipeline accidents	Low-moderate; low for large spills or releases; moderate for relatively small chronic releases	Low-moderate; low for minor chronic releases; moderate for large spills	Risk assessment and analysis of how readily the brine pond liner may permit brine releases

APPENDIX B

WITHDRAWAL OF WATER FROM THE GULF INTRACOASTAL WATERWAY FOR BIG HILL LEACHING-DISPLACEMENT OPERATIONS

APPENDIX B

WITHDRAWAL OF WATER FROM THE GULF INTRACOASTAL WATERWAY FOR BIG HILL LEACHING-DISPLACEMENT OPERATIONS

If the Gulf Intracoastal Waterway (ICW) is used as a source of displacement water, replenishment would be supplied from Galveston Bay and from Sabine Lake by way of the Sabine-Neches and Port Arthur Canals. The flow may also be influenced by runoff from the wetlands adjoining the ICW as well as by other water bodies intersecting the ICW. The governing equations for such a flow process are complex and must be solved numerically. The MIT Water Quality Network Model has been used to provide such a solution. This model was developed by the Ralph M. Parsons Laboratory for Water Resources and Hydrodynamics, Department of Civil Engineering, Massachusetts Institute of Technology (Harleman et al., 1976). In the model, the one-dimensional continuity and momentum equations are solved for a modeled network of connected water bodies. The conservation of species equations for water quality variables such as salinity are solved by using such hydrodynamic information and equations of state. The solutions are provided from an implicit finite element scheme. The characteristics of the model include:

- Strict adherence to the mass conservation principle in the water quality considerations.
- Formulation of the structure of the model so that the level of complexity would not be too complex to the point of diminishing returns, nor too simplified to the point where rate-governing parameters must be determined by curve-fitting the available field data.

A network was developed consisting of (1) the ICW from Galveston Bay to Sabine Lake, including the Sabine-Neches Canal and the Port Arthur Canal, (2) Spindletop Ditch, and (3) the withdrawal point as shown schematically in Figure B-1. The dimensions assumed for these water bodies are presented in Table B-1. A trapezoidal, prismatic cross-sectional shape and a friction coefficient of 0.045 were assumed throughout the network.

All other water bodies are taken into account implicitly by way of boundary conditions or by assumed distributed lateral inflows into the ICW. A lateral inflow of 0.0025 cfs/ft was assumed along the entire length of the ICW. Boundary conditions are given below:

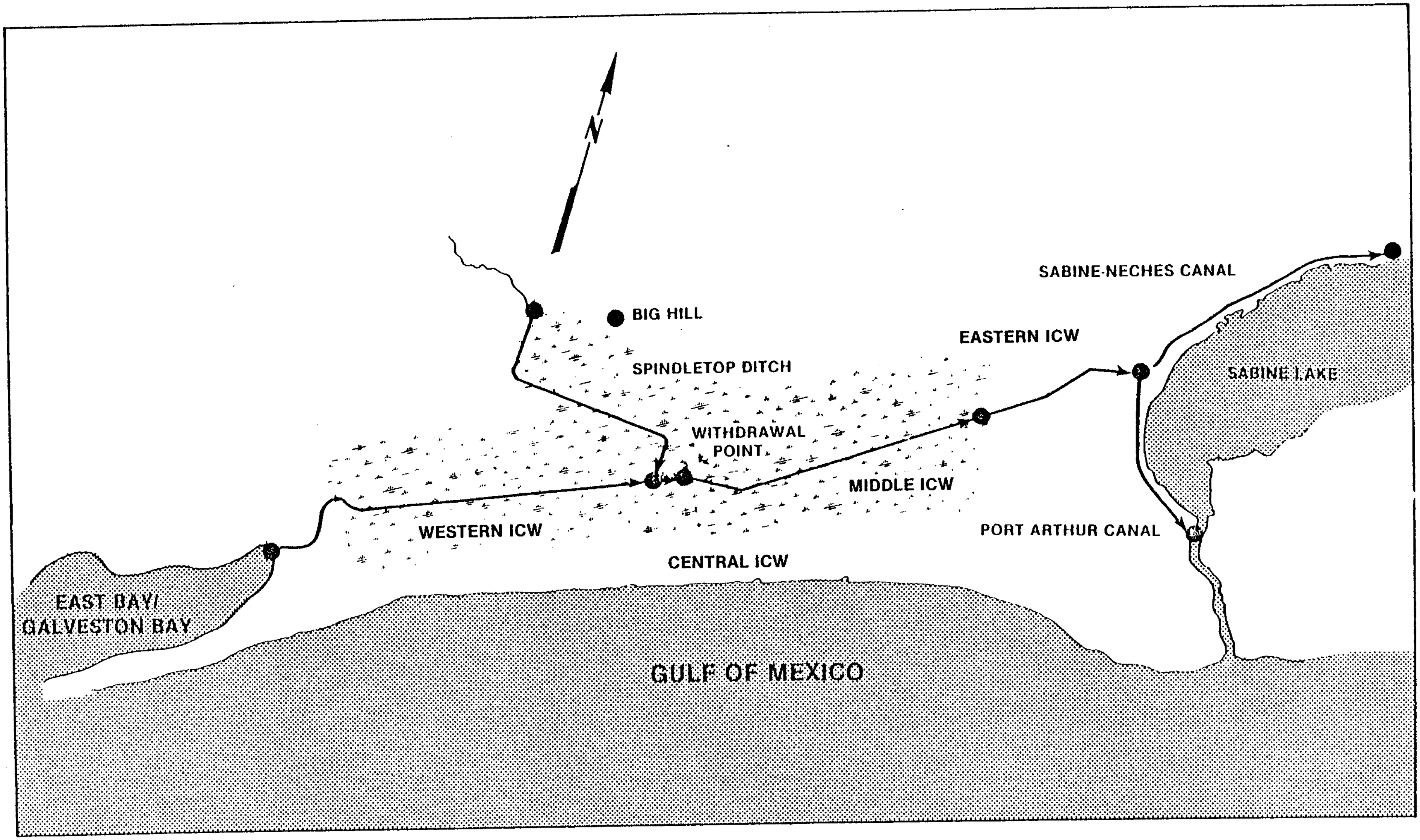

Figure B-1. Map of the water body network for the Big Hill region. Dots show nodal points for the network analysis. Arrows show initial direction of water flow.

Table B-1. Geometry of water bodies modeled in the Big Hill water withdrawal analysis

Water body	Bottom width (ft)	Side slope vertical:horizontal	Depth (ft)	Length (miles)
1 Western ICW	125	0.5	12	16.9
2 Spindletop Ditch	50	0.1	5	11.5
3 Central ICW	125	0.5	12	1.3
4 Middle ICW	125	0.5	12	11.8
5 Eastern ICW	125	0.5	12	5.5
6 Sabine Neches Canal	400	0.5	40	12.0
7 Port Arthur Canal	400	0.5	40	6.0

Location	Hydraulic	Water quality
Junction of ICW with Galveston Bay	Sinusoidal variation of surface height with a range of 1 ft, period of 12 h, and lag time of 25 min	Constant salinity of 24 ppt
Junction of Sabine-Neches Canal with Sabine Lake	Sinusoidal variation of surface height with a range of 1 ft, period of 12 h, and zero lag time	Constant salinity of 14 ppt
Junction of Port Arthur Canal with Sabine River	Sinusoidal variation of surface height with a range of 1 ft, period of 12 h, and lag time of 1.5 min	Constant salinity of 21 ppt
Far end of Spindletop Ditch	Constant surface height of 5 ft	Constant salinity of 1 ppt
Entire length of ICW and Spindletop Ditch	Constant lateral inflow of 0.0025 cfs/ft	Constant salinity of 1 ppt for lateral inflow
Withdrawal point in the ICW	Zero withdrawal for 60 d followed by 82 cfs for 150 d	Zero diffusive flux

During an initial 60-d period, no water was withdrawn, and the network of water bodies was allowed to approach equilibrium. The resulting variation in water surface height and salinity near the withdrawal point of this startup period is included in Fig. B-2. The spatial distribution of salinity in the western ICW, the middle ICW, and Port Arthur Canal at the end of the 50-d startup period is included in Figs. B-3, B-4, and B-5. The corresponding spatial distribution of flow velocities is included in Figs. B-6 through B-8.

Examination of Fig. B-2 reveals that water depth reaches equilibrium within 1 d after the start of water withdrawal. Equilibrium with respect to salinity is reached within 10 d after initiation of withdrawal. Near the withdrawal point, the variation in water depth is projected to be no more than 0.04 ft. Salinity will differ by less than 1 ppt near the withdrawal point. The maximum change in salinity (an increase of less than 2 parts per thousand [ppt]) is projected for the western ICW near its junction with Galveston/East Bay. Velocities will be relatively unaffected, increasing by about 0.03 ft/s near the withdrawal point and by no more than 0.05 ft/s in the western end of the ICW.

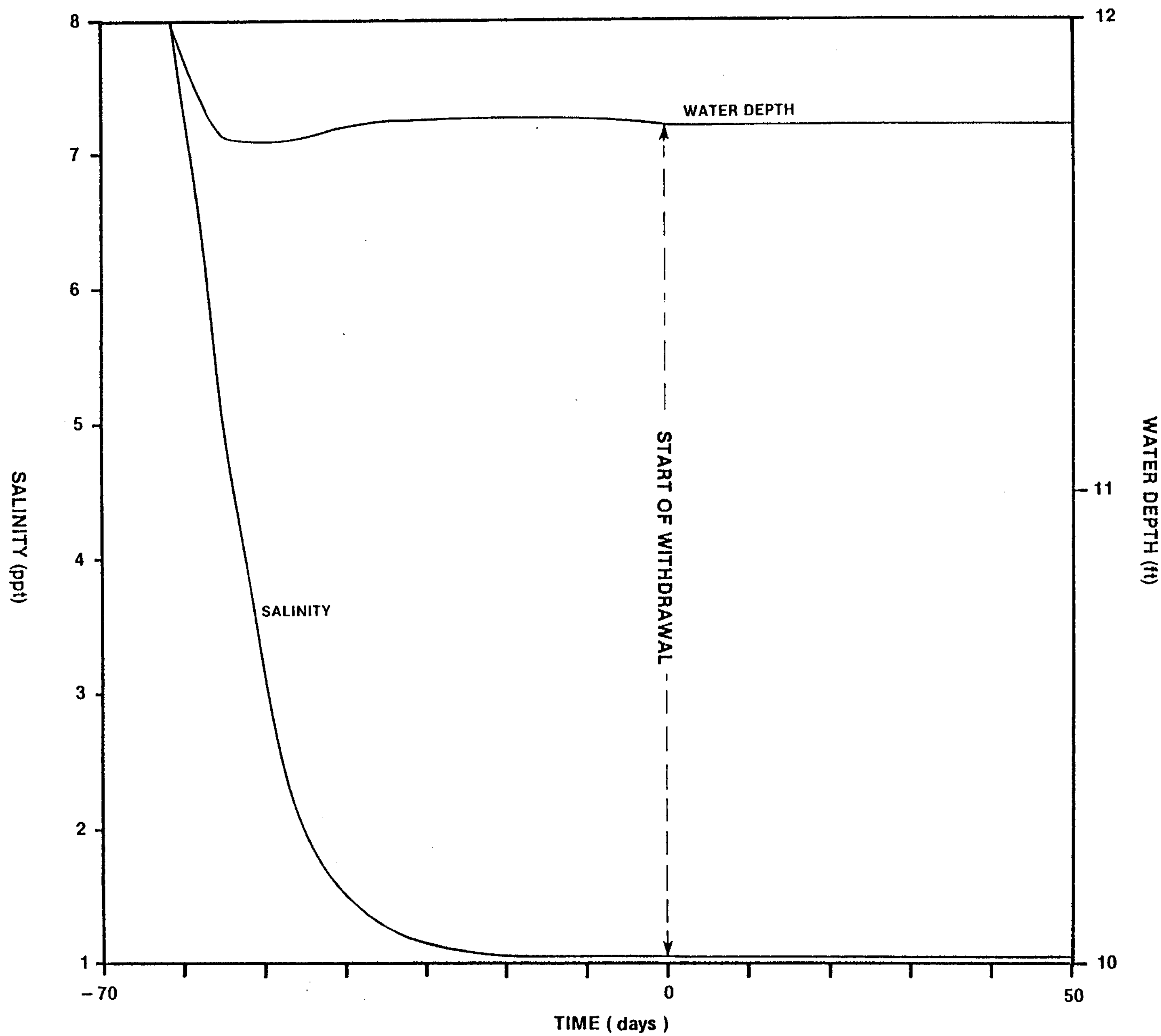

Figure B-2. Temporal variation of depth and salinity in the ICW near the point of withdrawal.

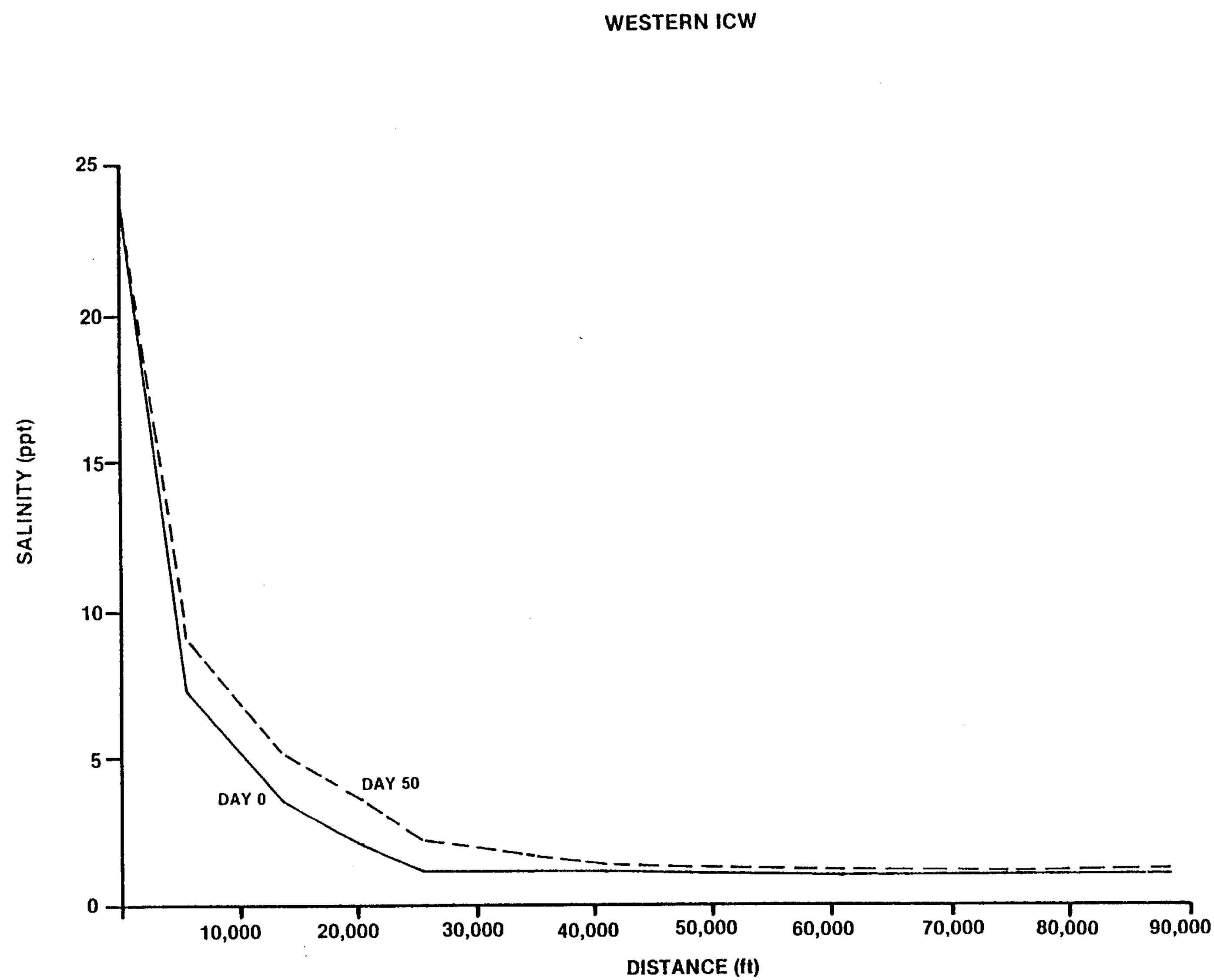

Figure B-3. Salinity profile for the western ICW at day 0 and day 50 after the start of withdrawal.

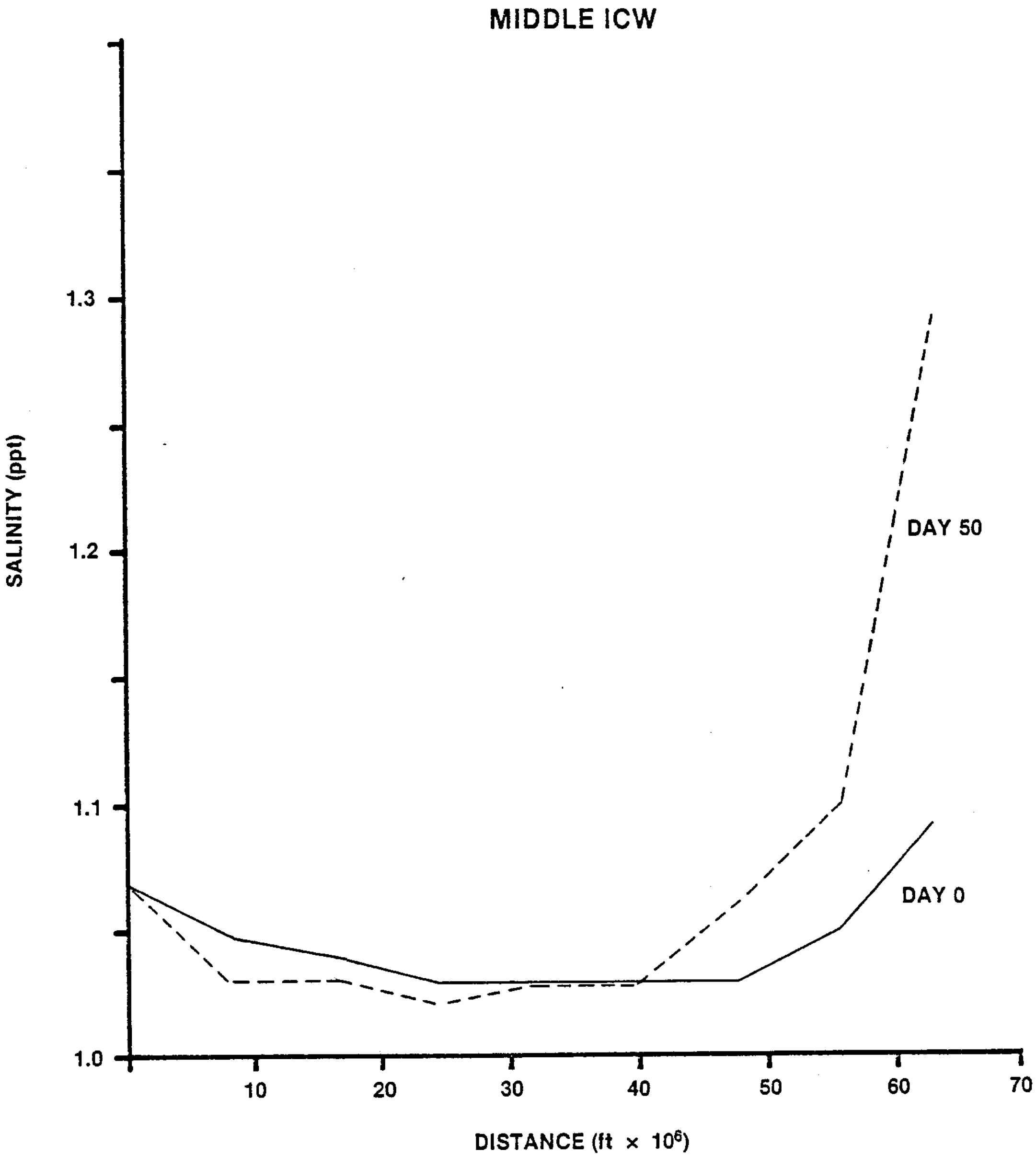

Figure B-4. Salinity profile for the middle ICW at day 0 and day 50 after the start of withdrawal.

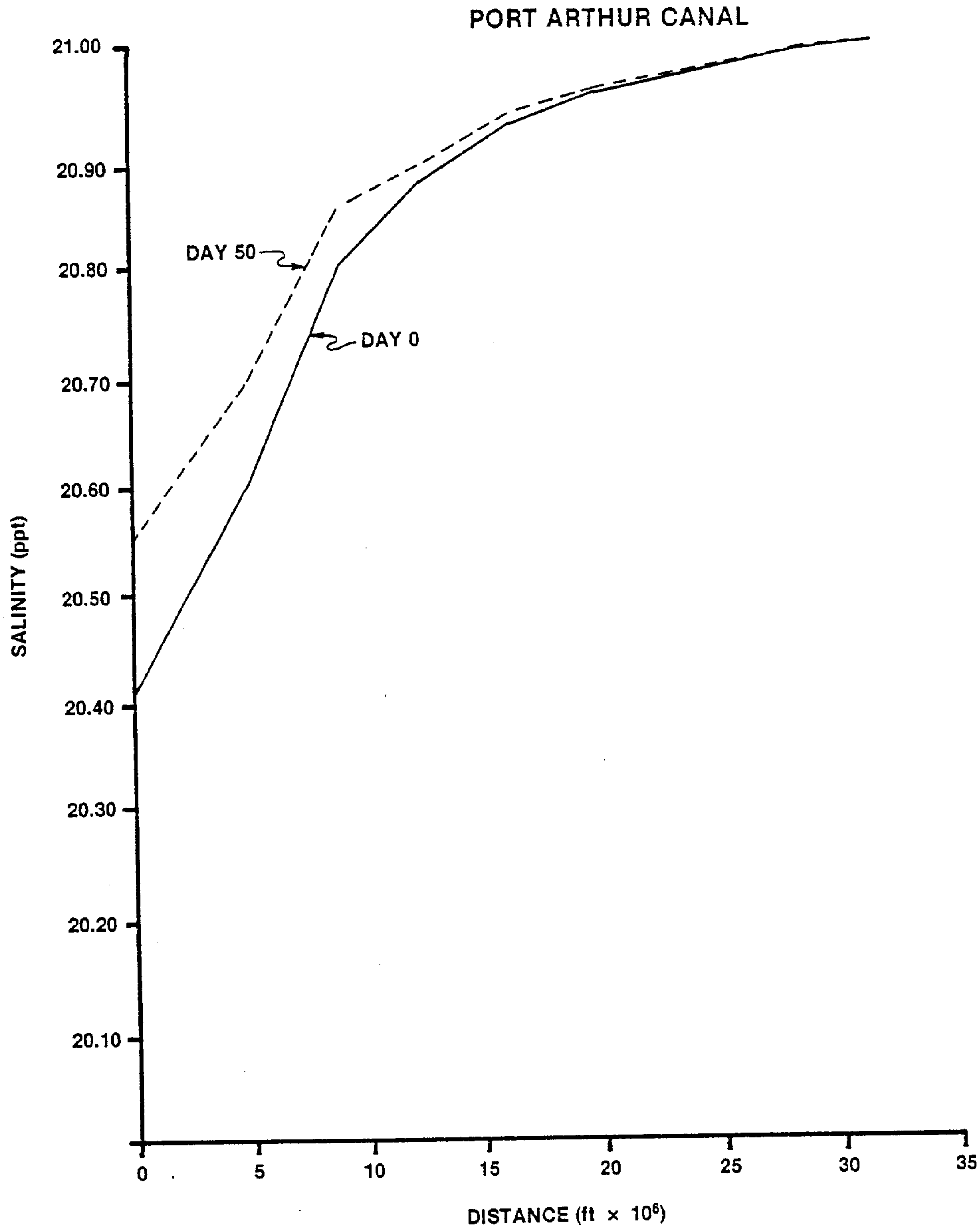

Figure B-5. Salinity profile for the Port Arthur Canal at day 0 and day 50 after the start of withdrawal.

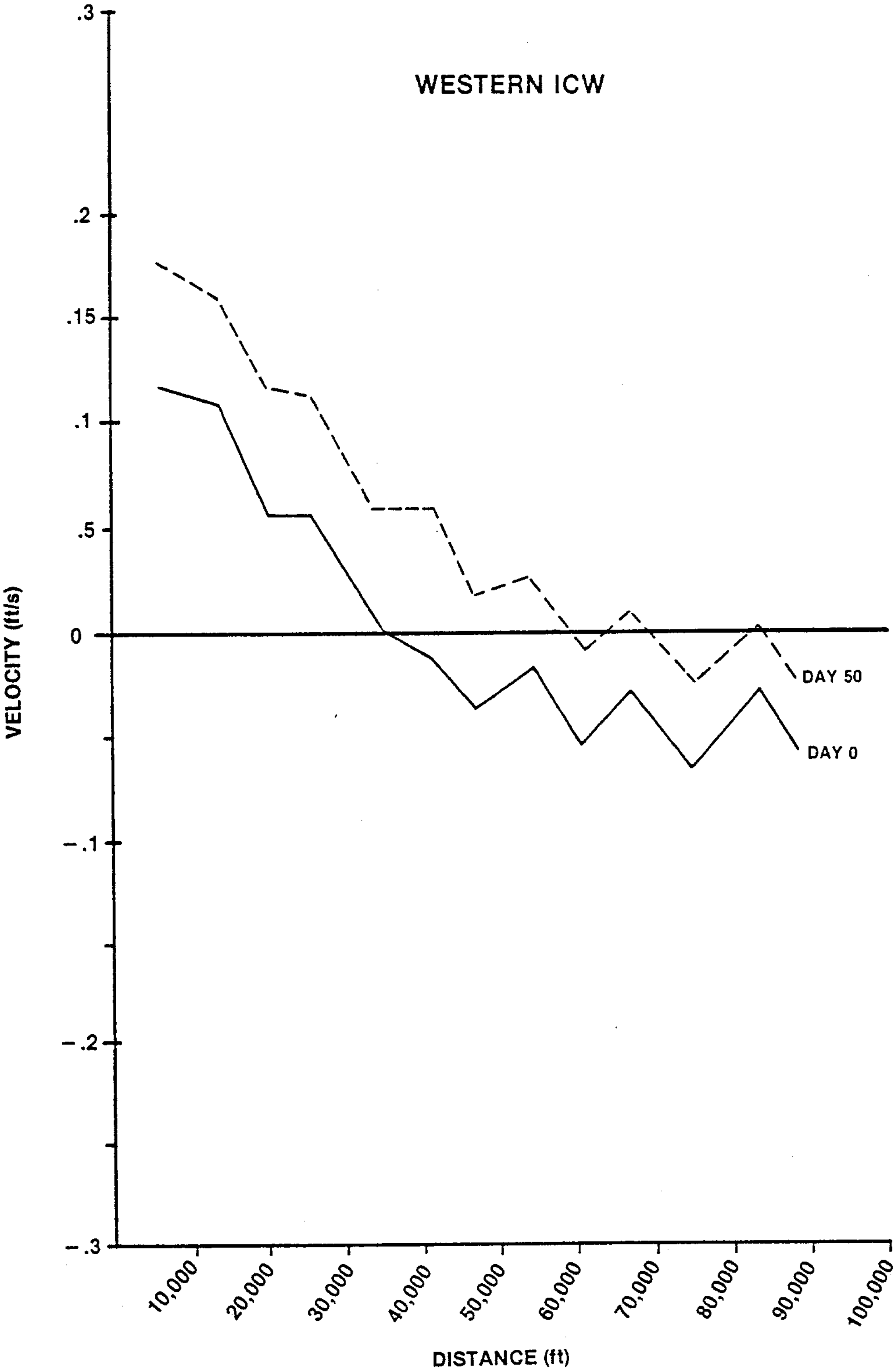

Figure B-6. Velocity profile for the western ICW at day 0 and day 50 after the start of withdrawal.

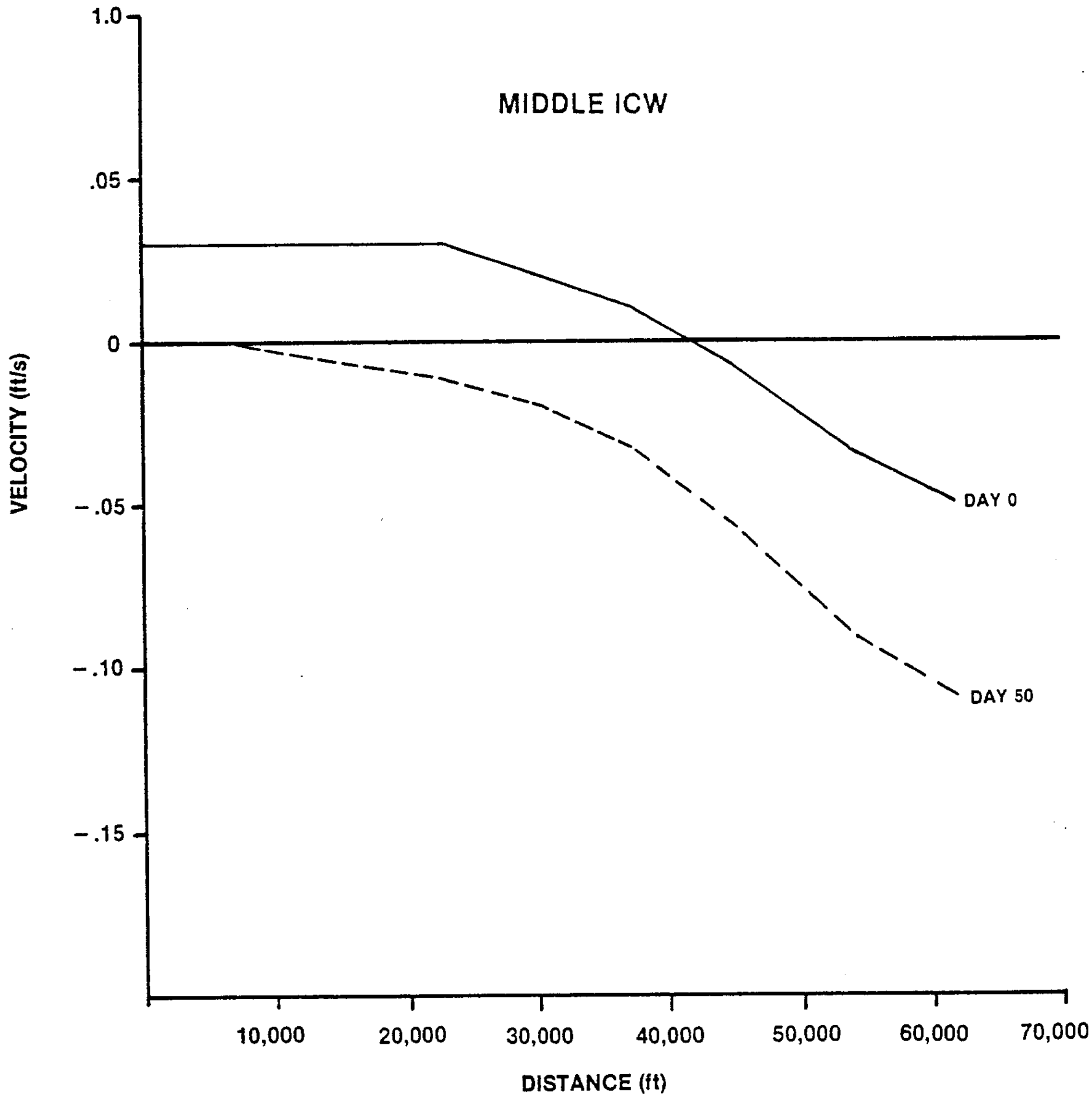

Figure B-7. Velocity profile for the middle ICW at day 0 and day 50 after the start of withdrawal.

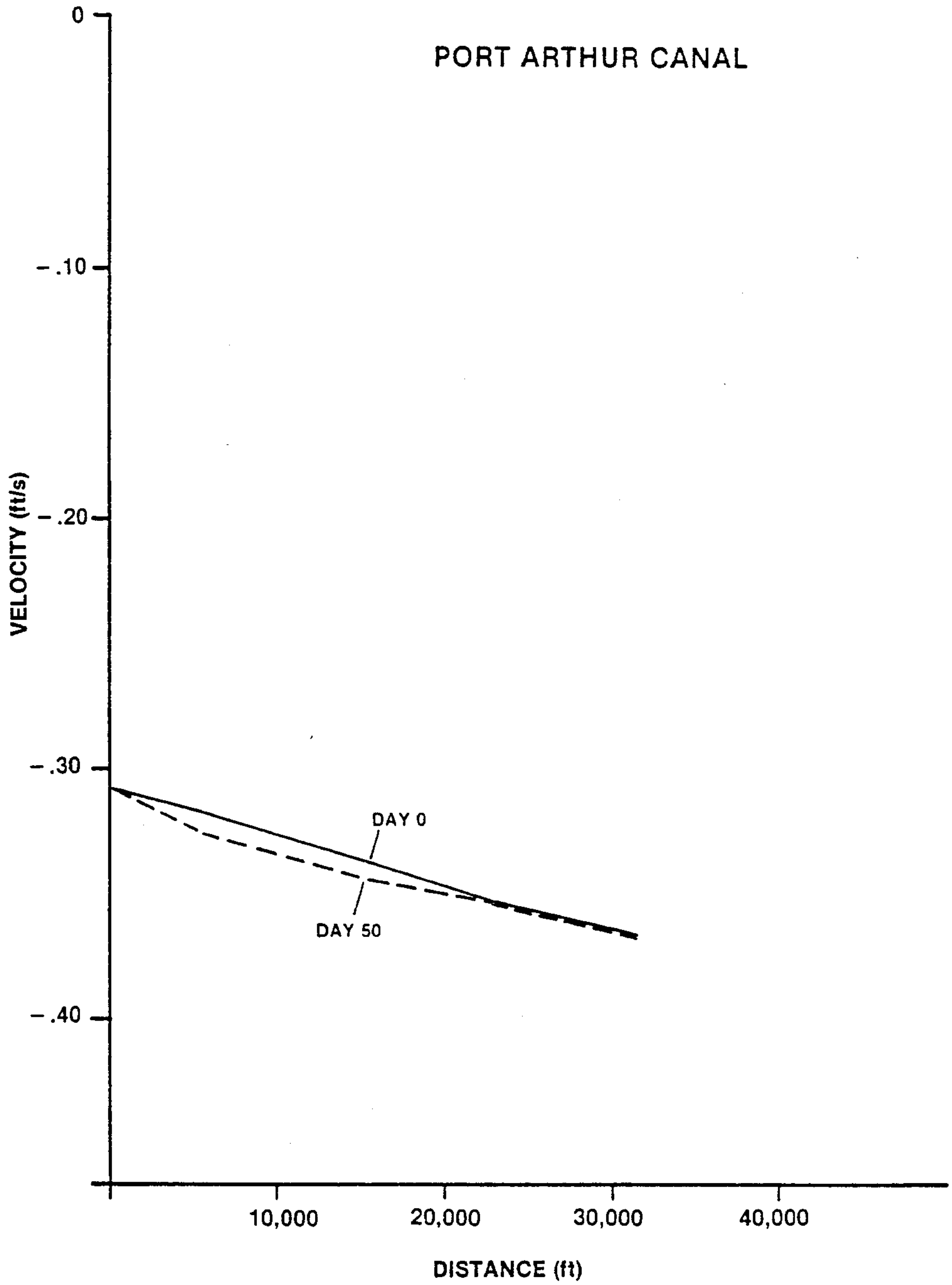

Figure B-8. Velocity profile for the Port Arthur Canal at day 0 and day 50 after the start of withdrawal.

Phase III expansion of the SPR would require the acquisition of or amendment to various state and Federal permits related to water pollution control and water rights.

Construction of the Big Hill facility would require application to the Texas Department of Water Resources (TDWR) for permits to appropriate the necessary State water from, and construct the raw water intake structure at mile 305 of the Gulf Intracoastal Waterway for leaching and displacement operations pursuant to Sections 11.021 and 11.212 of the Texas Water Code.

Applications would also be required for permits to dispose of brine and other waste under the National Pollution Discharge Elimination System (NPDES) currently under dual authority of EPA and TDWR. Construction of the brine line and diffuser in Texas coastal waters would require a permit from TDWR pursuant to Chapter 26 and Section 16.238 of the Texas Water Code and Article 4477-7 of Vernon's Annotated Civil Statutes. Expansion of the Bryan Mound and West Hackberry sites would require amendments to existing permits on file with EPA and the states of Texas and Louisiana. These permits cover the disposal of brine and other wastes as well as appropriation of water for leaching and displacement operations. Both the water quality and water appropriation parts of the permit will have to be modified if the leach rate at Bryan Mound is increased to 980,000 bbl/d.

APPENDIX B

REFERENCES

Harleman, D. R. F., Dailey, J. E., Thatcher, M. L., Najarian, T. O., Brocard, D. N., and Ferrara, R. A., 1976. User's Manual for the M.I.T. Transient Water Quality Network Model Including Nitrogen-Cycle Dynamics for Rivers and Estuaries. Report No. 216, Ralph M. Parsons Laboratory for Water Resources and Hydrodynamics, Department of Civil Engineering, Massachusetts Institute of Technology.

APPENDIX C

AIR QUALITY ANALYSIS

APPENDIX C.1

INTRODUCTION

Appendix C presents detailed information and data on air quality considerations for the expansion sites.

Part C.2 explains the oil-brine model and assumptions made in deriving the emission rates for the various activities at the three sites. Part C.3 details the methodology and assumptions used for determining on-site emissions other than the oil-brine emissions. Part C.4 is comprised of computer output from the various air quality modeling runs. References are given in Part C.5.

APPENDIX C.2

BRINE EMISSIONS

Oil/brine interactions resulting from the contact of crude oil with brine inside salt dome caverns and the resulting emissions to the atmosphere from surface brine ponds were initially assessed in the absence of any comparable experience or directly applicable data (DOE, 1977, Appendices A and B). Since then, the planned cavern dimensions, which play a role in oil/brine interactions, have been substantially changed; the solution mining, or leaching, process has been refined in detail; and certain data and experience have been obtained. A re-evaluation of the previous brine emission model and assessment, then, begins with a description of current cavern leaching plans.

Cavern Development

Each new 10 MMB cavern is developed by leaching a 2,400-foot uncased portion of borehole (or boreholes) beginning several hundred feet within the salt stock. The leaching program is designed to produce a cavern with total leached volume of 12.3 MMB: 10 MMB for oil, 1 MMB for a brine buffer and a 1.3 MMB sump for insolubles. A prototype cavern is shown at the depth interval for Big Hill in Figure C.2-1 which is drawn without horizontal exaggeration, i.e., to the same scale vertically and horizontally. For comparison, Bryan Mound Cavern No. 2, which was an existing cavern acquired for the SPR in Phase I, is shown at the same scale.

Among the Bryan Mound, West Hackberry and Big Hill sites, a mix of cavern leaching configurations will be employed; caverns will have one, two or three wells and these may or may not have suspended concentric tubing strings. Sufficient work has been done to indicate that the leaching configuration has little impact on cavern geometry or volume or on the physical factors affecting oil/brine interactions for a given brine production rate. Therefore, the leaching configuration is not of concern in this assessment and, for simplicity of illustration, cavern development is described for the case of one well with concentric tubing strings.

The maximum diameter of the prototype 10 MMB cavern is 230 ft which occurs at the base of the conical roof, 100 ft below the apex (Figure C.2-1). The diameter 2,000 ft below the roof is 170 ft. Increasing cavern height and reducing the diameter relative to earlier designs results in a cavern design that maximizes vertical separation among raw water and oil injection points, the brine production point and the oil-brine interface, thereby minimizing turbulence at the interface. In addition, the current design minimizes the area of the interface. A further advantage is the reduced spacing on centers among caverns necessary to maintain stability and integrity of the salt dome.

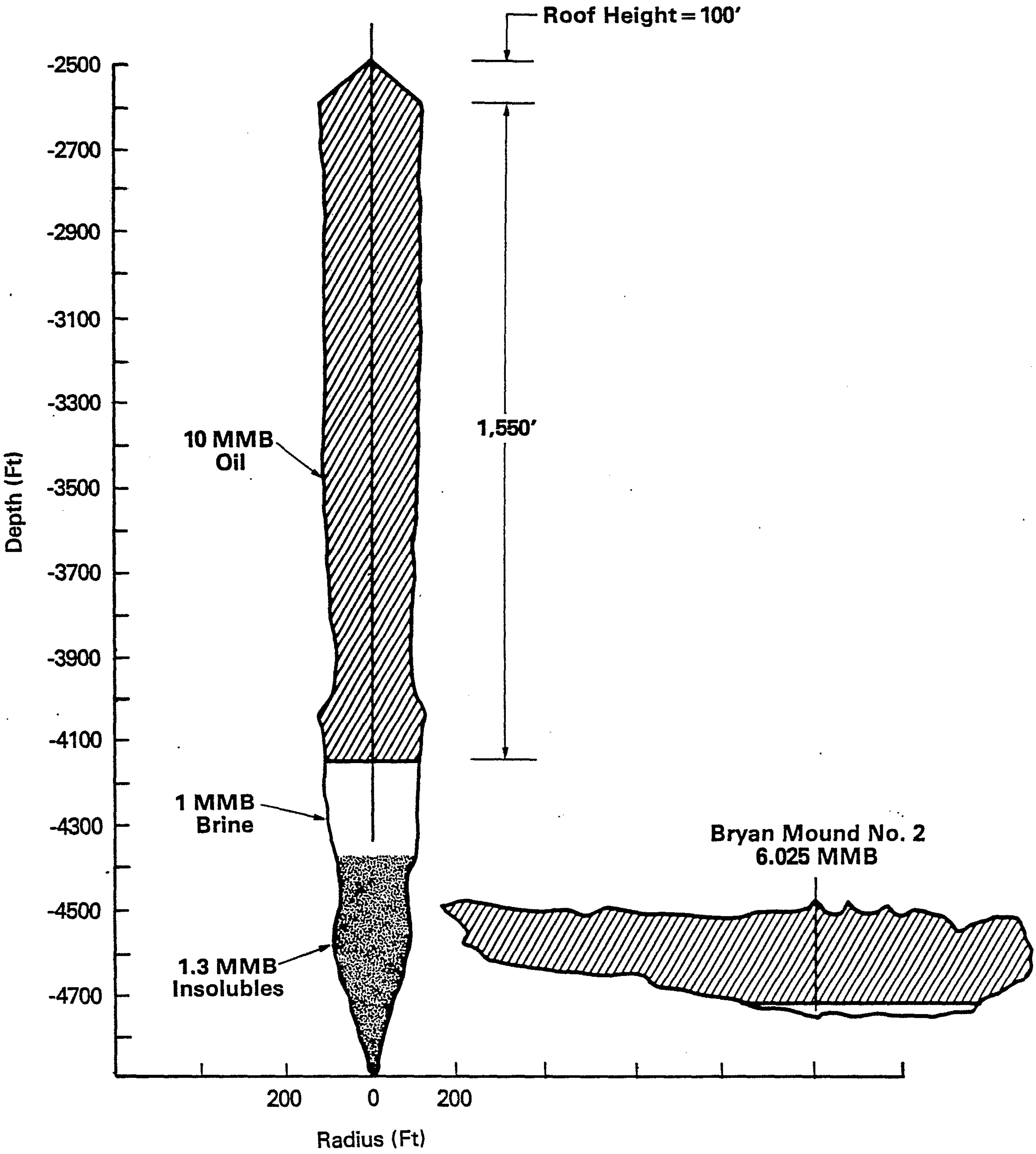

Figure C.2-1 Comparison of a prototype new-leached cavern with an existing Phase I cavern.

Cavern development may be characterized in terms of five stages which are defined by the relative positions of the oil level, the water injection point and the brine production point. The oil level determines the upper limit of leaching. The relative levels of water injection and brine production points control the change in diameter with depth. The five stages of development are called sump, sump/chimney, first reverse (or roof development), second reverse and third reverse. Significant oil injection rates do not occur until the second and third reverse stages.

To begin development of the sump, the inner tubing string used for raw water injection is extended to near the bottom of the uncased borehole; the bottom of the brine tubing string is positioned 400 to 500 ft above; and the hole is flooded with oil down the annulus (the space between the outer tubing string and the cemented casing). Water is introduced to displace the oil level to a point 850 ft above the bottom of the hole where it is maintained throughout this stage of development (Figure C.2-2). With the commencement of leaching, salinity increases rapidly, typically approaching 200 ppt in less than a month. As the lighter water rises through the dense brine, it rapidly increases in salinity which results in faster growth at the bottom than at the top of the borehole interval below the oil. Growth at the bottom 100 to 200 ft, however, is inhibited by the accumulation of insolubles which quickly buries the water injection point. If circulation is interrupted, however briefly, the water tubing may be plugged by a backflow of insolubles. Therefore, the uncertainty in development schedule is greatest for this stage, as the difficulty in clearing a plugged well varies drastically.

When a volume of between 0.2 and 0.5 MMB is estimated to have been leached, cavern development is temporarily halted and a sonar caliper survey is performed to confirm size and shape. Leaching progress is estimated during operations by continual observations of brine salinity and production rate which are input to a computerized leaching model. The leaching model is accurate to within 5 percent of actual volume, the major source of error being inhomogeneities in the salt stock.

Following the sonar caliper survey, the tubing strings are repositioned to develop the sump/chimney. The bottom of the water injection tubing is raised 150 to 300 ft, the bottom of the brine production tubing is raised 1,800 ft, and the oil/brine interface is displaced upward to the top of the uncased portion of the borehole, 2,400 ft above total depth. This point will become the apex of the cavern roof (Figure C.2-2). Total workover time for these operations is about two weeks.

As is the case for sump development, brine is produced above the level at which water is injected during sump/chimney development and results in greatest growth at the bottom of the cavern. Leaching continues until the desired diameter at the bottom of the cavern, 170 ft, is obtained. At this point, total cavern volume is about 3.5 MMB. The oil/brine interface is in the annulus at the peak of the cavern throughout this stage. (In Figure C.2-2, the tubing strings are omitted for clarity.)

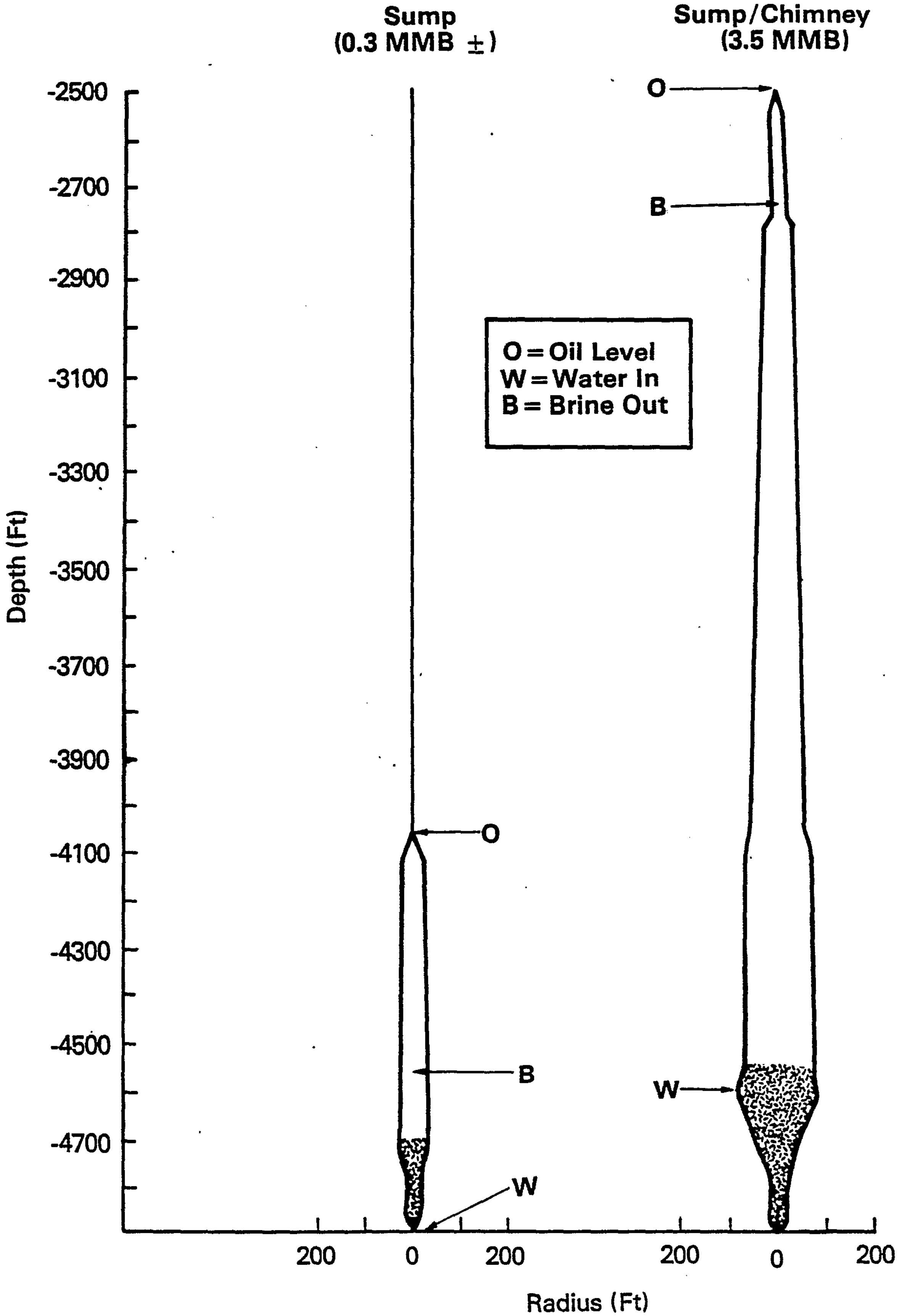

Figure C.2-2 Prototype cavern at the end of the first and second development stages.

Upon completion of the sump/chimney, cavern development is halted and another two-week period is devoted to a sonar caliper survey and to repositioning the tubing strings in preparation for leaching the cavern roof.

To create the roof, it is necessary to reverse the direction of cavern growth from the bottom upward to the top downward, hence the phrase, first reverse. This is accomplished by reversing the water and brine flow direction in the respective tubing strings, such that brine is now produced up the inner tubing from a point near the bottom and water is injected from the outer tubing at a point slightly below the desired level for the base of the roof (Figure C.2-3). To create a conical roof 100 ft high, the water injection point is set 250 ft below the roof peak, while the brine production point is set about 1,650 ft below the water injection point.

Because of the water/brine density difference, the relative tubing string positions of the first reverse result in accelerated growth rates over a smaller interval of cavern wall compared to the direct leaching mode of the sump and sump/chimney. Once the desired diameter of a given interval is obtained, further growth is prevented by filling the interval with blanket oil; thus, the roof is filled with about 0.25 MMB of oil at completion. The average rate of oil injection during roof development is less than one thousand barrels per day, a relatively insignificant rate. In developing the 0.25 MMB capacity roof, the cavern grows overall by about 3 MMB to a total of 6.5 MMB.

The remainder of the cavern is developed in two further reverse leaching stages, each preceded by a sonar caliper survey and repositioning of tubing strings. Each stage entails leaching relatively small intervals of cavern wall to the desired diameter from the top downward.

Saturated brine inhibits further growth in the bottom few hundred feet. For each stage, the brine tubing string is raised to accommodate the rising level of insolubles and the water tubing string is lowered. For the final setting of the third reverse, the water injection and brine production points are separated by about 200 ft. At completion of leaching, the 12.3 MMB cavern contains about 60 percent of its 10 MMB oil capacity and the oil/brine interface is about 650 ft above the water injection point (Figure C.2-3).

Significant rates of oil fill during leaching occur only during the second and third reverse stages, ranging from 10 to 20 thousand barrels per day per cavern. At rates greater than ten thousand barrels per day, leaching is interrupted. At an average brine production rate of 100 thousand barrels per day per cavern, about 1,200 days are required to leach a 12.3 MMB cavern.

<u>Sample Collection and Analysis</u>

Data of oil and grease dissolved in brine at the brine pit have been collected routinely by DOE since commencement of brine discharge to the Gulf of Mexico in March 1980 as a requirement of DOE's wastewater discharge permit. Similar data have been collected in Germany and

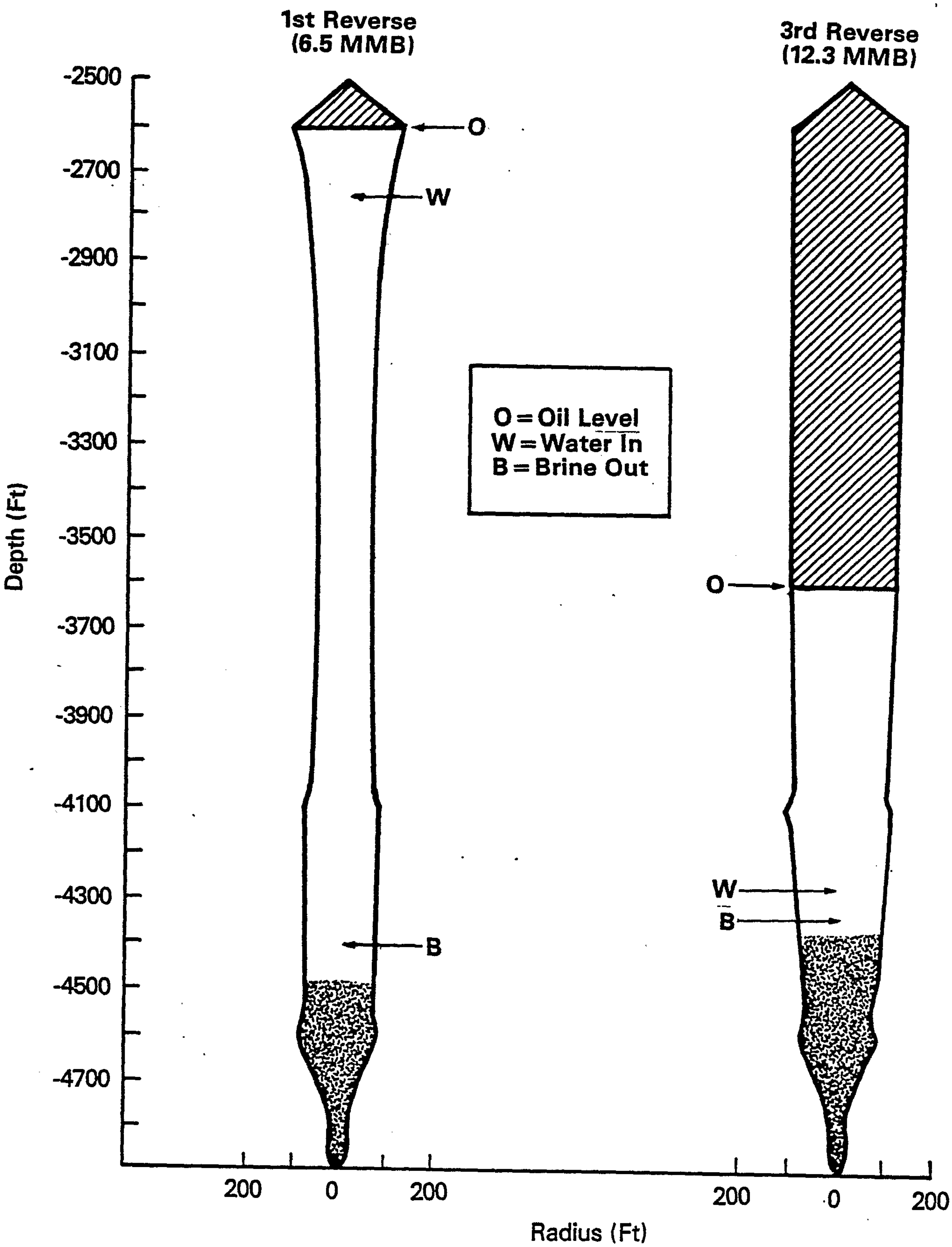

Figure C.2-3 Prototype cavern at the end of roof development and at completion.

France. However, as best as can be determined, there are no data previously available of observed composition and concentration of hydrocarbons dissolved in brine inside the caverns and subsequent emissions at the point where brine is first exposed to the atmosphere, i.e., the oil-brine separators. With the accomplishment of significant levels of oil fill in existing SPR caverns and substantial development of new leached caverns, DOE initiated an ongoing sampling program in late spring 1981 to characterize hydrocarbon composition and concentration in brine as the brine exits the cavern. Brine samples are collected from a point and in a manner which precludes loss of dissolved gases and volatile constituents. Clean, evacuated 3.8-liter stainless steel, high-pressure cylinders are connected to a valve on the brine production pipe directly at the wellhead. New caverns actively being leached, and existing caverns filled or nearly filled with oil are sampled. In the latter case, if the cavern is quiescent, a quantity of brine equivalent to 150 percent of the volume of the brine production string is bled off prior to sample collection. If the cavern is being filled with oil, a sample of the brine effluent is collected.

Brine at the wellhead has frequently been noted to effervesce or foam as a result of the pressure drop and degassing. This causes the observed headspace in the sampling cylinders of between 0.5 and 5 percent of their volume. The headspace gas consists principally of nitrogen, and of minor to trace amounts of oxygen, carbon dioxide, and methane through heptane. Pressures within the cylinders range from one to about two atmospheres (absolute), i.e., the cylinders exhibit a slight positive pressure relative to the atmosphere. This is consistent with sampling of a closed system, as the brine production string typically exhibits pressures on the order of four atmospheres.

In the laboratory, the headspace gas is sampled first using a gas-tight syringe. This subsample, typically less than 5 ml, is analyzed by gas chromatography and the concentration of each component determined using standard mixtures for reference. Pressure-volume-temperature corrections are used in computing concentration of each component.

Next, a subsample of the brine, generally 250 g, is withdrawn from the cylinder directly into an evacuated flask. The brine subsample is degassed using a Toepler pump and the evolved gases collected in a cold-trap. The recovered volatiles are then analyzed by gas chromatography and the concentration of each component determined in the same manner as for the headspace sample. From the time of collection and throughout the analysis, the sample is not exposed to atmospheric conditions, which effectively precludes loss of any volatile constituents.

Density of the brine is measured to within 0.0002 g/ml using a digital densitometer calibrated with water at 15.6°C (60°F). Volume of brine in the cylinder and volume of the cylinder are measured, and volume of the headspace gas determined by difference.

Results and Discussion

To date, laboratory analyses have been completed on twelve samples which were collected at Bryan Mound on two dates, six each on June 4, 1981 and June 24, 1981. The results are presented in Tables C.2-1, C.2-2, and C.2-3 according to the status of caverns from which samples were drawn.

Data of hydrocarbons and atmospheric gases dissolved in brine in existing Phase I caverns is shown in Table C.2-1. Total concentration represents concentration in brine within the cavern. Concentrations in brine and in vapor represent the partitioning of constituents between vapor and liquid phases upon sample depressuring upon collection.

The maximum total NMHC concentration observed was 3.0 ppm which occurred in the two samples from Bryan Mound Cavern 2. This cavern was 75 percent filled with crude oil in March 1978, 90 percent filled in July 1978 and 100 percent filled in February 1979, and it has remained quiescent since that time. The brine volume is estimated to be less than 100 thousand barrels and, as is indicated in Figure C.2-1, the area of the oil/brine interface is large and the brine column height is small. Therefore, it is reasonable to assume that NMHC is at equilibrium in the brine of Cavern 2 and that 3.0 ppm is, therefore, a worst case concentration. This is substantially lower than the 31.4 ppm previously predicted for equilibrium conditions (DOE, 1977, Appendix A).

The fraction of NMHC which went to vapor varied from 50 to 90 percent among the five samples from existing caverns.

Four samples were collected from caverns actively being leached in the sump/chimney stage (Table C.2-2). Of these, only the two collected from Cavern 109 had appreciable amounts of NMHC. The sample from the largest cavern of the group, Cavern 105, had no detectable NMHC. The low levels of NMHC observed for the sump/chimney leaching samples is not surprising since there is essentially no oil blanket in contact with brine during this stage of development.

Three samples were collected from caverns actively being leached in the middle to late stages of roof development (first reverse). Cavern volume ranged from 4.3 to 6.3 MMB and brine production from each cavern at the time of sampling ranged from 6,950 to 9,100 barrels per hour (Table C.2-3). At 6.3 MMB, Cavern 106 was the most advanced new leached cavern in the SPR. While total NMHC concentrations were intermediate between sump/chimney leaching and quiescent, filled caverns, averaging 1.19 ± 0.72 ppm, the fraction going to the vapor phase was low, averaging 37 ± 8 percent.

In addition to the low NMHC concentrations observed, another unexpected result was the composition of NMHC constituents. Among the set of twelve samples, NMHC constituents consisted of C_2 through C_7 paraffins. No cycloparaffins or aromatics were detected. Relative composition was variable within cavern groups; sample populations were too small to distinguish patterns or trends (Table C.2-4).

Table C.2-1 Hydrocarbons and gases in brine in existing caverns.

Sample[a]	2_1	2_2	4_1	4_2	5
Cavern Oil Fill (%)	100	100	83	92	94
Carbon Dioxide (ppm)					
Total	9.73	10.44	0.11	0.02	2.07
in brine	8.11	8.49	0.02	0.02	1.93
in vapor	1.62	1.95	0.09	0.00	0.14
Oxygen (ppm)					
Total	4.66	2.27	5.82	4.52	4.03
in brine	2.55	1.37	3.64	0.95	3.57
in vapor	2.11	0.90	2.18	3.57	0.46
Nitrogen (ppm)					
Total	54.50	13.09	52.74	32.49	36.87
in brine	11.70	4.95	18.56	6.14	18.44
in vapor	42.70	8.14	34.18	26.35	18.43
Methane (ppm)					
Total	22.51	19.66	0.24	0.26	4.61
in brine	2.86	3.64	0.08	0.06	2.05
in vapor	19.65	16.02	0.16	0.20	2.55
NMHC[b] (ppm)					
Total	2.98	2.99	1.16	1.18	2.44
in brine	0.30	0.66	0.29	0.14	1.22
in vapor	2.68	2.33	0.87	1.04	1.22

[a] Sample numbers refer to Bryan Mound caverns; subscripts 1 and 2 refer to collection on June 4, 1981 and June 24, 1981, respectively.

[b] NMHC = Non-methane hydrocarbons.

Table C.2-2 Hydrocarbons and gases in brine during sump/chimney leaching.

Sample[a]	105	108	109_1	109_2
Cavern Volume (MMB)	2.3	0.9	1.8	1.8
Discharge (bbl/h)	6,423	1,849	2,559	1,855
Salinity (ppt)	263	264	264	261
Density (g/ml)	1.2036	1.2046	1.2044	1.2018
Carbon Dioxide (ppm)				
Total	2.95	1.55	3.07	1.47
in brine	2.93	1.45	2.96	1.44
in vapor	0.02	0.10	0.11	0.03
Oxygen (ppm)				
Total	2.74	2.20	1.58	1.75
in brine	2.58	0.51	1.04	1.64
in vapor	0.16	1.69	0.54	0.11
Nitrogen (ppm)				
Total	16.79	30.28	13.11	9.09
in brine	11.95	6.09	7.81	6.98
in vapor	4.84	24.19	5.30	2.11
Methane (ppm)				
Total	0.01	0.07	11.26	6.30
in brine	0.01	0.02	4.38	4.01
in vapor	0.00	0.05	6.88	2.29
NMHC[b] (ppm)				
Total	0.00	0.02	0.53	0.22
in brine	0.00	0.02	0.16	0.13
in vapor	0.00	0.00	0.37	0.09

[a]Sample numbers refer to Bryan Mound caverns; subscripts 1 and 2 refer to collection on June 4, 1981 and June 24, 1981, respectively.

[b]NMHC = Non-methane hydrocarbons.

Table C.2-3 Hydrocarbons and gases in brine during first reverse leaching.

Sample[a]	106_1	106_2	107
Cavern Volume (MMB)	5.8	6.3	4.3
Discharge (bbl/h)	9,103	6,953	7,129
Salinity (ppt)	263	263	265
Density (g/ml)	1.2033	1.2037	1.2053
Carbon Dioxide (ppm)			
Total	2.25	3.25	1.78
in brine	2.18	3.10	1.76
in vapor	0.07	0.15	0.02
Oxygen (ppm)			
Total	1.59	4.50	3.48
in brine	1.38	2.20	3.28
in vapor	0.21	2.30	0.20
Nitrogen (ppm)			
Total	23.78	37.35	27.16
in brine	10.99	10.83	17.36
in vapor	12.79	26.52	9.80
Methane (ppm)			
Total	6.20	8.18	4.54
in brine	3.11	2.04	2.50
in vapor	3.09	6.14	2.04
NMHC[b] (ppm)			
Total	0.19	1.81	1.58
in brine	0.10	1.31	1.00
in vapor	0.09	0.50	0.58

[a]Sample numbers refer to Bryan Mound caverns; subscripts 1 and 2 refer to collection on June 4, 1981 and June 24, 1981, respectively.

[b]NMHC = Non-methane hydrocarbons.

Table C.2-4 Relative composition of NMHC constituents.

Cavern Status	Alkane Carbon No.	Composition as % of Total NMHC	Coefficient of Variation (%)
Existing, Quiescent (n = 5)	C_2	16.9 ± 10.5	62.1
	C_3	37.9 ± 5.7	15.0
	C_4	26.8 ± 9.8	36.6
	C_5	11.1 ± 4.2	37.8
	C_6	4.7 ± 0.4	8.5
	C_7	2.5 ± 3.4	136
Leaching, First Reverse (n = 3)	C_2	23.9 ± 15.2	63.6
	C_3	12.7 ± 7.7	60.6
	C_4	10.6 ± 5.2	49.1
	C_5	22.1 ± 10.4	47.1
	C_6	15.0 ± 17.3	115
	C_7	15.6 ± 12.2	78.2

In the quiescent caverns, NMHC were predominantly ethane and propane; C_7 was frequently absent and $C_6 + C_7$ accounted for less than ten percent. For the sump/chimney leaching stage, only the two samples from Cavern 109 had appreciable amounts of NMHC; of these amounts, 86 percent was ethane and propane. For first reverse, relative composition was also highly variable. Most of the NMHC variation between the two samples from Cavern 106 is due to C_6 and C_7. C_6 and C_7 were absent from the first sample but were 0.7 and 0.5 ppm, respectively, in the second. The latter was the only sample in which either C_6 or C_7 was greater than 0.3 ppm.

Oil in Brine Model

Hydrocarbon emissions from brine should be dependent to a significant degree on the status and operations of the caverns. To model impacts on air quality, cavern operations may be classified by four categories: leach, leach/fill, final fill, and refill. A fifth category, drawdown, is of no concern to the oil in brine model since drawdown does not entail brine discharge; however, drawdown is taken into account in estimating other on-site emission sources, such as surge tankage (see Appendix C.3).

Leaching is defined as the development period prior to the start of significant oil fill and includes the sump, sump/chimney and first reverse. At the completion of the roof during first reverse, the 0.25 MMB roof volume is filled with crude oil. At an average brine production rate of 100 thousand barrels per day per cavern, it takes about 638 days from teh start of cavern leaching through completion of the roof. Sump and sump/chimney development requires the first 253 days during which the average oil injection rate is essentially zero. Average oil injection for the 385 day period of roof development is 650 barrels per day.

Leach/fill refers to the period of significant oil fill during leaching which occurs during the second and third reverses at rates ranging from 10 to 20 thousand barrels per day per cavern. According to current plans, when fill rates exceed ten thousand barrels per day, leaching will be interrupted. At a brine production rate of 100 thousand barrels per day per cavern, leach/fill will last 365 days and oil injection will average 16,500 barrels per day.

When leach/fill is complete, the cavern will be 60 to 65 percent full of crude oil. The period to complete oil fill of the new cavern after completion of leaching is referred to as final fill; its duration is dependent on site-specific logistic constraints at the terminals. Similarly, cavern refill after a drawdown will be dependent upon site-specific constraints of oil logistics.

Emissions from leaching may be computed from the data of the seven Bryan Mound samples in Tables C.2-2 and C.2-3. The mix of cavern development stages and operations that were sampled are believed to be typical. Emissions in grams per second were calculated from total NMHC in brine, the fraction going to vapor and the brine production rate from each cavern at the time of sampling. Results are shown in Table C.2-5 for each cavern and the composite for sampled caverns on each date. On both

Table C.2-5 Bryan Mound NMHC Emissions from leaching.

Date: June 4, 1981

	Cavern No.			
	106	107	109	Composite
Discharge (MBD)	218.5	171.1	61.4	415
NMHC Emissions (g/s)				
@ Actual Discharge	0.04	0.22	0.05	0.31
@ 680 MBD	0.14	0.87	0.56	0.47
@ 980 MBD	0.20	1.26	0.80	0.67

Date: June 24, 1981

	Cavern No.				
	105	106	108	109	Composite
Discharge (MBD)	154	167	44	45	410
NMHC Emissions (g/s)					
@ Actual Discharge	0.00	0.18	0.00	0.01	0.19
@ 680 MBD	0.00	0.30	0.00	0.02	0.32
@ 980 MBD	0.00	0.43	0.00	0.02	0.45

Mean concentration of NMHC to vapor phase for 7 samples = 0.26 ppm days, the composite brine discharge rate from sampled caverns was sufficiently large that their emissions are believed to be representative for the site overall. Therefore, extrapolation of the composite discharge rate to 980 thousand barrels per day results in 0.67 g/s. The comparable emission rate for 1.4 MMB per day at Big Hill is 0.80 g/s. This corresponds to a generalized NMHC emission factor for leaching of 0.26 ppm.

An estimate of equilibrium solubility and composition of hydrocarbons in brine within the caverns is fundamental to modeling brine emissions for cavern development stages and operations not yet experienced, i.e., during leach/fill, final fill and refill. As previously discussed, there is substantial justification for assuming that oil and brine were at equilibrium in Bryan Mound Cavern 2 when samples were collected in June 1981. In contrast, an earlier model on which prior assessments were based predicted an equilibrium concentration of 31.4 ppm (DOE, 1977). Resolution of the apparent discrepancy between the two estimates is not difficult upon re-examination of assumptions and inputs in the 1977 publication.

Lacking observations of directly applicable experience at the time, the strategy in the 1977 publication was to develop a conservative worst case estimate by applying conservative estimates of salinity, temperature and pressure corrections for anticipated cavern conditions to an acceptable estimate of equilibrium concentration of crude oil dissolved in seawater. It was necessary to extrapolate salinity, temperature and pressure effects data developed in the laboratory over limited ranges and for a limited number of compounds, classes of compounds and distillate fractions to crude oil under cavern conditions. Because of the obviously high uncertainty this introduced to the analysis, these solubility effects were deliberately overstated. Further, with the benefit of hindsight, it appears that the equilibrium crude oil concentration in seawater was unnecessarily conservative.

It was observed that equilibrium concentrations reported in the literature for crude oil in freshwater and saltwater range from 7 to 40 ppm with the preponderance of data ranging from 20 to 30 ppm. It was not noted, however, that much data older than the mid-1970's are suspect due to imprecision of the analytical techniques used at the time. A worst case equilibrium concentration of 27.9 ppm was adopted based on McAuliffe's data (1976) which showed results ranging from 19.0 to 27.9 ppm for four crude oils. The highest value was for Middle East Murban Crude which was a candidate at the time for SPR storage. However, more than 60 percent of the total consisted of dissolved aromatics; C_2 through C_7 paraffins accounted for 11.1 ppm.

More recently, Caudle (1977) used nine domestic crude oils of widely ranging properties in a study conducted for the American Petroleum Institute Committee on Offshore Safety and Anti-pollution Research, Subcommittee on Oil Detection or Removal. The purpose of the study was to evaluate disagreement among analytical methods and to show how various methods are affected by dissolved organics, solids and treating chemicals. Particular emphasis was placed on distinguishing between true dissolution and dispersion. Oils were allowed to equilibrate with brines of 1, 30 and 100 ppt salinity for 14 days. To avoid dispersions no forced blending was used. The methods compared included common extraction solvents (freon and carbon tetrachloride) and two commonly used quantitative finishes (gravimetric and infrared). It was concluded that the IR/freon method avoids the positive errors due to solids and negative errors due to loss of volatile constituents that significantly affect gravimetric methods. Results for brines of 30 ppt utilizing the IR/freon method ranged from 0.56 ppm for California low gravity crude (18° API) to 8.29 ppm for Florida crude (54° API). Alaska crude (30° API) produced 7.72 ppm in 30 ppt brine. The mean NMHC solubility in 30 ppt brine for the nine domestic crudes was 5.54 ± 2.44 ppm.

To account for temperature effects on solubility, a temperature multiplier of 1.5 was applied based on an assumed cavern temperature of 150 °F and non-linear temperature/solubility relationships for high-boiling distillate fractions (132-371 °C) of Arabian crude oil. Given the fact that cavern temperatures are now expected to be 130 °F or less and given the observed NMHC composition of C_2 through C_7 aliphatics, it is no longer believed that temperature is a significant factor in equilibrium solubility.

A pressure multiplier of 5 was estimated from pressure/solubility effects data for methane and butane. However, based on the data presented in the analysis, there was equal justification for any value between 5 and 6.5.

Aqueous solubility of hydrocarbons is an inverse function of salinity. A salinity multiplier of 0.15 (i.e., a solubility reduction of 85 percent) was employed as a conservative extrapolation of data indicating a reduction of solubility of pentane in saturated brine relative to seawater by as much as 92.5 percent.

The equation for correcting crude oil solubility in seawater to cavern conditions of salinity, temperature and pressure may be calculated, in terms of the uncertainties discussed above, as follows:

Seawater Equilibrium X Temperature Multiplier X Salinity Multiplier X Pressure Multiplier = Cavern Equilibrium

$$\begin{bmatrix} 40 \text{ ppm} \\ 0.56 \text{ ppm} \end{bmatrix} \times \begin{bmatrix} 1.5 \\ 1.0 \end{bmatrix} \times \begin{bmatrix} 0.15 \\ 0.075 \end{bmatrix} \times \begin{bmatrix} 6.5 \\ 5 \end{bmatrix} = \begin{bmatrix} 58.5 \text{ ppm} \\ 0.21 \text{ ppm} \end{bmatrix}$$

That is, based on the uncertainties in the data used in the previous oil in brine model, the equilibrium solubility of NMHC in the caverns could range between 0.21 and 58.5 ppm. Therefore, cavern equilibrium solubility would not necessarily be greater than seawater equilibrium solubility at atmospheric pressure.

Assuming the conservative salinity and pressure multipliers of 0.15 and 5, respectively, which were previously used, and discounting temperature effects on a composition of C_2 through C_7 aliphatics, a cavern equilibrium solubility of 3.0 ppm would correspond to a seawater equilibrium solubility of 4.0 ppm at atmospheric pressure. This corresponds well with the mean NMHC solubility for Caudle's nine domestic crudes of 5.54 ± 2.44 ppm (Caudle, 1977). Therefore, it appears reasonable to assume that the observed NMHC concentration of 3.0 ppm in Cavern 2 is representative of cavern equilibrium solubilities. This is not to say that equilibrium solubility will not vary among caverns; the assumed equilibrium solubility of 3.0 ppm input to the oil in brine model is subject to revision as additional data are acquired.

In estimating brine emissions during leach/fill, it is assumed that the NMHC concentration at the start of the the second reverse is equivalent to the mean of observed NMHC concentration in the three samples of middle to late stages of roof development, 1.19 ppm, multiplied by the mean vapor partition factor, 0.372 (Table C.2-3) or 0.44 ppm. Emissions at the end of leach/fill are assumed to be equilibrium solubility, 3.0 ppm, multiplied by a vapor partition factor of 0.85, or 2.55 ppm. Finally, a linear rate of increase from 0.44 to 2.55 ppm is assumed resulting in a mean emission factor of 1.5 ppm during leach/fill.

The assumption of a linear rate of increase in NMHC concentration is worst case given the separation among oil/brine interface and oil and water injection and brine production points. Turbulence due to fluid injection extends downward approximately 50 jet diameters, or about 40 to 50 feet. The blanket oil filling the roof at the start of significant rates of oil fill, i.e., at the start of leach/fill, has a column height of 100 ft; therefore, there is no turbulence at the interface from oil fill. The separation between the oil/brine interface and the water injection point ranges from 600 to 950 ft for the second reverse and from 650 to 1,300 ft for the third reverse; hence, there will be no turbulence at the interface due to water injection. The distance between the interface and brine production point ranges from 1,600 to 1,700 ft over both reverses. The absence of turbulence in the region of the interface may result in lower rates of increase in NMHC concentration downward through the brine column, and hence, lower average emissions than are assumed in this model.

As NMHC is assumed to be at equilibrium concentration at the completion of leach/fill, it will remain at equilibrium concentration during the displacement of 3.7 to 4 MMB of brine for final fill. Therefore, the brine emission factor during final fill is estimated to be the equilibrium solubility, 3.0 ppm, multiplied by the mean vapor partition factor, 0.85, or 2.6 ppm.

To estimate brine emissions during refill, it is necessary to take into account the component resulting from the removal of oil coating the cavern wall into the brine during drawdown and the component due to the residual brine concentration after long-term storage which is diluted by drawdown.

For the latter component, it is assumed that a 1 MMB brine buffer at equilibrium is diluted to the total cavern operating volume of 11 MMB during a complete drawdown. Therefore, the residual concentraton component is 3.0 ppm divided by the drawdown dilution factor, 11, or 0.27 ppm.

To estimate contribution of the wall coating component, the previous assumption of a monomolecular coating 50 microns thick is used. For the cavern dimensions of Figure C.2-1, a 50 micron coating would entail about 29.2 barrels. Dissolution of 29.2 barrels of crude oil in 11 MMB of dilute brine during drawdown would result in a concentration of 2.0 ppm. However, not all of the oil coating would go into solution. The oil would tend to be leached off the walls during drawdown as a dispersion of small droplets which would rise rapidly to the oil/brine interface, given the density difference between brine and oil. The fractional component of the wall coating which would dissolve from the rising oil droplets into the brine is conservatively assumed to be equivalent to the mean fraction of C_2 through C_7 paraffins dissolved in seawater in the data of McAuliffe (1976), or about 50 percent. Therefore, the estimated component of residual NMHC concentration in brine after drawdown is half the theoretical maximum of 2.0 ppm, or 1.0 ppm.

Based on the preceding discussion, the NMHC concentration at the start of refill is estimated to be the sum of the residual brine component and wall coating component or 1.3 ppm. Assuming worst case linear increase in NMHC concentration during refill to equilibrium solubility at completion, 3.0 ppm, the mean concentration during refill is 2.2 ppm. Applying the mean vapor partition coefficient of 0.85 results in a mean emission factor during refill of 1.9 ppm.

APPENDIX C.3

ADDITIONAL ON-SITE EMISSION SOURCES

Storage/Surge Tank Emissions

All storage and surge tank calculations are based on the revised form of three formulas devised by the American Petroleum Institute. These formulas apply to floating roof tanks and distinguish between standing storage losses that occur primarily as the result of wind-induced pressure differences and withdrawal losses that occur as the result of the evaporation of crude oil, which clings to the tank shell when the floating roof descends.

The equations are as follows:

Standing Loss (AP-42)

$$L_S = 9.21 \times 10^{-3}\ M \left(\frac{P}{14.7-P}\right)^{0.7} D^{1.5} V_w^{\ 0.7} K_t K_s K_p K_c$$

where: L_S = Floating roof standing storage loss (lb/day)

M = Molecular weight of vapor in storage tank (lb/lb mole) - 50 for crude oil.

P = True vapor pressure at bulk liquid conditions (psia) - 2.8 for crude oil at 60°F and RVP of 5.

D = Tank diameter (ft)

V_w = Average wind velocity (mi/hr) - 7.6 (average wind speed Houston area).

K_t = Tank type factor (dimensionless) - .045 for welded tank with pan or pontoon roof.

K_s = Seal factor (dimensionless) - 1.00 for modern tanks.

K_p = Paint factor (dimensionless) - 1.00 for aluminum.

K_c = Crude oil factor (dimensionless) - .84 for crude oil.

Withdrawal (Operating) Loss (API 2517)

$$L_w = \frac{(0.943) Q C W_\ell}{D}$$

where: L_w = withdrawal loss (lb/day).

Q = average throughput (bbl/day).

C = shell clingage factor - .006 for crude oil in new tank.

W_ℓ = average stock liquid density (lb/day) - 7.1 for crude oil.

D = tank diameter (ft).

Standing Loss (API 2517)

$$L_s = (.00274)K_s V^n P^* D M_v K_c$$

where: L_s = standing storage loss (lb/day).

K_s = seal factor (dimensionless) - .2 for vapor mounted resilient filled seal with rim-mounted secondary.

V = average wind speed (mi/hr) - 4 for internal floating roof tanks.

n = seal-related wind speed exponent (dimensionless) - 2.6 for vapor mounted resilient filled seal with rim-mounted secondary.

P* = vapor pressure function (dimensionless) - .052 for crude oil at 60°F and RVP of 5.

D = tank diameter (ft).

M_v = average molecular weight of stock vapor (lb/lb-mole) - 50 for crude oil.

K_c = product factor - .4 for crude oil.

The values assigned to the variables were taken from publications AP-42, API 2517, and 2519. The third equation was used for calculating the internal floating roof surge tank emissions at Bryan Mound.

Valve and Seal Emissions

Valve and seal emissions were calculated by using emission factors and assumptions established previously (Texoma Group FEIS). For pump seals, a factor of 1.13 lb/d per seal at two seals per pump was used in conjunction with the pump requirements listed for the individual activities. Valve emissions were estimated at 0.108 lb/d per valve and 6.25 valves per pump. One generalized emission rate was used for valve, seals and slop tank losses at all sites.

Crude Oil Transfer Emissions

The crude oil transfer and related ship emissions occur as the result of two activities--ballasting and tanker loading. It is assumed that there are no hydrocarbon emissions during unloading of crude oil from tankers. Normally, venting during this operation is limited to emergency situations.

Ballasting emissions are generated when ballast water is pumped into the cargo tanks, displacing hydrocarbon vapors of an equal volume. Normally, a ship ballasts between 20 and 33 percent of capacity to provide stability for the ship during transit. To provide a conservative estimate of emissions in this analysis, a 33-percent ballasting level was assumed for the short-term scenario, whereas a 25-percent level was assumed for the long-term averages. These values are doubly conservative since only a fraction of the ballast is taken on at the tanker berth under normal circumstances. A pumping rate of 40,000 bbl/h is assumed for ballasting operations.

Tanker loading emissions result from the crude oil as it is pumped into the ship's cargo tanks, displacing an equivalent volume of air-vapor mixture. The hydrocarbon emission rate is a function of several parameters, as discussed in the Texoma Group FEIS (Sect. C.3.1.3), which includes the loading rate. A loading rate of 60,000 bbl/h per ship has been assumed in this analysis. The resulting emission rates for ballasting and tanker loading are as follows:

Ballasting - 0.42 lb per 1000 gal
Loading - 0.55 lb per 1000 gal

Ship Engine Emissions

The treatment of ship engine emissions has not been reconsidered in this analysis because it has received extensive treatment in previous documents pertaining to the Strategic Petroleum Reserve (SPR) (Seaway and Texoma Group FEIS).

Additional Assumption

Table C.3-1 and C.3-2 list additonal assumptions used in determining the short- and long-term emission rates as well as annual values.

Table C.3-1. Assumptions used in hydrocarbon emission scenarios (preferred alternative)

Variable		Short-term scenario value		Long-term scenario value	
		Fill	Drawdown	Fill	Drawdown
Average temperature, °F		88	88	70	70
Average wind speed, mph		12	12	10.1	10.1
Reid vapor pressure		5	5	4	4
Number of ships at dock		2	4	1	4
Average ship capacity, bbl		320,000	320,000	320,000	320,000
Number of pumps[1]	Terminal	6	4	6	4
	Big Hill	4	9	2	9
Number of seals[2]	Terminal	12	8	12	8
	Big Hill	4	18	4	18
Number of valves[3]	Terminal	37.50	25.00	37.50	25.00
	Big Hill	12.50	56.25	12.50	56.25
Number of storage tanks used at terminal		5	8	5	8
Tanker ballasting rate, %		33	-	25	-

[1]Pumps used for oil only.

[2]Based on 2 seals/pump.

[3]Based on 6.25 valves/pump average.

Table C.3-2. Assumptions used in terminal hydrocarbon emission scenarios (alternative crude oil pipeline)

Variable	Short-term scenario value		Long-term scenario value	
	Fill	Drawdown	Fill	Drawdown
Average temperature, °F	88	88	70	70
Average wind speed, mph	12	12	10.1	10.1
Reid vapor pressure	5	5	4	4
Number of ships at dock	2	2	1	1
Average ship capacity, bbl	320,000	320,000	320,000	320,000
Number of pumps[1]	6	6	6	6
Number of seals[2]	12	12	12	12
Number of valves[3]	37.50	37.50	37.50	37.50
Number of storage tanks[4]	4	6	4	6
Tanker ballasting rate, %	33	-	25	-

[1]Pumps used for oil only.

[2]Based on 2 seals/pump.

[3]Based on 6.25 valves/pump average.

[4]Assumes 2 new tanks with remainder existing tanks.

APPENDIX C.4

AIR QUALITY MODELING OUTPUT

Table C.4-1 CRSTER modeling results

```
BATCH.LOG;1                                30-JUN-1981 15:17:26.15          Page 2
PLANT NAME:                                      POLLUTANT:              EMISSION UNITS: GM/SEC    AIR QUALITY UNITS: GM/M**3
SPR SITE SAMPLE RUN *** NMHC
1GM/SEC EMISSION RATE
SIMULATED STACK SOURCE

               MET FILE       REQUESTED
              STN NO. YR     STN NO. YR
 SURFACE       12918  64      12918  64
 UPPER AIR      3927  64       3927  64
PLANT LOCATION: RURAL
NO TAPE OUTPUT
MET DATA WILL NOT BE PRINTED

DAY--  1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1
       1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1
       1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1
       1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1
       1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1
       1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1
       1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1 1 1 1 1
       1 1 1 1 1 1 1 1 1 1   1 1 1 1 1 1

 * * * * * * * * * * * * * * * * * * * * N O T E * * * * * * * * * * * * * * * * * * * *
         ALL TABLES, INCLUDING SOURCE CONTRIBUTION, THAT CONTAIN "ANNUAL" IN THE HEADING ARE BASED ONLY ON THOSE DAYS
         MARKED BY "1" IN THE ABOVE TABLE
```

Table C.4-1 (continued)

BATCH.LOG;1 8-JUL-1981 14:48:33.85 Page 4

STACK # 1--SPR AREA SOURCE

STACK	MONTH	EMISSION RATE (GMS/SEC)	HEIGHT (METERS)	DIAMETER (METERS)	EXIT VELOCITY (M/SEC)	TEMP (DEG.K)	VOLUMETRIC FLOW (M**3/SEC)
1	ALL	1.0000	3.00	56.40	0.01	295.00	24.98

Table C.4-1 (continued)

BATCH.LOG;1 8-JUL-1981 14:48:33.85 Page 22
PLANT NAME: POLLUTANT: EMISSION UNITS: GM/SEC AIR QUALITY UNITS: GM/M**3

MAXIMUM HOURLY CONCENTRATIONS

DAY	1-HOUR CONCENTRATION	DIRECTION	DISTANCE	HOUR
176	2.2687E-03	20	0.50	22
167	2.2242E-03	30	0.50	3
247	2.2242E-03	19	0.50	8
212	1.6577E-03	29	0.50	2
215	1.6577E-03	25	0.50	7
238	1.6577E-03	30	0.50	5
248	1.6577E-03	15	0.50	8
271	1.6577E-03	34	0.50	4
208	1.5925E-03	9	0.50	2
133	1.4732E-03	36	0.50	1
177	1.4732E-03	12	0.50	24
211	1.4732E-03	30	0.50	5
211	1.4732E-03	31	0.50	22
222	1.4732E-03	1	0.50	3
223	1.4732E-03	1	0.50	3
226	1.4732E-03	24	0.50	7
265	1.4732E-03	27	0.50	8
208	1.2453E-03	31	0.50	5
264	1.2453E-03	24	0.50	8
171	1.1320E-03	36	0.50	7
159	1.1067E-03	34	0.50	2
165	1.1067E-03	28	0.50	7
186	1.1067E-03	7	0.50	1
186	1.1067E-03	2	0.50	22
205	1.1067E-03	36	0.50	1
205	1.1067E-03	23	0.50	7
219	1.1067E-03	16	0.50	3
224	1.1067E-03	34	0.50	23
227	1.1067E-03	32	0.50	2
227	1.1067E-03	36	0.50	23
232	1.1067E-03	2	0.50	7
239	1.1067E-03	28	0.50	3
255	1.1067E-03	12	0.50	8
260	1.1067E-03	27	0.50	5
235	1.0744E-03	16	0.50	8
243	1.0744E-03	28	0.50	8
164	1.0341E-03	31	0.50	7
178	1.0341E-03	26	0.50	23
180	1.0341E-03	10	0.50	4
208	1.0341E-03	6	0.50	7
225	1.0341E-03	8	0.50	7
237	1.0341E-03	30	0.50	24
246	1.0341E-03	9	0.50	4
246	1.0341E-03	28	0.50	21
246	1.0341E-03	36	0.50	23
265	1.0341E-03	23	0.50	6
189	9.9330E-04	9	0.50	4
189	9.9330E-04	1	0.50	22
190	9.9330E-04	1	0.50	23
271	9.9330E-04	30	0.50	6

FORTRAN STOP
%DCL-W-SKPDAT, data records encountered by system were ignored
SPR job terminated at 8-JUL-1981 14:48:14.32

Accounting information:
Buffered I/O count: 94 Peak working set size: 231

Table C.4-2 RAM NMHC modeling results at 1 gm/sec emission rate

```
BATCH.LOG;1                    8-JUL-1981 10:51:52.70          Page 1

$ SET NOVERIFY
FUNDS EXPENDED SO FAR IN FISCAL 1982 ARE     956.97  ON ACCOUNT  1-143- 8-200-20

FUNDS REMAINING = $     543.03  OUT OF $    1500.00

----------------------------------------------------------------------------------
        Dialup lines: 482-6982 (300 baud, 4 line rotary)
                      482-6986/7 (1200 baud line 3rd/4th in rotary)
                      525-3757 (300 baud)
                      525-0102 (1200 baud)
        Operator coverage:  8:30 - 5:30 Mon - Fri
        Scheduled downtime:
          1st Tuesday of Month 4:00-8:00PM Prevt. Maint.
          Saturdays 8:00 - 11:00 AM System Backup

           In case of off-shift emergency call
                Charlie Thompson  483-7560
                           or
                 Larry Peck  482-2185
run ramr

SPR SAMPLE RUN BY MARK MITCKES--RAMR
HOUSTON/ LA. CHARLES MET DATA
1 GRAM/SEC EMISSION RATE

THIS IS THE NORMAL RURAL VERSION(78124) OF RAMR FOR APPLICATION TO ONE OR SEVERAL DAYS DATA.

 OPTION        OPTION LIST                          OPTION SPECIFICATION : 0= IGNORE OPTION
                                                                           1= USE OPTION
      1        POINT SOURCE DATA                     0
      2        AREA SOURCE DATA                      1
      3        PERMANENT RECEPTORS                   0
      4        SIGNIFICANT POINT RECEPTORS           0
      5        SIGNIFICANT AREA RECEPTORS            1
      6        HONEYCOMB RECEPTORS                   1
      7        HOURLYOUTPUT                          0
      8        PARTIAL CONC. WRITTEN TO DISK/TAPE    0
      9        PRINT ONLY SUMMARY HOURLY OUTPUT      0
     10        PUNCH CARDS FOR CONTOURS              0
     11        READ METDATA FROM CARDS               0
     12        SPECIFY SIGNIFICANT SOURCE NUMBERS    0
     13        READ HOURLY EMISSIONS                 0

                     GENERAL INFORMATION FROM RAMU

 UNITS - THEREARE       1.0000000 USER UNITS(INPUT UNITS) PER SMALLEST AREA SOURCE SQUARE SIDE LENGTH (INTERNAL UNIT)
 CONONE - THERE ARE      0.0500000 KILOMETERS PER USER UNIT
 CONTWO - IT IS CALCULATED THAT THERE ARE      0.0500000 KILOMETERS PER SMALLEST AREA SOURCE SQUARE SIDE LENGTH (INTERNAL UNIT)
 THIS RUN IS FOR  HC    SINCE IPOL= 3

                     GENERAL INPUT DATA

 NUMBER OF PERIODS TO BE SIMULATED(NPER)=   24
AVERAGING TIME IN HOURS FOR EACH PERIOD(NAVG)=      1
 STARTING DATE(IDATE(2),IDATE(1),IHSTRT): JULIAN DAY  176, YEAR 1964 HOUR=  1
 RECEPTOR HEIGHT FOR ALL RECEPTORS(Z)  2.000 METERS
 ASSUMED POLLUTANT HALF-LIFE(HAFL)     7200.00 SECONDS
 SURFACE MET DATA FROM STATION(ISFCD)  12918, YEAR(ISFCYP) 1964
```

Table C.4-2 (continued)

```
BATCH.LOG;1                    8-JUL-1981 10:51:52.70        Page 2
 MIXING HEIGHT DATA FROM STATION(IMXD)   3927, YEAR(IMXYR) 1964


SPR SAMPLE RUN BY MARK MITCKES--RAMR
HOUSTON/ LA. CHARLES MET DATA
1 GRAM/SEC EMISSION RATE

                  AREA SOURCE INFORMATION

 EMISSION INFORMATION FOR    1 (NAS) AREA SOURCES HAS BEEN DETERMINED BY RAMQ
  1 SIGNIFICANT AREA SOURCES(NSIGA) ARE TO BE USED FOR THIS RUN
  THE ORDER OF SIGNIFICANCE(INAS) FOR 10 OR LESS  AREA SOURCES DETERMINED BY RAMQ IS LISTED BY  AREA SOURCE NUMBER:
     1
 NUMBER OF AREA HEIGHT CLASSES(NHTS)= 1
 REPRESENTATIVE AREA SOURCE HEIGHTS FOR EACH HEIGHT CLASS(HINT) IN METERS=      2.00
 BREAK POINT HEIGHT BETWEEN THE AREA HEIGHT CLASSES(BPH) IN METERS=      4.00
 FRACTION OF AREA SOURCE HEIGHT WHICH IS PHYSICAL HEIGHT(FH)=      0.100
 LIMIT OF DISTANCE FOR AREA SOURCE INTEGRATION TABLES(XLIM) IN USER UNITS =    85.000
 BOUNDARIES OF THE AREA SOURCE GRID IN USER UNITS:
    RMIN=     59.500     RMAX=     60.500     SMIN=     59.500     SMAX=     60.500
 SIZE(IRSIZE X ISSIZE) OF AREA SOURCE MAP ARRAY(IA) IN INTERNAL UNITS =  1 EAST-WEST BY   1 NORTH-SOUTH


              AREA SOURCE MAP ARRAY(IA)

  1    1

       1

                 AREA SOURCE LISTING

SOURCE  EAST    NORTH   HC(G/SEC-M**2)    PART(G/SEC-M**2)  SIDEEFFECTIVE
        COORD   COORD     EMISSIONS          EMISSIONS        LENGTH    HEIGHT
         (USER UNITS)                                      (USER UNITS)   (M)

  1         59.5     59.5    4.0000E-04         0.0000E+00         1.0       3.0
SPR SAMPLE RUN BY MARK MITCKES--RAMR
HOUSTON/ LA. CHARLES MET DATA
1 GRAM/SEC EMISSION RATE

INPUT MET DATA  64/ 1/6
HOUR    THETA    SPEED   MIXING    TEMP     STABILITY
        (DEG)    (M/S)  HEIGHT(M) (DEG-K)   CLASS

  1    240.00     3.09  1381.64   298.70      6

RESULTANT MET CONDITIONS

 WIND DIRECTION= 240.00            RESULTANT WIND SPEED=   3.08
 AVERAGE WIND SPEED=    3.08       AVERAGE TEMP= 298.70
 WIND PERSISTENCE= 1.000           MODAL STABILITY= 6
```

Table C.4-2 (continued)

BATCH.LOG;1   8-JUL-1991 10:51:52.70   Page 3

SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR #	EAST	NORTH
1 A 1	62.28	61.32

GENERATED HONEYCOMB RECEPTORS

THE AREA TO BE COVERED BY HONEYCOMB RECEPTORS IS BOUNDED BY:
RMIN= 1.000 RMAX= 119.000 SMIN= 1.000 SMAX= 119.000

DISTANCE BETWEEN HONEYCOMB RECEPTORS(GRIDSP) IN USER UNITS= 10.000

RECEPTOR	EAST	NORTH
2 H	11.00	5.33
3 H	21.00	5.33
4 H	31.00	5.33
5 H	41.00	5.33
6 H	51.00	5.33
7 H	61.00	5.33
8 H	71.00	5.33
9 H	81.00	5.33
10 H	91.00	5.33
11 H	101.00	5.33
12 H	111.00	5.33
13 H	6.00	13.99
14 H	16.00	13.99
15 H	26.00	13.99
16 H	36.00	13.99
17 H	46.00	13.99
18 H	56.00	13.99
19 H	66.00	13.99
20 H	76.00	13.99
21 H	86.00	13.99
22 H	96.00	13.99
23 H	106.00	13.99
24 H	116.00	13.99
25 H	11.00	22.65
26 H	21.00	22.65
27 H	31.00	22.65
28 H	41.00	22.65
29 H	51.00	22.65
30 H	61.00	22.65
31 H	71.00	22.65
32 H	81.00	22.65
33 H	91.00	22.65
34 H	101.00	22.65
35 H	111.00	22.65
36 H	6.00	31.31
37 H	16.00	31.31
38 H	26.00	31.31
39 H	36.00	31.31
40 H	46.00	31.31
41 H	56.00	31.31
42 H	66.00	31.31
43 H	76.00	31.31
44 H	86.00	31.31

Table C.4-2 (continued)

45	H	96.00	31.31
46	H	106.00	31.31
47	H	116.00	31.31
48	H	11.00	39.97
49	H	21.00	39.97
50	H	31.00	39.97
51	H	41.00	39.97
52	H	51.00	39.97
53	H	61.00	39.97
54	H	71.00	39.97
55	H	81.00	39.97
56	H	91.00	39.97
57	H	101.00	39.97
58	H	111.00	39.97
59	H	6.00	48.63
60	H	16.00	49.63
61	H	26.00	49.63
62	H	36.00	48.63
63	H	46.00	48.63
64	H	55.00	49.63
65	H	65.00	48.63
66	H	76.00	48.63
67	H	86.00	48.63
68	H	96.00	48.63
69	H	106.00	48.63
70	H	116.00	48.63
71	H	11.00	57.29
72	H	21.00	57.29
73	H	31.00	57.29
74	H	41.00	57.29
75	H	51.00	57.29
76	H	71.00	57.29
77	H	81.00	57.29
78	H	91.00	57.29
79	H	101.00	57.29
80	H	111.00	57.29
81	H	6.00	65.95
82	H	16.00	65.95
83	H	26.00	65.95
84	H	36.00	65.95
85	H	46.00	65.95
86	H	56.00	65.95
87	H	66.00	65.95
88	H	76.00	65.95
89	H	86.00	65.95
90	H	96.00	65.95
91	H	106.00	65.95
92	H	116.00	65.95
93	H	11.00	74.61
94	H	21.00	74.61
95	H	31.00	74.61
96	H	41.00	74.61
97	H	51.00	74.61
98	H	61.00	74.61
99	H	71.00	74.61
100	H	81.00	74.61
101	H	91.00	74.61
102	H	101.00	74.61
103	H	111.00	74.61

Table C.4-2 (continued)

104	H	6.00	83.27
105	H	16.00	83.27
106	H	26.00	83.27
107	H	36.00	83.27
108	H	46.00	83.27
109	H	56.00	83.27
110	H	66.00	83.27
111	H	76.00	83.27
112	H	86.00	83.27
113	H	96.00	83.27
114	H	106.00	83.27
115	H	116.00	83.27
116	H	11.00	91.93
117	H	21.00	91.93
118	H	31.00	91.93
119	H	41.00	91.93
120	H	51.00	91.93
121	H	61.00	91.93
122	H	71.00	91.93
123	H	81.00	91.93
124	H	91.00	91.93
125	H	101.00	91.93
126	H	111.00	91.93
127	H	6.00	100.59
128	H	16.00	100.59
129	H	26.00	100.59
130	H	36.00	100.59
131	H	46.00	100.59
132	H	56.00	100.59
133	H	66.00	100.59
134	H	76.00	100.59
135	H	86.00	100.59
136	H	96.00	100.59
137	H	106.00	100.59
138	H	116.00	100.59
139	H	11.00	109.25
140	H	21.00	109.25
141	H	31.00	109.25
142	H	41.00	109.25
143	H	51.00	109.25
144	H	61.00	109.25
145	H	71.00	109.25
146	H	81.00	109.25
147	H	91.00	109.25
148	H	101.00	109.25
149	H	111.00	109.25
150	H	6.00	117.91

THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
NO OTHERS WILL BE ACCEPTED.
PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR THE PRECEDING AVERAGING PERIOD.

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 1

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK

Table C.4-2 (continued)

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   1 A  1        62.28     61.32        0.0000        0.0000      155.9925      155.9925      155.9925         1
   2 H  0        11.00      5.33        0.0000        0.0000        0.0000        0.0000        0.0000         2
   3 H  0        21.00      5.33        0.0000        0.0000        0.0000        0.0000        0.0000         3
   4 H  0        31.00      5.33        0.0000        0.0000        0.0000        0.0000        0.0000         4
   5 H  0        41.00      5.33        0.0000        0.0000        0.0000        0.0000        0.0000         5
   6 H  0        51.00      5.33        0.0000        0.0000        0.0000        0.0000        0.0000         6

SPP SAMPLE RUN BY MARK HITCKES--PAMR
HOUSTON/ LA. CHARLES MET DATA
1 GRAM/SEC EMISSION RATE

INPUT MET DATA  64/ 176
HOUR    THETA     SPEED    MIXING    TEMP      STABILITY
        (DEG)     (M/S)   HEIGHT(M) (DEG-K)    CLASS

  2   127.00      1.54   1441.00   297.00       6

RESULTANT MET CONDITIONS

 WIND DIRECTION= 127.00           RESULTANT WIND SPEED=   1.54
 AVERAGE WIND SPEED=    1.54      AVERAGE TEMP= 297.00
 WIND PERSISTENCE= 1.000          MODAL STABILITY= 6


      SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR #   EAST      NORTH

  1 A  1      57.86      61.61
THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
 NO OTHERS WILL BE ACCEPTED.
***PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR
                     THE PRECEDING AVERAGING PERIOD.***

                      1-HOUR AVERAGE HC   SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3)     64/176  START HOUR:  2

RECEPTOR NO.   EAST      NORTH        TOTAL FROM    TOTAL FROM    TOTAL FROM    TOTAL FROM    TOTAL FROM   CONCENTRATION
                                     SIGNIF POINT   ALL POINT    SIGNIF AREA    ALL AREA     ALL SOURCES      RANK
                                       SOURCES       SOURCES       SOURCES       SOURCES

   1 A  1        57.86     61.61        0.0000        0.0000      183.6134      183.6134      183.6134         3
   2 H  0        11.00      5.33        0.0000        0.0000        0.0000        0.0000        0.0000         4
   3 H  0        21.00      5.33        0.0000        0.0000        0.0000        0.0000        0.0000         5
   4 H  0        31.00      5.33        0.0000        0.0000        0.0000        0.0000        0.0000         6
  96 H  0        41.00     74.61        0.0000        0.0000      740.6631      740.6631      740.6631         1
 127 H  0         6.00    100.59        0.0000        0.0000      494.7052      494.7052      494.7052         2

SPP SAMPLE RUN BY MARK HITCKES--PAMR
HOUSTON/ LA. CHARLES MET DATA
1 GRAM/SEC EMISSION RATE

INPUT MET DATA  64/ 176
HOUR    THETA     SPEED    MIXING    TEMP      STABILITY
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Table C.4-2 (continued)

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       (DEG)     (M/S)  HEIGHT(M) (DEG-K)  CLASS

   3   243.00     1.54  1497.36   297.50      6

RESULTANT MET CONDITIONS

 WIND DIRECTION= 243.00          RESULTANT WIND SPEED=   1.54
 AVERAGE WIND SPEED=    1.54     AVERAGE TEMP= 297.50
 WIND PERSISTENCE= 1.000         MODAL STABILITY= 6


      SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR #   EAST      NORTH

  1 A  1      62.33      61.19
THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
 NO OTHERS WILL BE ACCEPTED.
***PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR
                THE PRECEEDING AVERAGING PERIOD.***
                   1-HOUR AVERAGE HC   SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3)     64/176   START HOUR:  3
```

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 A 1	62.33	61.19	0.0000	0.0000	147.8868	147.8868	147.8868	2
2 H 0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	3
3 H 0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
4 H 0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
5 H 0	41.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6
114 H 0	106.00	83.27	0.0000	0.0000	525.6500	525.6500	525.6500	1

```
SPR SAMPLE RUN BY MARK WITCKES--PANR
HOUSTON/ LA. CHARLES MET DATA
1 GRAM/SEC EMISSION RATE

INPUT MET DATA   64/ 176
HOUR   THETA      SPEED    MIXING   TEMP     STABILITY
       (DEG)      (M/S)  HEIGHT(M) (DEG-K)   CLASS

  4   251.00      2.05    318.64   297.00      6

RESULTANT MET CONDITIONS

 WIND DIRECTION= 251.00          RESULTANT WIND SPEED=   2.05
 AVERAGE WIND SPEED=    2.05     AVERAGE TEMP= 297.00
 WIND PERSISTENCE= 1.000         MODAL STABILITY= 6


      SIGNIFICANT AREA SOURCE RECEPTORS
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Table C.4-2 (continued)

RECEPTOR # EAST NORTH

1 A 1 62.44 60.94
THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
NO OTHERS WILL BE ACCEPTED.
PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR THE PRECEEDING AVERAGING PERIOD.

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 4

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 A 1	62.44	60.84	0.0000	0.0000	132.6859	132.6859	132.6859	3
2 H 0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
3 H 0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
4 H 0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6
88 H 0	76.00	65.95	0.0000	0.0000	634.3681	634.3681	634.3681	1
102 H 0	101.00	74.61	0.0000	0.0000	291.7480	291.7480	291.7480	2

SPR SAMPLE RUN BY MARK WITCKES--RAMR
HOUSTON/ LA. CHARLES MET DATA
1 GRAM/SEC EMISSION RATE

INPUT MET DATA 64/ 176

HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (DEG-K)	STABILITY CLASS
5	296.00	2.57	727.88	297.00	6

RESULTANT MET CONDITIONS

WIND DIRECTION= 296.00
AVERAGE WIND SPEED= 2.57
WIND PERSISTENCE= 1.000

RESULTANT WIND SPEED= 2.57
AVERAGE TEMP= 297.00
MODAL STABILITY= 6

SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR # EAST NORTH

1 A 1 62.35 58.86
THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
NO OTHERS WILL BE ACCEPTED.
PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR THE PRECEEDING AVERAGING PERIOD.

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 5

RECEPTOR NO. EAST NORTH TOTAL FROM TOTAL FROM TOTAL FROM TOTAL FROM TOTAL FROM CONCENTRATION

Table C.4-2 (continued)

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Receptor			East	North	SIGNIF POINT SOURCES	ALL POINT SOURCES	SIGNIF AREA SOURCES	ALL AREA SOURCES	ALL SOURCES	RANK
1	A	1	62.35	58.86	0.0000	0.0000	145.6024	145.6024	145.6024	2
2	H	0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	3
3	H	0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
4	H	0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
5	H	0	41.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6
57	H	0	101.00	39.97	0.0000	0.0000	568.2800	568.2800	568.2800	1

SPP SAMPLE RUN BY MARK MITCKES--RAMR
HOUSTON/ LA. CHARLES MET DATA
1 GRAM/SEC EMISSION RATE

INPUT MET DATA 64/ 176

HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (DEG-K)	STABILITY CLASS
6	305.00	3.08	1137.13	297.00	6

RESULTANT MET CONDITIONS

WIND DIRECTION= 305.00   RESULTANT WIND SPEED= 3.08
AVERAGE WIND SPEED= 3.08   AVERAGE TEMP= 297.00
WIND PERSISTENCE= 1.000   MODAL STABILITY= 6

SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR #			EAST	NORTH
1	A	1	62.18	58.47

THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
NO OTHERS WILL BE ACCEPTED.
PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR THE PRECEDING AVERAGING PERIOD.

1-HOUR AVERAGE HC   SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3)   64/176   START HOUR: 6

RECEPTOR NO.			EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1	A	1	62.18	58.47	0.0000	0.0000	174.7233	174.7233	174.7233	2
2	H	0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	3
3	H	0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
4	H	0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
5	H	0	41.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6
66	H	0	76.00	48.01	0.0000	0.0000	1008.8516	1008.8516	1008.8516	1

SPP SAMPLE RUN BY MARK MITCKES--RAMR
HOUSTON/ LA. CHARLES MET DATA
1 GRAM/SEC EMISSION RATE

Table C.4-2 (continued)

```
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INPUT MET DATA  64/ 176
HOUR   THETA     SPEED    MIXING    TEMP     STABILITY
       (DEG)     (M/S)  HEIGHT(M) (DEG-K)   CLASS

  7   299.00     4.11   1546.38   297.00       4

RESULTANT MET CONDITIONS

 WIND DIRECTION= 299.00           RESULTANT WIND SPEED=   4.11
 AVERAGE WIND SPEED=    4.11      AVERAGE TEMP= 297.00
 WIND PERSISTENCE= 1.000          MODAL STABILITY= 4


      SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR #   EAST      NORTH


  1 A  1     61.56      59.46
THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
 NO OTHERS WILL BE ACCEPTED.
***PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR
                  THE PRECEEDING AVERAGING PERIOD.***
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1-HOUR AVERAGE HC   SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3)   64/176   START HOUR: 7

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 A 1	61.56	59.46	0.0000	0.0000	844.4205	844.4205	844.4205	1
2 H 0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	2
3 H 0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	3
4 H 0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
5 H 0	41.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
6 H 0	51.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6

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SPR SAMPLE RUN BY MARK FITCKES--RAMR
HOUSTON/ LA. CHARLES MET DATA
1 GRAM/SEC EMISSION RATE

INPUT MET DATA  64/ 176
HOUR   THETA     SPEED    MIXING    TEMP     STABILITY
       (DEG)     (M/S)  HEIGHT(M) (DEG-K)   CLASS

  8   299.00     3.60   1751.00   298.70       3

RESULTANT MET CONDITIONS

 WIND DIRECTION= 299.00           RESULTANT WIND SPEED=   3.60
 AVERAGE WIND SPEED=    3.60      AVERAGE TEMP= 298.70
 WIND PERSISTENCE= 1.000          MODAL STABILITY= 3
```

Table C.4-2 (continued)

SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR # EAST NORTH

1 A 1 61.15 59.37
THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
NO OTHERS WILL BE ACCEPTED.
PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR THE PRECEEDING AVERAGING PERIOD.

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 9

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 A 1	61.15	59.37	0.0000	0.0000	900.0789	900.0789	900.0789	1
2 H 0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	2
3 H 0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	3
4 H 0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
5 H 0	41.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
6 H 0	51.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6

SPP SAMPLE RUN BY MARK HICKES--PAMR
HOUSTON/ LA. CHARLES MET DATA
1 GRAM/SEC EMISSION RATE

INPUT MET DATA 64/ 176

HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (DEG-K)	STABILITY CLASS
9	312.00	4.11	1751.00	300.90	3

RESULTANT MET CONDITIONS

WIND DIRECTION= 312.00 RESULTANT WIND SPEED= 4.11
AVERAGE WIND SPEED= 4.11 AVERAGE TEMP= 300.90
WIND PERSISTENCE= 1.000 MODAL STABILITY= 3

SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR # EAST NORTH

1 A 1 61.05 59.06
THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
NO OTHERS WILL BE ACCEPTED.
PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR THE PRECEEDING AVERAGING PERIOD.

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 9

Table C.4-2 (continued)

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RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 A 1	61.05	59.06	0.0000	0.0000	958.4217	958.4217	958.4217	1
2 H 0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	3
3 H 0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
4 H 0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
5 H 0	41.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6
34 H 0	101.00	22.65	0.0000	0.0000	22.2505	22.2505	22.2505	2

SPP SAMPLE RUN BY MARK STICKES--PAMR
HOUSTON/ LA. CHARLES MET DATA
1 GRAM/SEC EMISSION RATE

INPUT MET DATA 64/ 176

HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (DEG-K)	STABILITY CLASS
10	307.00	4.62	1751.00	304.80	3

RESULTANT MET CONDITIONS

WIND DIRECTION= 307.00 RESULTANT WIND SPEED= 4.62
AVERAGE WIND SPEED= 4.62 AVERAGE TEMP= 304.80
WIND PERSISTENCE= 1.000 MODAL STABILITY= 3

SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR #	EAST	NORTH
1 A 1	61.09	59.18

THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
NO OTHERS WILL BE ACCEPTED.
PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR THE PRECEEDING AVERAGING PERIOD.

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 10

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 A 1	61.09	59.18	0.0000	0.0000	842.4128	842.4128	842.4128	1
2 H 0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	3
3 H 0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
4 H 0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
5 H 0	41.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6
66 H 0	76.00	18.63	0.0000	0.0000	22.8566	22.8566	22.8566	2

SPP SAMPLE RUN BY MARK STICKES--PAMR
HOUSTON/ LA. CHARLES MET DATA

Table C.4-2 (continued)

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1 GRAM/SEC EMISSION RATE

INPUT MET DATA 64/ 176 HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (DEG-K)	STABILITY CLASS
11	321.00	4.11	1744.58	305.90	3

RESULTANT MET CONDITIONS

WIND DIRECTION= 321.00 RESULTANT WIND SPEED= 4.11
AVERAGE WIND SPEED= 4.11 AVERAGE TEMP= 305.90
WIND PERSISTENCE= 1.000 MODAL STABILITY= 3

SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR # EAST NORTH

1 A 1 60.87 58.93
THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
NO OTHERS WILL BE ACCEPTED.
PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR THE PRECEEDING AVERAGING PERIOD.

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 11

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 A 1	60.87	58.93	0.0000	0.0000	925.8484	925.8484	925.8484	1
2 H 0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	3
3 H 0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
4 H 0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
5 H 0	41.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6
33 H 0	91.00	22.65	0.0000	0.0000	7.7315	7.7315	7.7315	2

SPP SAMPLE RUN BY MARK HITCKES--RAMR
HOUSTON/ LA. CHARLES MET DATA
1 GRAM/SEC EMISSION RATE

INPUT MET DATA 64/ 176 HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (DEG-K)	STABILITY CLASS
12	9.00	7.20	1736.86	305.90	3

RESULTANT MET CONDITIONS

WIND DIRECTION= 9.00 RESULTANT WIND SPEED= 7.20
AVERAGE WIND SPEED= 7.20 AVERAGE TEMP= 305.90
WIND PERSISTENCE= 1.000 MODAL STABILITY= 3

Table C.4-2 (continued)


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      SIGNIFICANT AREA SOURCE RECEPTORS
RECEPTOR #  EAST      NORTH

  1 A  1      59.91       59.77
THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
 NO OTHERS WILL BE ACCEPTED.
***PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR
                      THE PRECEEDING AVERAGING PERIOD.***
```

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 12

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 A 1	59.81	58.77	0.0000	0.0000	508.7638	508.7638	508.7638	1
2 H 0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
3 H 0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
4 H 0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6
6 H 0	51.00	5.33	0.0000	0.0000	17.3501	17.3501	17.3501	2
41 H 0	56.00	31.31	0.0000	0.0000	7.0956	7.0956	7.0956	3

```
SPP SAMPLE RUN BY MARK HITCKES--RAMR
HOUSTON/ LA. CHARLES MET DATA
1 GRAM/SEC EMISSION RATE

INPUT MET DATA  64/ 176
HOUR    THETA     SPEED    MIXING     TEMP      STABILITY
        (DEG)     (M/S)  HEIGHT(M)  (DEG-K)   CLASS

 13    348.00     4.62   210.00    307.50       2

RESULTANT MET CONDITIONS

 WIND DIRECTION= 348.00            RESULTANT WIND SPEED=    4.62
 AVERAGE WIND SPEED=    4.62       AVERAGE TEMP= 307.50
 WIND PERSISTENCE= 1.000           MODAL STABILITY= 2


      SIGNIFICANT AREA SOURCE RECEPTORS
RECEPTOR #  EAST      NORTH

  1 A  1      60.21       59.00
THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
 NO OTHERS WILL BE ACCEPTED.
***PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR
                      THE PRECEEDING AVERAGING PERIOD.***
```

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 13

Table C.4-2 (continued)

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RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 A 1	60.21	59.00	0.0000	0.0000	634.5125	634.5125	634.5125	1
2 H 0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	3
3 H 0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
4 H 0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
5 H 0	41.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6
42 H 0	66.00	31.31	0.0000	0.0000	26.1649	26.1649	26.1649	2

SPR SAMPLE RUN BY MARK HITCKES--PAMR
HOUSTON/ LA. CHARLES MET DATA
1 GRAM/SEC EMISSION RATE

INPUT MET DATA 64/ 176

HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (DEG-K)	STABILITY CLASS
14	9.00	5.14	210.00	307.50	3

RESULTANT MET CONDITIONS

WIND DIRECTION= 9.00
AVERAGE WIND SPEED= 5.14
WIND PERSISTENCE= 1.000

RESULTANT WIND SPEED= 5.14
AVERAGE TEMP= 307.50
MODAL STABILITY= 3

SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR #	EAST	NORTH
1 A 1	59.81	58.77

THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
NO OTHERS WILL BE ACCEPTED.
PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR THE PRECEEDING AVERAGING PERIOD.

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 14

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 A 1	59.81	58.77	0.0000	0.0000	662.1694	662.1694	662.1694	1
2 H 0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
3 H 0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
4 H 0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6
6 H 0	51.00	5.33	0.0000	0.0000	24.9494	24.9494	24.9494	2
41 H 0	56.00	31.31	0.0000	0.0000	9.8238	9.8238	9.8238	3

Table C.4-2 (continued)

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SPR SAMPLE RUN BY MARK STICKES--RAMR
HOUSTON/ LA. CHARLES MET DATA
1 GRAM/SEC EMISSION RATE

INPUT MET DATA 64/ 176

HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (DEG-K)	STABILITY CLASS
15	44.00	4.62	210.00	307.50	2

RESULTANT MET CONDITIONS

WIND DIRECTION= 44.00 RESULTANT WIND SPEED= 4.62
AVERAGE WIND SPEED= 4.62 AVERAGE TEMP= 307.50
WIND PERSISTENCE= 1.000 MODAL STABILITY= 2

SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR #	EAST	NORTH
1 A 1	59.16	59.13

THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
NO OTHERS WILL BE ACCEPTED.
PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR THE PRECEDING AVERAGING PERIOD.

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 15

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 A 1	59.16	59.13	0.0000	0.0000	786.1867	786.1867	786.1867	1
2 H 0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
3 H 0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
4 H 0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6
14 H 0	16.00	13.99	0.0000	0.0000	17.5911	17.5911	17.5911	3
51 H 0	11.00	39.97	0.0000	0.0000	24.7182	24.7182	24.7182	2

SPR SAMPLE RUN BY MARK STICKES--RAMR
HOUSTON/ LA. CHARLES MET DATA
1 GRAM/SEC EMISSION RATE

INPUT MET DATA 64/ 176

HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (DEG-K)	STABILITY CLASS
16	49.00	4.62	490.42	307.50	4

RESULTANT MET CONDITIONS

WIND DIRECTION= 49.00 RESULTANT WIND SPEED= 4.62

Table C.4-2 (continued)

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AVERAGE WIND SPEED= 4.62 AVERAGE TEMP= 307.50
WIND PERSISTENCE= 1.000 MODAL STABILITY= 4

SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR # EAST NORTH

1 A 1 58.65 58.83
THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
NO OTHERS WILL BE ACCEPTED.
***PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR
THE PRECEDING AVERAGING PERIOD.***

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 16

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 A 1	58.65	58.83	0.0000	0.0000	1006.4342	1006.4342	1006.4342	1
2 H 0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
3 H 0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6
13 H 0	6.00	13.99	0.0000	0.0000	0.2743	0.2743	0.2743	4
38 H 0	26.00	31.31	0.0000	0.0000	8.6802	8.6802	8.6802	3
63 H 0	46.00	48.63	0.0000	0.0000	32.8100	32.8100	32.8100	2

SPF SAMPLE RUN BY MARK WICKES--RAMR
HOUSTON/ LA. CHARLES MET DATA
1 GRAM/SEC EMISSION RATE

INPUT MET DATA 64/ 176

HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (DEG-K)	STABILITY CLASS
17	354.00	13.37	850.59	300.90	4

RESULTANT MET CONDITIONS

WIND DIRECTION= 354.00 RESULTANT WIND SPEED= 13.37
AVERAGE WIND SPEED= 13.37 AVERAGE TEMP= 300.90
WIND PERSISTENCE= 1.000 MODAL STABILITY= 4

SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR # EAST NORTH

1 A 1 60.17 59.38
THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
NO OTHERS WILL BE ACCEPTED.

Table C.4-2 (continued)

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PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR THE PRECEEDING AVERAGING PERIOD.

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 17

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 A 1	60.17	58.38	0.0000	0.0000	367.3660	367.3660	367.3660	1
2 H 0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	2
3 H 0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	3
4 H 0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
5 H 0	41.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
6 H 0	51.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6

SPP SAMPLE RUN BY MARK HITCKES--RAHR
HOUSTON/ LA. CHARLES MET DATA
1 GRAM/SEC EMISSION RATE

INPUT MET DATA 64/ 176

HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (DEG-K)	STABILITY CLASS
18	203.00	4.62	1210.75	297.00	4

RESULTANT MET CONDITIONS

WIND DIRECTION= 203.00
AVERAGE WIND SPEED= 4.62
WIND PERSISTENCE= 1.000
RESULTANT WIND SPEED= 4.62
AVERAGE TEMP= 297.00
MODAL STABILITY= 4

SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR #	EAST	NORTH
1 A 1	60.65	61.53

THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
NO OTHERS WILL BE ACCEPTED.
PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR THE PRECEEDING AVERAGING PERIOD.

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 18

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 A 1	60.65	61.53	0.0000	0.0000	841.7049	841.7049	841.7049	1
2 H 0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	3
3 H 0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4

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4	H	0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
5	H	0	41.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6
146	H	0	81.00	109.25	0.0000	0.0000	79.5655	79.5655	79.5655	2

SPR SAMPLE RUN BY MARK MITCKES--RAMR
HOUSTON/ LA. CHARLES MET DATA
1 GRAM/SEC EMISSION RATE

INPUT MET DATA 64/ 176

HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (DEG-K)	STABILITY CLASS
19	224.00	4.11	1570.92	296.40	3

RESULTANT MET CONDITIONS

WIND DIRECTION= 224.00   RESULTANT WIND SPEED= 4.11
AVERAGE WIND SPEED= 4.11   AVERAGE TEMP= 296.40
WIND PERSISTENCE= 1.000   MODAL STABILITY= 3

SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR #	EAST	NORTH
1 A 1	61.00	61.03

THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
NO OTHERS WILL BE ACCEPTED.
PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR THE PRECEEDING AVERAGING PERIOD.

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 19

RECEPTOR NO.			EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1	A	1	61.00	61.03	0.0000	0.0000	983.0623	983.0623	983.0623	1
2	H	0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
3	H	0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
4	H	0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6
87	H	0	66.00	65.95	0.0000	0.0000	180.3188	180.3188	180.3188	2
124	H	0	91.00	91.93	0.0000	0.0000	41.5925	41.5925	41.5925	3

SPR SAMPLE RUN BY MARK MITCKES--RAMR
HOUSTON/ LA. CHARLES MET DATA
1 GRAM/SEC EMISSION RATE

INPUT MET DATA 64/ 176

HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (DEG-K)	STABILITY CLASS
20	119.00	2.57	1751.00	297.00	4

RESULTANT MET CONDITIONS

Table C.4-2 (continued)

WIND DIRECTION= 119.00 RESULTANT WIND SPEED= 2.57
AVERAGE WIND SPEED= 2.57 AVERAGE TEMP= 297.00
WIND PERSISTENCE= 1.000 MODAL STABILITY= 4

SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR # EAST NORTH

1 A 1 58.52 60.82
THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
NO OTHERS WILL BE ACCEPTED.
PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR THE PRECEDING AVERAGING PERIOD.

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 20

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 A 1	58.52	60.82	0.0000	0.0000	765.4833	765.4833	765.4833	1
2 H 0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	2
3 H 0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	3
4 H 0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
5 H 0	41.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
6 H 0	51.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6

SPR SAMPLE RUN BY MARK WITCKES--RAND
HOUSTON/ LA. CHARLES MET DATA
1 GRAM/SEC EMISSION RATE

INPUT MET DATA 64/ 176

HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (DEG-K)	STABILITY CLASS
21	21.00	1.54	1751.00	297.00	6

RESULTANT MET CONDITIONS

WIND DIRECTION= 21.00 RESULTANT WIND SPEED= 1.54
AVERAGE WIND SPEED= 1.54 AVERAGE TEMP= 297.00
WIND PERSISTENCE= 1.000 MODAL STABILITY= 6

SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR # EAST NORTH

Table C.4-2 (continued)

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  1 A  1       59.07       57.58
THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
 NO OTHERS WILL BE ACCEPTED.
***PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR
                  THE PRECEEDING AVERAGING PERIOD.***
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1-HOUR AVERAGE HC   SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3)   64/176   START HOUR: 21

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 A 1	59.07	57.58	0.0000	0.0000	135.8637	135.8637	135.8637	2
2 H 0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	3
3 H 0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
4 H 0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
5 H 0	41.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6
64 H 0	56.00	48.63	0.0000	0.0000	894.9875	894.9875	894.9875	1

```
SPR SAMPLE RUN BY MARK MITCKES--RAMR
HOUSTON/ LA. CHARLES MET DATA
1 GRAM/SEC EMISSION RATE

INPUT MET DATA  64/ 176
HOUR   THETA     SPEED    MIXING     TEMP      STABILITY
       (DEG)     (M/S)   HEIGHT(M) (DEG-K)    CLASS

 22    21.00      1.00   1751.00   297.00       6

RESULTANT MET CONDITIONS

 WIND DIRECTION=  21.00              RESULTANT WIND SPEED=   1.00
 AVERAGE WIND SPEED=    1.00         AVERAGE TEMP= 297.00
 WIND PERSISTENCE= 1.000             MODAL STABILITY= 6


      SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR #  EAST      NORTH .

  1 A  1       59.07       57.58
THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
 NO OTHERS WILL BE ACCEPTED.
***PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR
                  THE PRECEEDING AVERAGING PERIOD.***
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1-HOUR AVERAGE HC   SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3)   64/176   START HOUR: 22

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK

1	A	1	59.07	57.58	0.0000	0.0000	135.8637	135.8637	135.8637	2
2	H	0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	3
3	H	0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
4	H	0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
5	H	0	41.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6
64	H	0	56.00	48.63	0.0000	0.0000	894.9875	894.9875	894.9875	1

SPR SAMPLE RUN BY MARK RICKES--PAMR
HOUSTON/ LA. CHARLES MET DATA
1 GRAM/SEC EMISSION RATE

INPUT MET DATA 64/ 176

HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (DEG-K)	STABILITY CLASS
23	111.00	1.54	1309.21	297.00	6

RESULTANT MET CONDITIONS

WIND DIRECTION= 114.00   RESULTANT WIND SPEED= 1.54
AVERAGE WIND SPEED= 1.54   AVERAGE TEMP= 297.00
WIND PERSISTENCE= 1.000   MODAL STABILITY= 6

SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR #			EAST	NORTH
1	A	1	57.62	61.06

THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
NO OTHERS WILL BE ACCEPTED.
PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR THE PRECEEDING AVERAGING PERIOD.

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 23

RECEPTOR NO.			EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1	A	1	57.62	61.06	0.0000	0.0000	141.3822	141.3822	141.3822	2
2	H	0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	3
3	H	0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
4	H	0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
5	H	0	41.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6
86	H	0	16.00	65.95	0.0000	0.0000	1008.1145	1008.1145	1008.1145	1

SPR SAMPLE RUN BY MARK RICKES--PAMR
HOUSTON/ LA. CHARLES MET DATA
1 GRAM/SEC EMISSION RATE

INPUT MET DATA 64/ 176

HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (DEG-K)	STABILITY CLASS

Table C.4-2 (continued)

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 24   265.00      1.54   778.41   297.00       6
RESULTANT MET CONDITIONS

 WIND DIRECTION= 265.00            RESULTANT WIND SPEED=   1.54
 AVERAGE WIND SPEED=    1.54       AVERAGE TEMP= 297.00
 WIND PERSISTENCE= 1.000           MODAL STABILITY= 6


      SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR #  EAST      NORTH

  1 A  1     62.55     60.22
THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
 NO OTHERS WILL BE ACCEPTED.
***PLEASE NOTE; THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR
                   THE PRECEEDING AVERAGING PERIOD.***
```

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 24

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 A 1	62.55	60.22	0.0000	0.0000	120.0476	120.0476	120.0476	1
2 H 0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	2
3 H 0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	3
4 H 0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
5 H 0	41.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
6 H 0	51.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6

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SPR            job terminated at  8-JUL-1981 10:51:52.52

 Accounting information:
 Buffered I/O count:          93     Peak working set size:   251
 Direct I/O count:           310     Peak virtual size:       385
 Page faults:                943     Mounted volumes:           0
 Elapsed CPU time:     0 00:00:20.80 Elapsed time:     0 00:00:34.98
```

Table C.4-3 OZIPP modeling results; Winnie, Texas.

```
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                  ***  SPR PHASE III  ***

                  PHOTOLYTIC RATE CONSTANTS CALCULATED FOR

                           WINNIE, TEXAS

                  LATITUDE      29.670
                  LONGITUDE      94.450
                  TIME ZONE     6.0
                  DATE          6      25    1981
                  TIME          800    TO    1800     LOCAL DAYLIGHT TIME

                  DILUTION DETERMINED FROM THE FOLLOWING
                  INVERSION HEIGHTS      INITIAL  1309.     FINAL       1751.
                  TIMING                 START    1800.     STOP         300.

                  INITIAL PROPYLENE FRACTION     0.010      NO2/NOX   0.650
                  INITIAL ALDEHYDE FRACTION      0.050
```

Table C.4-3 (continued)

THE FOLLOWING SIMULATIONS WERE DONE.

HC	NOX	RATIO	OZONE
0.00000	0.00000	0.00000	0.00000
0.00000	0.28000	0.00000	0.02151
5.00000	0.28000	17.85714	0.65744
5.00000	0.00000	0.00000	0.00000
1.66667	0.28000	5.95238	0.25752
5.00000	0.03407	146.75009	0.26353
2.95310	0.16537	17.85714	0.47830
1.47655	0.08269	17.85714	0.30427
0.73828	0.04134	17.85714	0.19022
0.24795	0.01389	17.85714	0.08992
4.16667	0.28000	14.88095	0.61842
2.49885	0.16792	14.88095	0.45302
1.24943	0.08396	14.88095	0.28818
0.62471	0.04198	14.88095	0.18062
0.22310	0.01499	14.88095	0.08904
3.33333	0.28000	11.90476	0.56004
2.04926	0.17214	11.90476	0.41721
1.02463	0.08607	11.90476	0.26654
0.51232	0.04303	11.90476	0.16795
0.19953	0.01676	11.90476	0.08830
2.50000	0.28000	8.92857	0.45836
1.61588	0.18098	8.92857	0.35701
0.80794	0.09049	8.92857	0.23398
0.40397	0.04524	8.92857	0.15042
0.17882	0.02003	8.92857	0.08750
1.66667	0.28000	5.95238	0.25749
1.24432	0.20905	5.95238	0.23000
0.62216	0.10452	5.95238	0.16730

Table C.4-3 (continued)

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0.31108	0.05226	5.95238	0.11801
0.17787	0.02988	5.95238	0.08662
1.05702	0.28000	3.77508	0.08241
1.04921	0.27793	3.77508	0.08249
0.52460	0.13897	3.77508	0.07798
0.26230	0.06948	3.77508	0.06468
0.23607	0.06253	3.77508	0.06269
5.00000	0.22607	22.11718	0.61563
3.00201	0.13573	22.11718	0.44881
1.50101	0.06787	22.11718	0.28410
0.75050	0.03393	22.11718	0.17796
0.27263	0.01233	22.11718	0.08878
5.00000	0.17214	29.04659	0.55677
3.07839	0.10598	29.04659	0.40996
1.53920	0.05299	29.04659	0.25911
0.76960	0.02650	29.04659	0.16232
0.31300	0.01078	29.04659	0.08759
5.00000	0.11821	42.29908	0.47538
3.20246	0.07571	42.29908	0.35751
1.60123	0.03785	42.29908	0.22611
0.80061	0.01893	42.29908	0.14224
0.38230	0.00904	42.29908	0.08591
5.00000	0.06427	77.79134	0.35954
3.43403	0.04414	77.79134	0.28209
1.86695	0.02400	77.79134	0.18989
0.97312	0.01251	77.79134	0.12366
0.55486	0.00713	77.79134	0.08441
5.00000	0.02832	176.55211	0.24044
3.79746	0.02151	176.55211	0.20272
2.43003	0.01376	176.55211	0.15321

Table C.4-4 RAM NMHC modeling results at 3.50 gm/sec emission rate

```
$run ramr

SPR SAMPLE RUN BY MARK MITCKES--RAMR
HOUSTON/ LA. CHARLES MET DATA
3.5 GRAM/SEC EMISSION RATE

THIS IS THE NORMAL RURAL VERSION(78124) OF RAMR FOR APPLICATION TO ONE OR SEVERAL DAYS DATA.

 OPTION        OPTION LIST                          OPTION SPECIFICATION : 0= IGNORE OPTION
                                                                           1= USE OPTION
      1        POINT SOURCE DATA                    0
      2        AREA SOURCE DATA                     1
      3        PERMANENT RECEPTORS                  0
      4        SIGNIFICANT POINT RECEPTORS          0
      5        SIGNIFICANT AREA RECEPTORS           1
      6        HONEYCOMB RECEPTORS                  1
      7        HOURLYOUTPUT                         0
      8        PARTIAL CONC. WRITTEN TO DISK/TAPE   0
      9        PRINT ONLY SUMMARY HOURLY OUTPUT     0
     10        PUNCH CARDS FOR CONTOURS             0
     11        READ METDATA FROM CARDS              0
     12        SPECIFY SIGNIFICANT SOURCE NUMBERS   0
     13        READ HOURLY EMISSIONS                0
```

Table C.4-4 (continued)

```
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                         GENERAL INFORMATION FROM RAMQ

 UNITS - THEREARE     1.0000000 USER UNITS(INPUT UNITS) PER SMALLEST AREA SOURCE SQUARE SIDE LENGTH (INTERNAL UNIT)
 CONONE - THERE ARE      0.0500000 KILOMETERS PER USER UNIT
 CONTWO - IT IS CALCULATED THAT THERE ARE     0.0500000 KILOMETERS PER SMALLEST AREA SOURCE SQUARE SIDE LENGTH (INTERNAL UNIT)
 THIS RUN IS FOR  HC   SINCE IPOL= 3

                         GENERAL INPUT DATA

 NUMBER OF PERIODS TO BE SIMULATED(NPER)=    24
AVERAGING TIME IN HOURS FOR EACH PERIOD(NAVG)=      1
 STARTING DATE(IDATE(2),IDATE(1),IHSTRT): JULIAN DAY  176, YEAR 1964 HOUR=  1
 RECEPTOR HEIGHT FOR ALL RECEPTORS(Z)    2.000 METERS
 ASSUMED POLLUTANT HALF-LIFE(HAFL)     7200.00 SECONDS
 SURFACE MET DATA FROM STATION(ISFCD)   12919, YEAR(ISFCYR) 1964
 MIXING HEIGHT DATA FROM STATION(IMXD)    3927, YEAR(IMXYR) 1964


SPR SAMPLE RUN BY MARK MITCKES--RAMR
HOUSTON/ LA. CHARLES MET DATA
3.5 GRAM/SEC EMISSION RATE

                         AREA SOURCE INFORMATION

 EMISSION INFORMATION FOR    1 (NAS) AREA SOURCES HAS BEEN DETERMINED BY RAMQ
  1 SIGNIFICANT AREA SOURCES(NSIGA) ARE TO BE USED FOR THIS RUN
  THE ORDER OF SIGNIFICANCE(IMAS) FOR 10 OR LESS  AREA SOURCES DETERMINED BY RAMQ IS LISTED BY  AREA SOURCE NUMBER:
    1
 NUMBER OF AREA HEIGHT CLASSES(NHTS)= 1
 REPRESENTATIVE AREA SOURCE HEIGHTS FOR EACH HEIGHT CLASS(HINT) IN METERS=     2.00
 BREAK POINT HEIGHT BETWEEN THE AREA HEIGHT CLASSES(BPH) IN METERS=     4.00
 FRACTION OF AREA SOURCE HEIGHT WHICH IS PHYSICAL HEIGHT(FH)=     0.100
 LIMIT OF DISTANCE FOR AREA SOURCE INTEGRATION TABLES(XLIM) IN USER UNITS =    85.000
 BOUNDARIES OF THE AREA SOURCE GRID IN USER UNITS:
    RMIN=    59.500     RMAX=    60.500     SMIN=    59.500     SMAX=    60.500
 SIZE(IRSIZE X ISSIZE) OF AREA SOURCE MAP ARRAY(IA) IN INTERNAL UNITS =  1 EAST-WEST BY   1 NORTH-SOUTH


                 AREA SOURCE MAP ARRAY(IA)

   1     1

         1
                         AREA SOURCE LISTING

 SOURCE   EAST    NORTH   HC(G/SEC-M**2)     PART(G/SEC-M**2)  SIDEEFFECTIVE
          COORD   COORD     EMISSIONS          EMISSIONS       LENGTH    HEIGHT
           (USER UNITS)                                      (USER UNITS)   (M)

    1      59.5    59.5    1.4000E-03         0.0000E+00        1.0        3.0

 SPR SAMPLE RUN BY MARK MITCKES--RAMR
 HOUSTON/ LA. CHARLES MET DATA
```

```
BATCH2.LOG;1                    13-AUG-1981 16:19:31.89         Page 3
3.5 GRAM/SEC EMISSION RATE

INPUT MET DATA  64/ 176
HOUR   THETA      SPEED    MIXING     TEMP     STABILITY
       (DEG)      (M/S)   HEIGHT(M)  (DEG-K)   CLASS

  1   240.00      3.08   1384.64    298.70       6

RESULTANT MET CONDITIONS

 WIND DIRECTION= 240.00           RESULTANT WIND SPEED=   3.08
 AVERAGE WIND SPEED=    3.08      AVERAGE TEMP= 298.70
 WIND PERSISTENCE= 1.000          MODAL STABILITY= 6


      SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR #  EAST      NORTH

  1 A  1     62.28     61.32
                 GENERATED HONEYCOMB RECEPTORS

THE AREA TO BE COVERED BY HONEYCOMB RECEPTORS IS BOUNDED BY:
 RMIN=     1.000 RMAX=   119.000 SMIN=     1.000 SMAX=   119.000

DISTANCE BETWEEN HONEYCOMB RECEPTORS(GRIDSP) IN USER UNITS= 10.000

RECEPTOR     EAST       NORTH
    2 H      11.00       5.33
    3 H      21.00       5.33
    4 H      31.00       5.33
    5 H      41.00       5.33
    6 H      51.00       5.33
    7 H      61.00       5.33
    8 H      71.00       5.33
    9 H      81.00       5.33
   10 H      91.00       5.33
   11 H     101.00       5.33
   12 H     111.00       5.33
   13 H       6.00      13.99
   14 H      16.00      13.99
   15 H      26.00      13.99
   16 H      36.00      13.99
   17 H      46.00      13.99
   18 H      56.00      13.99
   19 H      66.00      13.99
   20 H      76.00      13.99
   21 H      86.00      13.99
   22 H      96.00      13.99
   23 H     106.00      13.99
   24 H     116.00      13.99
   25 H      11.00      22.65
   26 H      21.00      22.65
   27 H      31.00      22.65
   28 H      41.00      22.65
```

Table C.4-4 (continued)

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29	H	51.00	22.65
30	H	61.00	22.65
31	H	71.00	22.65
32	H	81.00	22.65
33	H	91.00	22.65
34	H	101.00	22.65
35	H	111.00	22.65
36	H	6.00	31.31
37	H	16.00	31.31
38	H	26.00	31.31
39	H	36.00	31.31
40	H	46.00	31.31
41	H	56.00	31.31
42	H	66.00	31.31
43	H	76.00	31.31
44	H	86.00	31.31
45	H	96.00	31.31
46	H	106.00	31.31
47	H	116.00	31.31
48	H	11.00	39.97
49	H	21.00	39.97
50	H	31.00	39.97
51	H	41.00	39.97
52	H	51.00	39.97
53	H	61.00	39.97
54	H	71.00	39.97
55	H	81.00	39.97
56	H	91.00	39.97
57	H	101.00	39.97
58	H	111.00	39.97
59	H	6.00	48.63
60	H	16.00	48.63
61	H	26.00	48.63
62	H	36.00	48.63
63	H	46.00	48.63
64	H	56.00	48.63
65	H	66.00	48.63
66	H	76.00	48.63
67	H	86.00	48.63
68	H	96.00	48.63
69	H	106.00	48.63
70	H	116.00	48.63
71	H	11.00	57.29
72	H	21.00	57.29
73	H	31.00	57.29
74	H	41.00	57.29
75	H	51.00	57.29
76	H	71.00	57.29
77	H	81.00	57.29
78	H	91.00	57.29
79	H	101.00	57.29
80	H	111.00	57.29
81	H	6.00	65.95
82	H	16.00	65.95
83	H	26.00	65.95
84	H	36.00	65.95
85	H	46.00	65.95
86	H	56.00	65.95
87	H	66.00	65.95

Table C.4-4 (continued)

88	H	76.00	65.95
89	H	86.00	65.95
90	H	96.00	65.95
91	H	106.00	65.95
92	H	116.00	65.95
93	H	11.00	74.61
94	H	21.00	74.61
95	H	31.00	74.61
96	H	41.00	74.61
97	H	51.00	74.61
98	H	61.00	74.61
99	H	71.00	74.61
100	H	81.00	74.61
101	H	91.00	74.61
102	H	101.00	74.61
103	H	111.00	74.61
104	H	6.00	83.27
105	H	16.00	83.27
106	H	26.00	83.27
107	H	36.00	83.27
108	H	46.00	83.27
109	H	56.00	83.27
110	H	66.00	83.27
111	H	76.00	83.27
112	H	86.00	83.27
113	H	96.00	83.27
114	H	106.00	83.27
115	H	116.00	83.27
116	H	11.00	91.93
117	H	21.00	91.93
118	H	31.00	91.93
119	H	41.00	91.93
120	H	51.00	91.93
121	H	61.00	91.93
122	H	71.00	91.93
123	H	81.00	91.93
124	H	91.00	91.93
125	H	101.00	91.93
126	H	111.00	91.93
127	H	6.00	100.59
128	H	16.00	100.59
129	H	26.00	100.59
130	H	36.00	100.59
131	H	46.00	100.59
132	H	56.00	100.59
133	H	66.00	100.59
134	H	76.00	100.59
135	H	86.00	100.59
136	H	96.00	100.59
137	H	106.00	100.59
138	H	116.00	100.59
139	H	11.00	109.25
140	H	21.00	109.25
141	H	31.00	109.25
142	H	41.00	109.25
143	H	51.00	109.25
144	H	61.00	109.25
145	H	71.00	109.25
146	H	81.00	109.25

Table C.4-4 (continued)

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```
 147 H       91.00      109.25
 148 H      101.00      109.25
 149 H      111.00      109.25
 150 H        6.00      117.91
THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
 NO OTHERS WILL BE ACCEPTED.
***PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR
                THE PRECEEDING AVERAGING PERIOD.***
```

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 1

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 A 1	62.28	61.32	0.0000	0.0000	545.9737	545.9737	545.9737	1
2 H 0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	2
3 H 0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	3
4 H 0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
5 H 0	41.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
6 H 0	51.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6

```
SPR SAMPLE RUN BY MARK MITCKES--RAMR
HOUSTON/ LA. CHARLES MET DATA
3.5 GRAM/SEC EMISSION RATE

INPUT MET DATA  64/ 176
HOUR   THETA    SPEED    MIXING     TEMP      STABILITY
       (DEG)    (M/S)   HEIGHT(M)  (DEG-K)    CLASS

  2   127.00     1.54   1441.00    297.00       6

RESULTANT MET CONDITIONS

  WIND DIRECTION= 127.00          RESULTANT WIND SPEED=   1.54
  AVERAGE WIND SPEED=   1.54      AVERAGE TEMP= 297.00
  WIND PERSISTENCE= 1.000         MODAL STABILITY= 6


      SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR #   EAST      NORTH

  1 A  1     57.86     61.61
THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
 NO OTHERS WILL BE ACCEPTED.
***PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR
                THE PRECEEDING AVERAGING PERIOD.***
```

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 2

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT	TOTAL FROM ALL POINT	TOTAL FROM SIGNIF AREA	TOTAL FROM ALL AREA	TOTAL FROM ALL SOURCES	CONCENTRATION RANK

Table C.4-4 (continued)

RECEPTOR NO.			EAST	NORTH	SOURCES	SOURCES	SOURCES	SOURCES		
1	A	1	57.86	61.61	0.0000	0.0000	642.6468	642.6468	642.6468	3
2	H	0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
3	H	0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
4	H	0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6
96	H	0	41.00	74.61	0.0000	0.0000	2592.3210	2592.3210	2592.3210	1
127	H	0	6.00	100.59	0.0000	0.0000	1731.4681	1731.4681	1731.4681	2

SPR SAMPLE RUN BY MARK MITCKES--RAMR
HOUSTON/ LA. CHARLES MET DATA
3.5 GRAM/SEC EMISSION RATE

INPUT MET DATA 64/ 176

HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (DEG-K)	STABILITY CLASS
3	243.00	1.54	1497.36	297.50	6

RESULTANT MET CONDITIONS

WIND DIRECTION= 243.00 RESULTANT WIND SPEED= 1.54
AVERAGE WIND SPEED= 1.54 AVERAGE TEMP= 297.50
WIND PERSISTENCE= 1.000 MODAL STABILITY= 6

SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR #			EAST	NORTH
1	A	1	62.33	61.19

THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
NO OTHERS WILL BE ACCEPTED.
PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR THE PRECEEDING AVERAGING PERIOD.

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 3

RECEPTOR NO.			EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1	A	1	62.33	61.19	0.0000	0.0000	517.6038	517.6038	517.6038	2
2	H	0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	3
3	H	0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
4	H	0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
5	H	0	41.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6
114	H	0	106.00	83.27	0.0000	0.0000	1839.7750	1839.7750	1839.7750	1

SPR SAMPLE RUN BY MARK MITCKES--RAMR
HOUSTON/ LA. CHARLES MET DATA
3.5 GRAM/SEC EMISSION RATE

INPUT MET DATA 64/ 176

Table C.4-4 (continued)

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HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (DEG-K)	STABILITY CLASS
4	251.00	2.05	318.64	297.00	6

RESULTANT MET CONDITIONS

WIND DIRECTION= 251.00 RESULTANT WIND SPEED= 2.05
AVERAGE WIND SPEED= 2.05 AVERAGE TEMP= 297.00
WIND PERSISTENCE= 1.000 MODAL STABILITY= 6

SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR #	EAST	NORTH
1 A 1	62.44	60.84

THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
NO OTHERS WILL BE ACCEPTED.
PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR THE PRECEEDING AVERAGING PERIOD.

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 4

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 A 1	62.44	60.84	0.0000	0.0000	464.4007	464.4007	464.4007	3
2 H 0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
3 H 0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
4 H 0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6
88 H 0	76.00	65.95	0.0000	0.0000	2220.2884	2220.2884	2220.2884	1
102 H 0	101.00	74.61	0.0000	0.0000	1021.1181	1021.1181	1021.1181	2

SPR SAMPLE RUN BY MARK MITCKES--RAMR
HOUSTON/ LA. CHARLES MET DATA
3.5 GRAM/SEC EMISSION RATE

INPUT MET DATA 64/ 176

HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (DEG-K)	STABILITY CLASS
5	296.00	2.57	727.88	297.00	6

RESULTANT MET CONDITIONS

WIND DIRECTION= 296.00 RESULTANT WIND SPEED= 2.57
AVERAGE WIND SPEED= 2.57 AVERAGE TEMP= 297.00
WIND PERSISTENCE= 1.000 MODAL STABILITY= 6

Table C.4-4 (continued)

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SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR # EAST NORTH

1 A 1 62.35 58.86
THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
NO OTHERS WILL BE ACCEPTED.
PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR THE PRECEEDING AVERAGING PERIOD.

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 5

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 A 1	62.35	58.86	0.0000	0.0000	509.6086	509.6086	509.6086	2
2 H 0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	3
3 H 0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
4 H 0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
5 H 0	41.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6
57 H 0	101.00	39.97	0.0000	0.0000	1988.9800	1988.9800	1988.9800	1

SPR SAMPLE RUN BY MARK MITCKES--RAMR
HOUSTON/ LA. CHARLES MET DATA
3.5 GRAM/SEC EMISSION RATE

INPUT MET DATA 64/ 176

HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (DEG-K)	STABILITY CLASS
6	305.00	3.08	1137.13	297.00	6

RESULTANT MET CONDITIONS

WIND DIRECTION= 305.00 RESULTANT WIND SPEED= 3.08
AVERAGE WIND SPEED= 3.08 AVERAGE TEMP= 297.00
WIND PERSISTENCE= 1.000 MODAL STABILITY= 6

SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR # EAST NORTH

1 A 1 62.18 58.47
THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
NO OTHERS WILL BE ACCEPTED.
PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR THE PRECEEDING AVERAGING PERIOD.

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 6

Table C.4-4 (continued)

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RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 A 1	62.18	58.47	0.0000	0.0000	611.5316	611.5316	611.5316	2
2 H 0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	3
3 H 0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
4 H 0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
5 H 0	41.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6
66 H 0	76.00	48.63	0.0000	0.0000	3530.9806	3530.9806	3530.9806	1

SPR SAMPLE RUN BY MARK MITCKES--RAMR
HOUSTON/ LA. CHARLES MET DATA
3.5 GRAM/SEC EMISSION RATE

INPUT MET DATA 64/ 176

HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (DEG-K)	STABILITY CLASS
7	289.00	4.11	1546.38	297.00	4

RESULTANT MET CONDITIONS

WIND DIRECTION= 289.00 RESULTANT WIND SPEED= 4.11
AVERAGE WIND SPEED= 4.11 AVERAGE TEMP= 297.00
WIND PERSISTENCE= 1.000 MODAL STABILITY= 4

SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR #	EAST	NORTH
1 A 1	61.56	59.46

THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
NO OTHERS WILL BE ACCEPTED.
PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR THE PRECEEDING AVERAGING PERIOD.

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 7

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 A 1	61.56	59.46	0.0000	0.0000	2955.4719	2955.4719	2955.4719	1
2 H 0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	2
3 H 0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	3
4 H 0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
5 H 0	41.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
6 H 0	51.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6

SPR SAMPLE RUN BY MARK MITCKES--RAMR
HOUSTON/ LA. CHARLES MET DATA

Table C.4-4 (continued)

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3.5 GRAM/SEC EMISSION RATE

INPUT MET DATA 64/ 176

HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (DEG-K)	STABILITY CLASS
8	299.00	3.60	1751.00	298.70	3

RESULTANT MET CONDITIONS

WIND DIRECTION= 299.00 RESULTANT WIND SPEED= 3.60
AVERAGE WIND SPEED= 3.60 AVERAGE TEMP= 298.70
WIND PERSISTENCE= 1.000 MODAL STABILITY= 3

SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR #	EAST	NORTH
1 A 1	61.15	59.37

THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
NO OTHERS WILL BE ACCEPTED.
PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR THE PRECEEDING AVERAGING PERIOD.

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 8

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 A 1	61.15	59.37	0.0000	0.0000	3150.2759	3150.2759	3150.2759	1
2 H 0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	2
3 H 0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	3
4 H 0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
5 H 0	41.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
6 H 0	51.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6

SPR SAMPLE RUN BY MARK MITCKES--RAMR
HOUSTON/ LA. CHARLES MET DATA
3.5 GRAM/SEC EMISSION RATE

INPUT MET DATA 64/ 176

HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (DEG-K)	STABILITY CLASS
9	312.00	4.11	1751.00	300.90	3

RESULTANT MET CONDITIONS

WIND DIRECTION= 312.00 RESULTANT WIND SPEED= 4.11
AVERAGE WIND SPEED= 4.11 AVERAGE TEMP= 300.90
WIND PERSISTENCE= 1.000 MODAL STABILITY= 3

Table C.4-4 (continued)

SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR # EAST NORTH

1 A 1 61.05 59.06
THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
NO OTHERS WILL BE ACCEPTED.
PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR THE PRECEEDING AVERAGING PERIOD.

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 9

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 A 1	61.05	59.06	0.0000	0.0000	3354.4761	3354.4761	3354.4761	1
2 H 0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	3
3 H 0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
4 H 0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
5 H 0	41.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6
34 H 0	101.00	22.65	0.0000	0.0000	77.8768	77.8768	77.8768	2

SPR SAMPLE RUN BY MARK MITCKES--RAHR
HOUSTON/ LA. CHARLES MET DATA
3.5 GRAM/SEC EMISSION RATE

INPUT MET DATA 64/ 176

HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (DEG-K)	STABILITY CLASS
10	307.00	4.62	1751.00	304.80	3

RESULTANT MET CONDITIONS

WIND DIRECTION= 307.00 RESULTANT WIND SPEED= 4.62
AVERAGE WIND SPEED= 4.62 AVERAGE TEMP= 304.80
WIND PERSISTENCE= 1.000 MODAL STABILITY= 3

SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR # EAST NORTH

1 A 1 61.09 59.18
THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
NO OTHERS WILL BE ACCEPTED.
PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR THE PRECEEDING AVERAGING PERIOD.

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 10

Table C.4-4 (continued)

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 A 1	61.09	59.18	0.0000	0.0000	2948.4448	2948.4448	2948.4448	1
2 H 0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	3
3 H 0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
4 H 0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
5 H 0	41.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6
66 H 0	76.00	48.63	0.0000	0.0000	79.9981	79.9981	79.9981	2

SPR SAMPLE RUN BY MARK MITCKES--RAMR
HOUSTON/ LA. CHARLES MET DATA
3.5 GRAM/SEC EMISSION RATE

INPUT MET DATA 64/ 176

HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (DEG-K)	STABILITY CLASS
11	321.00	4.11	1744.58	305.90	3

RESULTANT MET CONDITIONS

WIND DIRECTION= 321.00　　RESULTANT WIND SPEED= 4.11
AVERAGE WIND SPEED= 4.11　　AVERAGE TEMP= 305.90
WIND PERSISTENCE= 1.000　　MODAL STABILITY= 3

SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR #	EAST	NORTH
1 A 1	60.87	58.93

THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
NO OTHERS WILL BE ACCEPTED.
PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR THE PRECEEDING AVERAGING PERIOD.

1-HOUR AVERAGE HC　SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3)　64/176　START HOUR: 11

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 A 1	60.87	58.93	0.0000	0.0000	3240.4691	3240.4691	3240.4691	1
2 H 0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	3
3 H 0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
4 H 0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
5 H 0	41.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6
33 H 0	91.00	22.65	0.0000	0.0000	27.0604	27.0604	27.0604	2

Table C.4-4 (continued)

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SPR SAMPLE RUN BY MARK HITCKES--RAMR
HOUSTON/ LA. CHARLES MET DATA
3.5 GRAM/SEC EMISSION RATE

INPUT MET DATA 64/ 176

HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (DEG-K)	STABILITY CLASS
12	9.00	7.20	1736.86	305.90	3

RESULTANT MET CONDITIONS

WIND DIRECTION= 9.00 RESULTANT WIND SPEED= 7.20
AVERAGE WIND SPEED= 7.20 AVERAGE TEMP= 305.90
WIND PERSISTENCE= 1.000 MODAL STABILITY= 3

SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR #	EAST	NORTH
1 A 1	59.81	58.77

THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
NO OTHERS WILL BE ACCEPTED.
PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR THE PRECEEDING AVERAGING PERIOD.

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 12

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 A 1	59.81	58.77	0.0000	0.0000	1780.6732	1780.6732	1780.6732	1
2 H 0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
3 H 0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
4 H 0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6
6 H 0	51.00	5.33	0.0000	0.0000	60.7253	60.7253	60.7253	2
41 H 0	56.00	31.31	0.0000	0.0000	24.8345	24.8345	24.8345	3

SPR SAMPLE RUN BY MARK HITCKES--RAMR
HOUSTON/ LA. CHARLES MET DATA
3.5 GRAM/SEC EMISSION RATE

INPUT MET DATA 64/ 176

HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (DEG-K)	STABILITY CLASS
13	348.00	4.62	210.00	307.50	2

RESULTANT MET CONDITIONS

WIND DIRECTION= 348.00 RESULTANT WIND SPEED= 4.62

Table C.4-4 (continued)

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AVERAGE WIND SPEED= 4.62   AVERAGE TEMP= 307.50
WIND PERSISTENCE= 1.000   MODAL STABILITY= 2

SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR #	EAST	NORTH
1 A 1	60.21	59.00

THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
NO OTHERS WILL BE ACCEPTED.
PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR THE PRECEEDING AVERAGING PERIOD.

1-HOUR AVERAGE HC   SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3)   64/176   START HOUR: 13

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 A 1	60.21	59.00	0.0000	0.0000	2220.7939	2220.7939	2220.7939	1
2 H 0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	3
3 H 0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
4 H 0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
5 H 0	41.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6
42 H 0	66.00	31.31	0.0000	0.0000	91.5770	91.5770	91.5770	2

SPR SAMPLE RUN BY MARK HITCKES--RAPR
HOUSTON/ LA. CHARLES MET DATA
3.5 GRAM/SEC EMISSION RATE

INPUT MET DATA 64/ 176

HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (DEG-K)	STABILITY CLASS
14	9.00	5.14	210.00	307.50	3

RESULTANT MET CONDITIONS

WIND DIRECTION= 9.00   RESULTANT WIND SPEED= 5.14
AVERAGE WIND SPEED= 5.14   AVERAGE TEMP= 307.50
WIND PERSISTENCE= 1.000   MODAL STABILITY= 3

SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR #	EAST	NORTH
1 A 1	59.81	58.77

THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
NO OTHERS WILL BE ACCEPTED.

Table C.4-4 (continued)

PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR THE PRECEEDING AVERAGING PERIOD.

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 14

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 A 1	59.81	58.77	0.0000	0.0000	2317.5930	2317.5930	2317.5930	1
2 H 0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
3 H 0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
4 H 0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6
6 H 0	51.00	5.33	0.0000	0.0000	87.3229	87.3229	87.3229	2
41 H 0	56.00	31.31	0.0000	0.0000	34.3835	34.3835	34.3835	3

SPR SAMPLE RUN BY MARK MITCKES--RAMR
HOUSTON/ LA. CHARLES MET DATA
3.5 GRAM/SEC EMISSION RATE

INPUT MET DATA 64/ 176

HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (DEG-K)	STABILITY CLASS
15	44.00	4.62	210.00	307.50	2

RESULTANT MET CONDITIONS

WIND DIRECTION= 44.00 RESULTANT WIND SPEED= 4.62
AVERAGE WIND SPEED= 4.62 AVERAGE TEMP= 307.50
WIND PERSISTENCE= 1.000 MODAL STABILITY= 2

SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR #	EAST	NORTH
1 A 1	59.16	59.13

THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
NO OTHERS WILL BE ACCEPTED.
PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR THE PRECEEDING AVERAGING PERIOD.

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 15

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 A 1	59.16	59.13	0.0000	0.0000	2751.6535	2751.6535	2751.6535	1
2 H 0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
3 H 0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5

Table C.4-4 (continued)

4	H	0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6
14	H	0	16.00	13.99	0.0000	0.0000	61.5688	61.5688	61.5688	3
51	H	0	41.00	39.97	0.0000	0.0000	86.5138	86.5138	86.5138	2

SPR SAMPLE RUN BY MARK MITCKES--RAMR
HOUSTON/ LA. CHARLES MET DATA
3.5 GRAM/SEC EMISSION RATE

INPUT MET DATA 64/ 176

HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (DEG-K)	STABILITY CLASS
16	49.00	4.62	490.42	307.50	4

RESULTANT MET CONDITIONS

WIND DIRECTION= 49.00 RESULTANT WIND SPEED= 4.62
AVERAGE WIND SPEED= 4.62 AVERAGE TEMP= 307.50
WIND PERSISTENCE= 1.000 MODAL STABILITY= 4

SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR #			EAST	NORTH
1	A	1	58.65	58.83

THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
NO OTHERS WILL BE ACCEPTED.
PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR THE PRECEEDING AVERAGING PERIOD.

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 16

RECEPTOR NO.			EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1	A	1	58.65	58.83	0.0000	0.0000	3522.5195	3522.5195	3522.5195	1
2	H	0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
3	H	0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6
13	H	0	6.00	13.99	0.0000	0.0000	0.9601	0.9601	0.9601	4
38	H	0	26.00	31.31	0.0000	0.0000	30.3808	30.3808	30.3908	3
63	H	0	46.00	48.63	0.0000	0.0000	114.8350	114.8350	114.8350	2

SPR SAMPLE RUN BY MARK MITCKES--RAMR
HOUSTON/ LA. CHARLES MET DATA
3.5 GRAM/SEC EMISSION RATE

INPUT MET DATA 64/ 176

HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (DEG-K)	STABILITY CLASS
17	354.00	13.37	850.59	300.90	4

RESULTANT MET CONDITIONS

Table C.4-4 (continued)

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WIND DIRECTION= 354.00 RESULTANT WIND SPEED= 13.37
AVERAGE WIND SPEED= 13.37 AVERAGE TEMP= 300.90
WIND PERSISTENCE= 1.000 MODAL STABILITY= 4

SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR #	EAST	NORTH
1 A 1	60.17	58.38

THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
NO OTHERS WILL BE ACCEPTED.
PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR THE PRECEEDING AVERAGING PERIOD.

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 17

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 A 1	60.17	58.38	0.0000	0.0000	1285.7809	1285.7809	1285.7809	1
2 H 0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	2
3 H 0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	3
4 H 0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
5 H 0	41.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
6 H 0	51.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6

SPR SAMPLE RUN BY MARK HITCKES--RAMR
HOUSTON/ LA. CHARLES MET DATA
3.5 GRAM/SEC EMISSION RATE

INPUT MET DATA 64/ 176

HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (DEG-K)	STABILITY CLASS
18	203.00	4.62	1210.75	297.00	4

RESULTANT MET CONDITIONS

WIND DIRECTION= 203.00 RESULTANT WIND SPEED= 4.62
AVERAGE WIND SPEED= 4.62 AVERAGE TEMP= 297.00
WIND PERSISTENCE= 1.000 MODAL STABILITY= 4

SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR # EAST NORTH

Table C.4-4 (continued)

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  1 A  1      60.65      61.53
THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
 NO OTHERS WILL BE ACCEPTED.
***PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR
                THE PRECEEDING AVERAGING PERIOD.***
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1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 18

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 A 1	60.65	61.53	0.0000	0.0000	2945.9675	2945.9675	2945.9675	1
2 H 0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	3
3 H 0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
4 H 0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
5 H 0	41.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6
146 H 0	81.00	109.25	0.0000	0.0000	278.4792	278.4792	278.4792	2

SPR SAMPLE RUN BY MARK NITCKES--RAMR
HOUSTON/ LA. CHARLES MET DATA
3.5 GRAM/SEC EMISSION RATE

INPUT MET DATA 64/ 176

HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (DEG-K)	STABILITY CLASS
19	224.00	4.11	1570.92	296.40	3

RESULTANT MET CONDITIONS

```
 WIND DIRECTION= 224.00          RESULTANT WIND SPEED=   4.11
 AVERAGE WIND SPEED=    4.11     AVERAGE TEMP= 296.40
 WIND PERSISTENCE= 1.000         MODAL STABILITY= 3
```

SIGNIFICANT AREA SOURCE RECEPTORS

```
RECEPTOR #  EAST       NORTH

  1 A  1      61.00      61.03
THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
 NO OTHERS WILL BE ACCEPTED.
***PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR
                THE PRECEEDING AVERAGING PERIOD.***
```

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 19

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK

Table C.4-4 (continued)

BATCH2.LOG;1 13-AUG-1981 16:19:31.89 Page 20

1 A 1	61.00	61.03	0.0000	0.0000	3440.7177	3440.7177	3440.7177	1
2 H 0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
3 H 0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
4 H 0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6
87 H 0	66.00	65.95	0.0000	0.0000	631.1158	631.1158	631.1158	2
124 H 0	91.00	91.93	0.0000	0.0000	145.5736	145.5736	145.5736	3

SPR SAMPLE RUN BY MARK MITCKES--RAMR
HOUSTON/ LA, CHARLES MET DATA
3.5 GRAM/SEC EMISSION RATE

INPUT MET DATA 64/ 176

HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (DEG-K)	STABILITY CLASS
20	119.00	2.57	1751.00	297.00	4

RESULTANT MET CONDITIONS

WIND DIRECTION= 119.00 RESULTANT WIND SPEED= 2.57
AVERAGE WIND SPEED= 2.57 AVERAGE TEMP= 297.00
WIND PERSISTENCE= 1.000 MODAL STABILITY= 4

SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR #	EAST	NORTH
1 A 1	58.52	60.82

THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
NO OTHERS WILL BE ACCEPTED.
PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR THE PRECEEDING AVERAGING PERIOD.

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 20

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 A 1	58.52	60.82	0.0000	0.0000	2679.1915	2679.1915	2679.1915	1
2 H 0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	2
3 H 0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	3
4 H 0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
5 H 0	41.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
6 H 0	51.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6

SPR SAMPLE RUN BY MARK MITCKES--RAMR
HOUSTON/ LA, CHARLES MET DATA
3.5 GRAM/SEC EMISSION RATE

INPUT MET DATA 64/ 176

HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (DEG-K)	STABILITY CLASS

Table C.4-4 (continued)

BATCH2.LOG;1 13-AUG-1981 16:19:31.89 Page 21

21	21.00	1.54	1751.00	297.00	6

RESULTANT MET CONDITIONS

WIND DIRECTION= 21.00 RESULTANT WIND SPEED= 1.54
AVERAGE WIND SPEED= 1.54 AVERAGE TEMP= 297.00
WIND PERSISTENCE= 1.000 MODAL STABILITY= 6

SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR #	EAST	NORTH
1 A 1	59.07	57.58

THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
NO OTHERS WILL BE ACCEPTED.
PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR THE PRECEEDING AVERAGING PERIOD.

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 21

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 A 1	59.07	57.58	0.0000	0.0000	475.5228	475.5228	475.5228	2
2 H 0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	3
3 H 0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
4 H 0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
5 H 0	41.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6
64 H 0	56.00	48.63	0.0000	0.0000	3132.4560	3132.4560	3132.4560	1

SPR SAMPLE RUN BY MARK MITCKES--RAMR
HOUSTON/ LA. CHARLES MET DATA
3.5 GRAM/SEC EMISSION RATE

INPUT MET DATA 64/ 176

HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (DEG-K)	STABILITY CLASS
22	21.00	1.00	1751.00	297.00	6

RESULTANT MET CONDITIONS

WIND DIRECTION= 21.00 RESULTANT WIND SPEED= 1.00
AVERAGE WIND SPEED= 1.00 AVERAGE TEMP= 297.00
WIND PERSISTENCE= 1.000 MODAL STABILITY= 6

SIGNIFICANT AREA SOURCE RECEPTORS

Table C.4-4 (continued)

BATCH2.LOG;1 13-AUG-1981 16:19:31.89 Page 22

RECEPTOR # EAST NORTH

1 A 1 59.07 57.58

THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED

NO OTHERS WILL BE ACCEPTED.

PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR THE PRECEEDING AVERAGING PERIOD.

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 22

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 A 1	59.07	57.58	0.0000	0.0000	475.5228	475.5228	475.5228	2
2 H 0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	3
3 H 0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
4 H 0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
5 H 0	41.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6
64 H 0	56.00	48.63	0.0000	0.0000	3132.4560	3132.4560	3132.4560	1

SPR SAMPLE RUN BY MARK MITCKES--RAMR

HOUSTON/ LA. CHARLES MET DATA

3.5 GRAM/SEC EMISSION RATE

INPUT MET DATA 64/ 176

HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (DEG-K)	STABILITY CLASS
23	114.00	1.54	1309.21	297.00	6

RESULTANT MET CONDITIONS

WIND DIRECTION= 114.00 RESULTANT WIND SPEED= 1.54

AVERAGE WIND SPEED= 1.54 AVERAGE TEMP= 297.00

WIND PERSISTENCE= 1.000 MODAL STABILITY= 6

SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR # EAST NORTH

1 A 1 57.62 61.06

THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED

NO OTHERS WILL BE ACCEPTED.

PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR THE PRECEEDING AVERAGING PERIOD.

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 23

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT	TOTAL FROM ALL POINT	TOTAL FROM SIGNIF AREA	TOTAL FROM ALL AREA	TOTAL FROM ALL SOURCES	CONCENTRATION RANK

Table C.4-4 (continued)

				SOURCES	SOURCES	SOURCES	SOURCES		
1 A 1	57.62	61.06	0.0000	0.0000	494.8376	494.8376	494.8376	2
2 H 0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	3
3 H 0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
4 H 0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
5 H 0	41.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6
86 H 0	46.00	65.95	0.0000	0.0000	3528.4010	3528.4010	3528.4010	1

SPR SAMPLE RUN BY MARK MITCKES--RAMR
HOUSTON/ LA. CHARLES MET DATA
3.5 GRAM/SEC EMISSION RATE

INPUT MET DATA 64/ 176

HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (DEG-K)	STABILITY CLASS
24	265.00	1.54	778.41	297.00	6

RESULTANT MET CONDITIONS

WIND DIRECTION= 265.00　　RESULTANT WIND SPEED= 1.54
AVERAGE WIND SPEED= 1.54　　AVERAGE TEMP= 297.00
WIND PERSISTENCE= 1.000　　MODAL STABILITY= 6

SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR #	EAST	NORTH
1 A 1	62.55	60.22

THE MAXIMUM NO. OF RECEPTORS HAS BEEN GENERATED
NO OTHERS WILL BE ACCEPTED.
PLEASE NOTE: THE RECEPTOR NUMBERS AND LOCATIONS GENERATED FOR THIS AVERAGING TIME PERIOD ARE DIFFERENT FROM THOSE GENERATED FOR THE PRECEEDING AVERAGING PERIOD.

1-HOUR AVERAGE HC SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 64/176 START HOUR: 24

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 A 1	62.55	60.22	0.0000	0.0000	420.1667	420.1667	420.1667	1
2 H 0	11.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	2
3 H 0	21.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	3
4 H 0	31.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	4
5 H 0	41.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	5
6 H 0	51.00	5.33	0.0000	0.0000	0.0000	0.0000	0.0000	6

$MC SLOW
SAI VAX USAGE AT 13-AUG-1981 16:19:31.26
COMPUTED AS IF THIS WERE A /QUE=SLOW BATCH JOB
JOB = $ 1.00
CONNECT = 0.02 HOURS $ 0.07

Table C.4-4 (continued)

```
BATCH2.LOG;1                     13-AUG-1981 16:19:31.89         Page 24

CPU      =    0.35 MINUTES  $   0.22
BUF I/O  =      89          $   0.00
DIR I/O  =     316          $   1.26
PAGEFLTS=      698          $   0.28

PEAK WORKING SET =       336
PEAK VIRTUAL ADDRESS SIZE =     387
TOTAL CHARGE  =     2.03 $$
PRIME
  SPR          job terminated at 13-AUG-1981 16:19:31.73

  Accounting information:
  Buffered I/O count:              97     Peak working set size:    336
  Direct I/O count:               318     Peak virtual size:        387
  Page faults:                    790     Mounted volumes:            0
  Elapsed CPU time:      0 00:00:21.25    Elapsed time:     0 00:00:59.65
```

APPENDIX C.5

REFERENCES

American Petroleum Institute, 1975, Use of Internal Covered Roofs to Reduce Evaporative Loss, A.P.I. Pub. 2519, Washington, D.C.

American Petroleum Institute, 1980, Evaporative Loss From External Floating-Roof Tanks, A.P.I. Pub. 2517, Washington, D.C.

Caudle, D. D., 1977, Analysis of Oil Content in Production Discharges. Presented at Annual Meeting of the American Petroleum Institute, Houston, Texas, April 4-6, 1977.

Federal Energy Administration, 1977, Strategic Petroleum Reserve, Bryan Mound Salt Dome, Final Environmental Impact Statement. FES 76/77-6, Washington, D.C.

McAuliffe, C., 1976, Dispersal and Alteration of Oil Discharged on a Water Surface. Presented at Symposium on Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms, Seattle, Washington, November 10-12, 1976.

U.S. Department of Energy, 1977, Strategic Petroleum Reserve, Bryan Mound Salt Dome, Final Supplement to Final Environmental Impact Statement. DOE/EIS-0001, Washington, D.C.

U.S. Department of Energy, 1978a, Strategic Petroleum Reserve, Seaway Group Salt Domes, Brazoria County, Texas Final Environmental Impact Statement. DOE/EIS-0021, Washington, D.C.

U.S. Department of Energy, 1978b, Strategic Petroleum Reserve, Texoma Group Salt Domes, Cameron and Calcasieu Parishes, Louisiana and Jefferson County, Texas, Final Environmental Impact Statement. DOE/EIS-0029, Washington, D.C.

U.S. Environmental Protection Agency, 1977, Compilation of Air Pollutant Factors, 3rd ed. Office of Air and Waste Management, Office of Air Quality Standards, Research Triangle Park, North Carolina.

Weaver, L. K., 1978, Texas Air Control Board General Application for the Bryan Mound SPR Facility, Filed December 13, 1978.

APPENDIX D

LETTER COMMUNICATIONS CONCERNING THE PROPOSED ACTION

APPENDIX D

LETTER COMMUNICATIONS CONCERNING THE PROPOSED ACTION

Appendix D contains letter communications involved in coordination and consultation efforts with agencies involved in review of the proposed action.

UNITED STATES
DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

POST OFFICE BOX 1306
ALBUQUERQUE, NEW MEXICO 87103

IN REPLY REFER TO:
LA-Texas
McFaddin NWR
Permits

December 18, 1980

Ms. Joyce Teerling
Department of Energy
900 Commerce Road East
New Orleans, Louisana 70123

Dear Ms. Teerling:

This will acknowledge your telephone request for information on the requirements necessary for a permit to construct pipelines across lands of the U.S. Fish and Wildlife Service.

Enclosed is a copy of our "Rights-of-Way General Provisions, the pipeline section of the Mineral Leasing Act of 1920, and the Endangered Species Act of 1973.

The following are required for a pipeline right-of-way application:

1. A letter of application stating the purpose of the proposed pipeline and the necessity for crossing wildlife refuge lands.

2. A nonreturnable application fee in accordance with the schedule in section 29.21-2 on page 43917 ($50 per mile).

3. Six sets of drawings and plans for construction, operation, and rehabilitation of the pipeline and right-of-way as it crosses refuge lands, and some information on the overall operation of the total pipeline.

4. A <u>centerline</u> description tied to the nearest Government survey monument at the points of entry and exit from the refuge boundary, together with enough detailed information to allow the proposed right-of-way to be accurately located on the ground. Permission to cross refuge lands to complete the centerline survey can be coordinated with the refuge manager.

5. Sufficient environmental data to assist us in determining if an environmental impact statement will be necessary.

6. Section 106 of the National Historic Preservation Act requires that a cultural resource evaluation be conducted over the area. A copy of this archaeological report must be furnished prior to approval of the application.

7. Evidence of approval from all State and Federal agencies to construct, operate, and maintain the pipeline.

Notice of application for a pipeline right-of-way will be published in the "Federal Register," and 30 days will be allowed for public comment. Any unusual inquiries that we receive will be forwarded to you for reply. Please note that publication of this notice is a routine procedure and does not constitute our approval of the proposed permit. For pipelines of 24 inches or larger, no right-of-way permit will be granted until 60 days after the House and Senate Committees on Interior and Insular Affairs have received notification of the application and have approved the terms and conditions to be included in the permit.

The right-of-way permit will be granted when certified compatible by the Regional Director. A lump sum payment for use and occupancy of wildlife refuge lands will be for the fair market value, as determined by appraisal, in addition to the charges for processing the permit.

A $10,000 indemnity bond must be furnished at the time the permit is granted and before construction begins.

If you have any questions or I can be of further assistance, please contact me at (505) 766-2174.

Sincerely yours,

Wm Fisher

William B. Fisher
Realty Specialist
Realty

Enclosures

TEXAS
PARKS AND WILDLIFE DEPARTMENT

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Santa Elena

October 1, 1980

Ms. Susan Turbak
Science Applications, Inc.
800 Oak Ridge Turnpike
Oak Ridge, Tennessee 37830

Dear Ms. Turbak:

This is in response to your recent request for information regarding endangered and/or nongame species.

Enclosed are state lists, annotated as to the estimated chances of encountering specific animal taxa in Jefferson County. Although these lists should prove useful to you as background material and for general planning purposes, they are not intended as substitutes for comprehensive onsite evaluations made by competent biologists. Determination of the actual presence of a species in a given project area depends on a number of variables such as seasonal and daily activity cycles, environmental activity cues, preferred habitat, transiency, and population density (both wildlife and human). Absence of a species can be demonstrated only with great difficulty and then only with repeated negative observations taking into account all of the variable factors contributing to the lack of observability.

Information regarding protected or rare plant species is summarized on an attached advisory sheet.

Please let us know if we may be of further help.

Sincerely,

Floyd E. Potter, Jr.
Wildlife Biologist

FEP:W100:gv

Enclosures

COMMENT ON PROTECTED NATIVE FLORA OF TEXAS

February, 1980

While the State of Texas has not adopted an official listing of endangered or threatened plant taxa, nor currently is there state endangered species legislation for flora of concern, there are several references which may be used for guidance in environmental planning.

Approximately 110 Texas plant species were proposed in 1976 for federal listing as endangered or threatened (41 FR 24523-72) but have now been withdrawn (44 FR 70796-7). However, withdrawn species remain under "Notice of Review" (40 FR 27823). Notice of Review species "should be considered in environmental planning" (44 FR 70796).

The first Texas plant species listed for federal protection as endangered was Texas wildrice (*Zizania texana*), 43 FR 17910-17916. Others have now been added as either endangered or threatened (see attached material).

One of the most entensive listings of Texas plant species of concern is that which is available from the Texas Organization for Endangered Species (T.O.E.S.), Post Office Box 12773, Austin, Texas 78711. For additional information, please contact:

Endangered Species Specialist
U. S. Fish and Wildlife Service
(505) 766-3972

or

David H. Riskind
Resource Management Section
Texas Parks and Wildlife Department
(512) 475-4848

None of the federally listed Texas plant species (currently 9; 7 endangered, 2 threatened) are known to occur within 200 miles of Jefferson County.

Notations made by Floyd Potter, Jr.

LISTED SOUTHWESTERN CACTI

TEXAS

Ancistrocactus tobuschii (Endangered: FR 44(217): 64736-64738)
(Tobusch fishook cactus)

1. Western Kerr County (Mountain Home to Ingram, Texas) and northern Bandera County.
2. Low limestone ridges or gravel bars near streams (upper Medina River and tributaries, upper Sabinal River and tributaries, and some tributaries of upper Guadalupe River).

Coryphantha minima (Endangered: FR 44(217): 64738-64740)
(Nelly Cory cactus)

1. Northern Brewster County, Texas.
2. Outcrops of noviculite on hilltops.

Coryphantha sneedii var. sneedii (Endangered: FR 44 (217): 64741-64743)
(Sneed pincushion cactus)

1. Southeastern Dona Ana County, NM. and northwestern El Paso County, Tx.
2. Southern Organ Mountains, Bishop's Cap, and Franklin Mountains. Elevation: 1300 - 1650 m.

Coryphantha ramillosa (Threatened: FR 44(216) 64247-64249)
(Bunched Cory cactus)

1. Extreme southern and southeastern Brewster County and extreme southwestern Terrell County, extending into adjacent Coahuilla, Mexico.
2. Very steep calcareous canyon sides and in adjacent summits.

Echinocereus lloydii (Endangered: FR 44(209): 61916-61917)
(Lloyd's hedgehog cactus)

1. Northeast Pecos County (east of Fort Stockton).
2. Variable--gentle slopes to tops of mesas.

Echinocereus reichenbachii var. albertii (Endangered: FR 44(209): 61918-61920)
(Black lace cactus)

1. Extreme southern Jim Wells County, Northern Kleberg County and possible discontinuous occurrence in Refugio County.
2. Transition between coastal plain and rolling interior.

Echinocereus viridiflorus var. davisii (Endangered: FR 44(217): 64738-64740)
(Davis' green pitaya)

1. Northern Brewster County (near Marathon, Texas).
2. Noviculite outcrops on hilltops at about 1200 m.

Neolloydia mariposensis (Threatened: FR 44(216): 64247-64249)
(Lloyd's Mariposa cactus)

1. Extreme southwestern Brewster County and possibly Presidio County.
2. Limestone gravel on hills on lower slopes of mesas.

REGULATIONS FOR TAKING, POSSESSING, TRANSPORTING, EXPORTING, PROCESSING, SELLING OR OFFERING FOR SALE, OR SHIPPING ENDANGERED SPECIES

127.30.09.001-.006

As Amended July 1977

The following rules are promulgated under the authority of Sections 43.021 through 43.030, Sections 67.001 through 67.005, and Sections 68.001 through 68.021, Texas Parks and Wildlife Code.

.001. Definition. "Person" means any individual, firm, corporation, association, or partnership.

.002. Permits to Take Certain Fish or Wildlife. No person may take, possess, or transport fish or wildlife classified as endangered species and named in this rule for zoological gardens or scientific purposes, to take or transport fish or wildlife classified as endangered species, as specified in this rule, from the wild, or from their natural habitat, for propagation for commercial purposes, unless he has obtained a valid permit from the Department as required by Sections 43.021 through 43.030 of the Texas Parks and Wildlife Code.

.003. Closed Seasons. Except as provided by Rule .002 above, it shall be unlawful for any person to take, possess, transport, export, process, sell or offer for sale, or ship any species of fish or wildlife within this State listed below; and no person shall possess, transport, export, process, sell or offer for sale goods made from the fish and wildlife listed below not born and raised in captivity.

.004. Penalties. Any person who violates any provisions of these rules is guilty of a misdemeanor: (a) On first conviction, he is punishable by a fine of not less than $100 (One Hundred Dollars) nor more than $200 (Two Hundred Dollars).

(b) On second conviction, he is punishable by a fine of not less than $200 (Two Hundred Dollars) nor more than $500 (Five Hundred Dollars), or confinement in county jail for not less than 30 (thirty) days nor more than 90 (ninety) days, or both fine and confinement in jail.

(c) On conviction of a third or subsequent violation, he is punishable by a fine of not less than $500 (Five Hundred Dollars) nor more than $2,000 (Two Thousand Dollars), and confinement in county jail for not less than 6 (six) months nor more than 1 (one) year.

.005. Amendments. Upon finding that need exists, the Commission may, at any meeting, amend, revoke, or modify any of these rules in compliance with Sections 68.001 through 68.021, Texas Parks and Wildlife Code.

.006. Effective Date. These rules shall become effective twenty days after the filing of two certified copies in the office of the Secretary of State.

MAMMALS

*	Blue whale	*Balaenoptera musculus*
*	Finback whale	*Balaenoptera physalus*
*	Right whale	*Eubalaena* spp. (all species)
*	Sperm whale	*Physeter catodon*
	Black-footed ferret	*Mustela nigripes*
	Jaguar	*Panthera onca*
	Jaguarundi	*Felis yagouaroundi cacomitli*
	Margay	*Felis wiedii*
	Ocelot	*Felis pardalis*
***	Red wolf	*Canis rufus*
	Gray wolf	*Canis lupus monstrabilis*
	Mexican wolf	*Canis lupus baileyi*
*	West Indian manatee	*Trichechus manatus*
	Bighorn sheep	*Ovis canadensis*

REPTILES

	Speckled racer	*Drymobius m. margaritiferus*
	Harter's water snake	*Natrix harteri*
***	Atlantic ridley turtle	*Lepidochelys kempii*
*	Hawksbill turtle	*Eretmochelys imbricata*
**	Leatherback turtle	*Dermochelys coriacea*
***	American alligator	*Alligator mississipiensis*

AMPHIBIANS

None!

	Cascade Cavern salamander	*Eurycea latitans*
	Texas blind salamander	*Typhlomolge rathbuni*
→	Houston toad	*Bufo houstonensis*

BIRDS

(mostly migratory!)

***	Brown pelican	*Pelecanus occidentalis*
***	Southern bald eagle	*Haliaeetus l. leucocephalus*
	American peregrine falcon	*Falco peregrinus anatum*
***	Arctic peregrine falcon	*Falco peregrinus tundrius*
	Attwater's greater prairie chicken	*Tympanuchus cupido attwateri*
	Whooping crane	*Grus americana*
*	Eskimo curlew (b-rly)	*Numenius borealis*
**	Interior least tern	*Sterna albifrons athalassos*
	Ivory-billed woodpecker	*Campephilus principalis*
**	Red-cockaded woodpecker	*Dendrocopos borealis*
	Bachman's warbler	*Vermivora bachmanii*

FISHES

*	Paddlefish	*Polyodon spathula*
	Shovelnose sturgeon	*Scaphirhynchus platorynchus*
	Amistad gambusia	*Gambusia amistadensis*
	San Marcos gambusia	*Gambusia georgei*
	Big Bend gambusia	*Gambusia gaigei*
	Clear Creek gambusia	*Gambusia heterochir*
	Pecos gambusia	*Gambusia nobilis*
	Comanche Springs pupfish	*Cyprinodon elegans*
	Leon Springs pupfish	*Cyprinodon bovinus*
	Fountain darter	*Etheostoma fonticola*
	Bluntnose shiner	*Notropis simus*

* possible
** probable
*** confirmed
} for Jefferson County!

PWD Leaflet 7000-21
March 1978

REGULATIONS FOR TAKING, POSSESSING, AND TRANSPORTING PROTECTED NONGAME SPECIES

127.70.12.001-.008

≐ threatened

The following rules are promulgated under the authority of Sections 43.021 through 43.030 and Sections 67.001 through 67.005, Texas Parks and Wildlife Code.

.001. Definition. "Person" means any individual, firm, corporation, association, or partnership.

.002. Closed Seasons. Except as provided by Rules .004, .005, or .006, no person may take, possess, transport, export, sell or offer for sale, or ship any species of fish or wildlife within this State listed as protected nongame; or possess, transport, export, sell, or offer for sale goods made from the fish and wildlife of this State listed as protected nongame.

.003. Protected Nongame Species. The following species are hereby designated as Protected Nongame Species:

MAMMALS

Bat, lesser yellow	*Lasiurus ega xanthinus*
*** Bat, Rafinesque's big-eared	*Plecotus rafinesquii*
*** Bat, southeastern	*Myotis austroriparius mumfordi*
Bat, spotted	*Euderma maculatum*
* Dolphin, bridled	*Stenella frontalis*
* Dolphin, rough-toothed	*Steno bredanensis*
* Dolphin, spotted	*Stenella plagiodon*
Mouse, Palo Duro	*Peromyscus comanche*
Rat, Texas kangaroo	*Dipodomys elator*
* Whale, dwarf sperm	*Kogia simus*
* Whale, false killer	*Pseudorca crassidens*
* Whale, goose-beaked	*Ziphius cavirostris*
* Whale, Gulf Stream beaked	*Mesoplodon europaeus*
* Whale, killer	*Orcinus orca*
* Whale, short-finned pilot	*Globicephala macrorhyncha*
* Whale, pygmy killer	*Feresa attenuata*
* Whale, pygmy sperm	*Kogia breviceps*

BIRDS

(mostly migratory!)

*** Egret, reddish	*Dichromanassa r. rufescens*
Falcon, aplomado	*Falco femoralis septentrionalis*
Hawk, black	*Buteogallus a. anthracinus*
Hawk, gray	*Buteo nitidus maximus*
* Hawk, white-tailed	*Buteo albicaudatus hypospodius*
Hawk, zone-tailed	*Buteo albonotatus*
*** Ibis, white-faced	*Plegadis chihi*
*** Kite, swallow-tailed	*Elanoides f. forficatus*
*** Osprey	*Pandion haliaetus carolinensis*
Owl, ferruginous	*Glaucidium brasilianum cactorum*
*** Stork, wood	*Mycteria americana*
*** Tern, least	*Sterna albifrons antillarum*
Warbler, golden-cheeked	*Dendroica chrysoparia*

* possible
** probable
*** confirmed
} for Jefferson County!

REPTILES

Loggerhead, Atlantic	*Caretta c. caretta*
Tortoise, Texas	*Gopherus berlandieri*
Turtle, Atlantic green	*Chelonia m. mydas*
Turtle, Big Bend mud	*Kinosternon hirtipes murrayi*
Gecko, Big Bend	*Coleonyx reticulatus*
Lizard, Big Bend canyon	*Sceloporus merriami annulatus*
Lizard, Presidio canyon	*Sceloporus merriami longipunctatus*
Lizard, reticulate collared	*Crotaphytus reticulatus*
*** Lizard, Texas horned	*Phrynosoma cornutum*
Lizard, mountain short-horned	*Phrynosoma douglassi hernandesi*
Copperhead, Trans-Pecos	*Agkistrodon contortrix pictigaster*
Kingsnake, gray-banded	*Lampropeltis mexicana alterna*
Rattlesnake, rock	*Crotalus lepidus*
Snake, black-striped	*Coniophanes i. imperialis*
Snake, northern cat-eyed	*Leptodeira s. septentrionalis*
Snake, Texas indigo	*Drymarchon corais erebennus*
Snake, Texas lyre	*Trimorphodon biscutatus vilkinsoni*
Snake, Big Bend milk	*Lampropeltis triangulum celaenops*
Snake, central plains milk	*Lampropeltis triangulum gentilis*
*** Snake, Louisiana milk	*Lampropeltis triangulum amaura*
Snake, Mexican milk	*Lampropeltis triangulum annulata*
* Snake, Louisiana pine	*Pituophis melanoleucus ruthveni*
Snake, Baird's rat	*Elaphe obsoleta bairdi*
Snake, Trans-Pecos rat	*Elaphe subocularis*

AMPHIBIANS

Frog, Mexican cliff	*Syrrhophus guttilatus*
Frog, Mexican tree	*Smilisca baudini*
Frog, Rio Grande	*Syrrhophus cystignathoides campi*
Frog, white-lipped	*Leptodactylus labialis*
Newt, black-spotted	*Notophthalmus m. meridionalis*
Salamander, Fern Bank	*Eurycea neotenes pterophila*
Salamander, Honey Creek	*Eurycea tridentifera*
* Salamander, mole	*Ambystoma talpoideum*
Salamander, San Marcos	*Eurycea nana*
Salamander, Valdina Farms	*Eurycea troglodytes*
Siren, Rio Grande	*Siren intermedia texana*
Toad, giant	*Bufo marinus*
Toad, Mexican burrowing	*Rhinophrynus dorsalis*

FISHES

Blindcat, toothless	*Trogloglanis pattersoni*
Blindcat, widemouth	*Satan eurystomus*
Chub, Rio Grande	*Gila pandora*
Darter, Rio Grande	*Etheostoma grahami*
** Darter, river	*Hadropterus shumardi*
** Darter, western sand	*Ammocrypta clara*
Gambusia, blotched	*Gambusia senilis*

(over)

Minnow, Devils River	*Dionda diaboli*
Pupfish, Conchos	*Cyprinodon eximius*
Shiner, Chihuahua	*Notropis chihuahua*
Shiner, Kiamichi	*Notropis ortenburgeri*
Shiner, proserpine	*Notropis proserpinus*
Stoneroller, Mexican	*Campostoma ornatum*
Sucker, blue	*Cycleptus elongatus*

.004. Permit Required. No person may take, possess, or transport fish or wildlife from the wild, classified as protected nongame by Rule .003, for scientific or zoological purposes unless a valid Scientific or Zoological Permit has been obtained from the Department as required by Sections 43.021 through 43.030 of the Texas Parks and Wildlife Code.

.005. Permit Exceptions. (a) No permit is required to take or transport any species listed as protected nongame to the nearest Department of Health or medical facility if the species poses an immediate threat to human safety or welfare.

(b) No permit is required to transport within this State mounted or preserved specimens of protected nongame species obtained after the effective date of these rules provided the transfer is without monetary consideration and is between public or private educational or research institutions, nonprofit municipal zoological gardens, or nonprofit foundations or associations, and provided the specimens to be transferred were originally obtained under the valid Scientific or Zoological Permit. A copy of the voucher or other instrument evidencing the transfer and indicating the species and numbers of specimens transferred will be forwarded to the Department within twenty days following the transfer.

(c) No permit is required to possess and transport live, mounted, or preserved specimens of protected nongame species legally collected in another state except that the Department may require adequate proof of the out-of-state acquisition of the specimens. A copy of a valid out-of-state permit authorizing the collection of the specimens must be carried by the person during transport within this State.

.006. Rule Exception. These rules do not apply to the possession of live, mounted, or preserved specimens of listed protected nongame species acquired from the wild in this State prior to the effective date of these rules nor to offspring of those specimens born and raised in captivity. Upon request by the Department, adequate proof must be provided to establish the date and circumstances regarding acquisition of any listed species.

.007. Penalties. Any person who violates any provisions of these rules is guilty of a misdemeanor and: (a) on first conviction, is punishable by a fine of not less than $100 (One Hundred Dollars) nor more than $200 (Two Hundred Dollars).

(b) On second conviction, is punishable by a fine of not less than $200 (Two Hundred Dollars) nor more than $500 (Five Hundred Dollars), or confinement in county jail for not less than 30 (thirty) days nor more than 90 (ninety) days, or both fine and confinement in jail.

(c) On conviction of a third or subsequent violation, is punishable by a fine of not less than $500 (Five Hundred Dollars) nor more than $2,000 (Two Thousand Dollars), and confinement in county jail for not less than 6 (six) months nor more than 1 (one) year.

.008. Effective Date. These rules are effective July 18, 1977, and remain in effect until amended, revoked, or modified.

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
200 EAST PASCAGOULA STREET, SUITE 300
JACKSON, MISSISSIPPI 39201

October 29, 1980

Dr. Joyce Teerling
Staff Environmentalist
Department of Energy
Strategic Petroleum Reserve Project
Management Office
900 Commerce Road East
New Orleans, Louisiana 70123

Dear Dr. Teerling:

This pertains to an October 21, 1980, letter we received from Dwayne Gray, Acting Director, Office of Technical Assurance, regarding expansion of the Strategic Petroleum Reserve near Hackberry, Louisiana.

There are no resident listed species or Critical Habitat in this area which we feel would be impacted by the proposed activity. There are some listed species that occur periodically in this area as transients, but we feel the likelihood of possible impact to such species by the proposed activity is unlikely.

Thank you for your letter and if we may be of further assistance in this or other matters, please don't hesitate to call on us.

Sincerely,

Gary L. Hickman

Gary L. Hickman
Area Manager

cc: ES. FWS, Lafayette, LA.
Department of Wildlife and Fisheries, New Orleans, LA.

RECEIVED
1980 OCT 31 PM 12: 16
S P R P M O
DEPT. OF ENERGY

UNITED STATES
DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

300 East 8th St., Rm. G-121
Austin, Texas 78701

RECEIVED
1980 OCT 31 PM 12:02
S P R P M O
DEPT. OF ENERGY

October 28, 1980

Mr. N. Dwayne Gray
Acting Director, Office of
Technical Assurance
Department of Energy
Strategic Petroleum Reserve
Project Management Office
900 Commerce Road East
New Orleans, LA 70123

Attn: Dr. Joyce Teerling, Staff Environmentalist, mail stop, RA-6521

Dear Mr. Gray:

This is in reply to your letter of October 21, 1980, which requested information about species which are listed or proposed to be listed as threatened or endangered as provided by the Endangered Species Act. Your area of interest the Phase III Expansion Plan - Strategic Petroleum Reserve at the Bryan Mound site Nederland, Jefferson County, Texas.

As provided by Section 7(c)(1) of the Endangered Species Act the Fish and Wildlife Service is required to furnish a list of those species, both proposed and listed, that may be affected by Federal construction activities.

Upon receipt of the Fish and Wildlife Service's species list, the Federal agency authorizing, funding or carrying out the construction action is required to conduct a biological assessment for the purpose of identifying listed and proposed species which are likely to be affected by such action.

The biological assessment shall be completed within 180 days after receipt of the species list, unless it is mutually agreed to extend this period. If the assessment is not initiated within 90 days after receipt of the species list, I suggest its current accuracy be verified before conducting the assessment.

Biological assessments should include as a minimum:

1) an on-site inspection of the area affected by the proposed activity or program, which may include a detailed survey of the area to determine if species are present and whether suitable habitat exists for either expanding the existing population or potential reintroductions of populations;

2) interview recognized experts on the species at issue, including the Fish and Wildlife Service, State conservation departments, universities and others who may have data not yet found in scientific literature;

3) review literature and other scientific data to determine the species distribution, habitat needs and other biological requirements;

4) review and analize the effects of the proposal on the species in terms of individuals and populations, including consideration of the cumulative effects of the proposal on the species and its habitat;

5) analyze alternative actions thay may provide conservation actions;

6) other relevant information;

7) written report documenting the assessment results.

For purposes of providing interim guidance, the Fish and Wildlife Service considers construction projects to be any major Federal action authorized, funded or carried out by a Federal agency which significantly affects the quality of the human environment and which is designed primarily to result in the building or erection of man-made structures such as dams, buildings, roads, pipelines, channels and the like.

If the biological assessment indicated the proposed project may affect listed species, the formal consultation process shall be initiated by writing to the Regional Director, Region 2, U. S. Fish and Wildlife Service, P.O. Box 1306, Albuquerque, New Mexico 87103. If no affect is evident, there is no need for further consultation. I would, however, appreciate the opportunity to review your biological assessment.

In addition, the Act (Sec. 7(c)(1)) now requires Federal agencies to confer with the Service on any agency action which is likely to jeopardize the continued existence of any species proposed to be listed as endangered or threatened or adversely modify critical habitat proposed to be designated for such species. The purpose of this requirement is to identify and resolve at the early planning stage of an action, all potential conflicts between the action and the respective species and critical habitat. The informal consultation process can accomplish this requirement.

The attached sheet provides information on species which may be affected by the proposed action in the area of interest. If we may be of further assistance, do not hesitate to call either the Endangered Species Specialist or me at 512-397-5438; FTS 734-5438.

Sincerely yours,

W. Ellis Klett

W. Ellis Klett
Area Manager

Attachment

Strategic Petroleum Reserve Project
Byran Mound Site, Big Hill Salt Dome
Jefferson County, Texas

LISTED SPECIES

Red Wolf (Canis rufus) - Limited in Texas to Orange and Jefferson Counties south of I-10. Probably will soon be extinct in its' final range in Texas.

Brown Pelican (Pelecanus occidentalis) - Brown pelicans may be found in adjacent Chambers County. A small resident flock is found along the Central Coast. Migratory flocks from the Mexican Gulf Coast frequently enter Texas waters.

Peregrine Falcon (Falco peregrinus tundrius) - May occur statewide during spring and fall migration. Concentrate along gulf coast, especially North and South Padre Island.

Bald Eagle (Haliaeetus leucocephalus) - May occur statewide as a wintering species around large bodies of water. The major concentrations generally occur from November to March.

Alligator (Alligator mississippiensis) - May be found anywhere along the Texas coast in rivers, swamps, marshes, lakes and estuaries.

PROPOSED SPECIES

NONE

CRITICAL HABITAT

NONE

TEXAS HISTORICAL COMMISSION

TRUETT LATIMER
EXECUTIVE DIRECTOR

P. O. BOX 12276
AUSTIN TEXAS 78711

November 12, 1980

Science Applications, Inc.
Jackson Plaza Tower
Suite 1000
800 Oak Ridge Turnpike
Oak Ridge, Tenn. 37830

Re: U.S. Department of Energy's Texoma Environmental
Impact Statement Supplement

Dear Mr. Ambrose:

Referencing your letter of October 28, 1980 concerning the U.S. Department of Energy's Texoma Environmental Impact Statement Supplement, we offer the following information concerning the two alternative routes proposed. This information is given to aid in the decision process of route selection with the understanding once a route is selected an in-depth archeological survey will be preformed in accordance with the Procedures for the Protection of Historical and Cultural Properties (36 C.F.R., Part 800) and attendent legislation.

We distinguished the routes illustrated on your map by describing the northern route as Alternate Route I - North and the southern route as Alternate Route II - South.

Alternate Route I - North passes through an extremely sensitive area which has numerous archeological and historical sites, some of which are on the National Register of Historic Places. This area is in and around the town of Anahcac.

Alternate Route II - Southpasses through a very sensitive area along the route from Pelican Island through the Texas Dike area. There is believed to to have been a Civil War era schoener sunk in the area of Texas Dike. Additionally, prehistoric artifacts have been brought up in dredge material in the Texas Dike area.

There are other concerns which are of a general nature which could be dealt with during pedestrian survey.

We appreciate this opportunity to cooperate with the Department of Energy and Science Applications, Inc. in the planning phase of the above referenced project.

The State Agency for Historic Preservation

If we may be of further assistance in this reguard, please advise.

Sincerely

Truett Latimer
State Historic Preservation Officer

by

LaVerne Herrington, Ph.D.
Director
Resource Conservation

PARSONS-GILBANE
A JOINT VENTURE

P.O. BOX 23702 800 COMMERCE ROAD, WEST NEW ORLEANS, LA. 70183 (504) 733-8517

In Reply
Refer To: HO-E-3-5124

December 2, 1980

Science Applications, Inc.
800 Oak Ridge Turnpike
Suite 1000
Oak Ridge, Tennessee 37830

ATTENTION: Ms. Susan Turbak

Subject: Cultural Resource Surveys for West Hackberry Phase II Property, Strategic Petroleum Reserve

Gentlemen:

In accordance with the request of your Ms. Susan Turbak today, we are forwarding two reports of pre-construction cultural resource surveys conducted for the Phase II expansion of the West Hackberry storage facility including the brine disposal pipeline to the Gulf of Mexico.

We can also report that no cultural resources have been uncovered during construction activities which are monitored daily by our subcontracted environmental specialist. With all major excavation completed at this time, we are reasonably certain that any buried cultural resources which may be present have been avoided.

Very truly yours,

PARSONS-GILBANE

Robert E. Cox

Robert E. Cox
Director of Environmental Control

REC:evs

Attachments:
1. Updated Cultural Resource Survey, West Hackberry. 9/79
2. Cultural Resources Survey, West Hackberry, Brine Pipeline, 1/80

cc: K. Hoag, DOE
J. Teerling, DOE

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE

Southeast Region
9450 Koger Building
St. Petersburg, FL 33702

June 29, 1981 F/SER64:DLP

N. Dwayne Gray
Department of Energy
Strategic Petroleum Reserve Project
Management Office
900 Commerce Road East
New Orleans, LA 70123

Dear Mr. Gray:

This is in response to your letter dated June 15, 1981, concerning the proposed Big Hill and Bryan Mound Strategic Petroleum Reserve project (Texas) and requirements of Section 7 of the Endangered Species Act of 1973. The biological assessment required by Section 7 of the Endangered Species Act was enclosed with your letter.

We have reviewed the biological assessment and conclude that the proposed project is not likely to jeopardize the continuous existence of endangered or threatened species of sea turtles and whales or result in the destruction or adverse modification of critical habitat of such species. We understand that the following sea turtle conservation measures are a part of the proposed project.

1. The raw water intake structure located at an abandoned barge slip on the north side of the Intracoastal Waterway at mile 305 will be fitted with a silt screen to eliminate the possibility of the incidental take of listed species of sea turtles.

2. The brine disposal pipeline will be buried beneath the ocean floor by use of a water jet or other trenching device to eliminate the possibility of taking listed species of sea turtles.

This concludes consultation responsibilities under Section 7 of the Endangered Species Act of 1973. However, consultation should be reinitiated if new information reveals impacts of the identified activity that may effect listed species or their critical habitat, a new species is listed, the identified activity is subsequently modified or critical habitat determined that may be effected by the proposed activity.

Sincerely yours,

D. R. Ekberg
D. R. Ekberg
Chief, Environmental and Technical
Services Division

cc: FWS, Austin TX
FWS, Albuquerque, NM

UNITED STATES
DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

300 East 8th St., Rm. G-121
Austin, Texas 78701
July 13, 1981

N. Dwayne Gray
Director - Office of Tech. Assurance
Department of Energy
Strategic Petroleum Reserve Project Management Office
900 Commerce Road East
New Orleans, Louisiana 70123

RE: Phase III Biological Assessment, Pursuant to the Endangered Species Act Amendments of 1978 and 1979, Section 7 (C). Bryan Mound and Big Hill Project, Brazoria and Jefferson Counties, Texas.

Dear Mr. Gray:

This is in response to your letter of June 15, 1981, relative to your biological assessment on the above named project. You asked that we review the assessment and provide a letter concurring that there is no further need for consultation.

We agree with you that the only species affected by the project would be the alligator. Since the alligator will be affected, you are required to request formal consultation from the Regional Director, Albuquerque, New Mexico. However, in order to alleviate the "effect" of the project on the alligators, an alternative would be to suspend construction in areas of known alligator nesting habitat during the period of June through September. This timeframe would allow the alligators to nest and the eggs to hatch.

If for some reason, you cannot utilize this suggested alternative, then it is incumbent upon you to request formal consultation from the Regional Director.

Sincerely,

W. Ellis Klett

W. Ellis Klett
Area Manager

cc: Regional Office, Region 2 (SE)
Galveston ES Field Office

APPENDIX E

RANGES OF ENDANGERED AND THREATENED FLORA AND FAUNA IN THE REGION OF THE PROPOSED BIG HILL SPR STORAGE SITE

APPENDIX E

RANGES OF ENDANGERED AND THREATENED FLORA AND FAUNA IN THE REGION OF THE PROPOSED BIG HILL SPR STORAGE SITE

Appendix E contains species lists and distributions of endangered and threatened flora and fauna in the Big Hill project region.

Table E-1. Rare plant species in proposed project area counties[1]

Scientific name	Common name	Counties				
		Galveston	Chambers	Jefferson	Brazoria	Harris
Aureolaria dispersa	Beaumont aureolaria			X		
Bothriochloa exaristata	Awnless bluestem	X	X	X	X	X
Carex albolutescens	Yellow-white sedge			X		
Carex gigantea	Giant sedge					X
Carex physorhyncha	Hidalgo sedge			X		
Carex stipata	Stalk-grain sedge				X	
Carex tribuloides	Bristle-bract sedge			X		
Carya myristicaeformis	Nutmeg hickory	X		X		
Chloris texensis	Texas windmill-grass				X	X
Cuphea glutinosa	Sticky waxweed				X	
Hymenoxys texana[3]	Texas bitterweed					X
Ilex cassine	Dahoon holly				X	
Ilex myrtifolia	Myrtle holly				X	
Juncus debilis	Weak rush	X				
Leitneria floridana	Corkwood		X	X	X	
Lemna obscura	Little water lentil			X		
Lithospermum tuberosum[2]	Bulb gromwell				X	
Lythrum ovalifolium	Loosestrife					X
Machaeranthera aurea[3]	Houston machaeranthera	X				X
Oenothera sessilis[2]	Coastal evening-primrose	X				
Onosmodium helleri	Heller false-gromwell				X	
Ophioglossum vulgatum	Common adder's-tongue			X		
Polygonum striatulum	Kleberg knotweed					X
Ruellia pinetorum	Pinebarren ruellia					X
Sabal minor (trunked form)	Louisiana palm	X			X	X
Scirpus cubensis	Cuban bulrush				X	
Scleria baldwinii	Baldwin stone-rush					X
Sebastiana fruticosa	Sebastian bush			X		X
Senecio glabellus	Butterweed					X
Sium suave[2]	Water parsnip			X		
Smilax herbacea[2]	Carrion-flower			X		
Thelypteris palustris var. *haleana*	Southern marsh fern			X		
Utricularis purpurea	Purple bladderwort				X	
Utricularis vulgaris	Common bladderwort			X		X
Willkommia texana	Willkommia				X	X
Wolffiella gladiata	Sword bog-mat				X	
Wolffiella lingulata	Tongue bog-mat				X	

[1]University of Texas Rare Plant Study Center (1974).
[2]Species now believed extinct in Texas include *L. tuberosum*, *S. suave*, *S. herbacea*, and *O. sessilis*.
[3]Species proposed for Federal protection include *M. aurea* and *H. texana*.

Data derived from USACE (1979).

Table E-2. **Threatened and endangered fauna possibly occurring in the region of the Big Hill facilities and crude oil distribution system [1]**

Red wolf	Canis rufus
Brown pelican	Pelecanus occidentalis
Arctic peregrine falcon	Falco peregrinus tundrius
Bald eagle	Haliaeetus leucocephalus
Attwater's prairie chicken	Tympanuchus cupido attwateri
Loggerhead sea turtle	Caretta caretta
Green sea turtle	Chelonia mydas
Leatherback sea turtle	Dermochelys coriacea
Hawksbill sea turtle	Eretmochelys imbricata
Kemp's ridley sea turtle	Lepidochelys kempi
American alligator	Alligator mississipiensis

[1]All data derived from USFWS (1980).
[2]Detailed descriptions of the individual species are presented in Tables E-3 through E-15 and Figs. E-1 through E-13.

Table E-3. Detailed description of red wolf (*Canis rufus*)

STATUS:	Endangered (35 FR 16047, October 13, 1970).
SPECIES DESCRIPTION:	A medium sized dog-like carnivore, generally appearing cinnamon-buff or tawny in color; however, like the coyote and gray wolf, may appear red, gray, or black. Mature adults weigh between 40-80 pounds.
HABITAT:	At present the red wolf's habitat is coastal prairie and marshes, but formerly also included eastern forests.
DISTRIBUTION:	
Historic:	Central Texas east to the coasts of Florida and Georgia, and from the Gulf of Mexico north to central Missouri and southern Illinois.
Present:	As of July 1980, thought, for all practical purposes, to be biologically extinct in the wild; however, a few individuals may still remain. Probably now limited in Texas to Orange and Jefferson Counties south of I-10. Also in Cameron and Calcasieu Parishes in Louisiana.
REASONS FOR DECLINE:	Loss of habitat, deliberate killing and hybridization with other canids.
OTHER INFORMATION:	Probably less than 50 wolves left in the wild. Recovery Team formed; Recovery Plan drafted. Captive breeding program underway at Point Defiance Zoo in Tacoma, Washington. Protected by the State of Texas.
REFERENCES:	Carley 1979; Davis 1966; Hall and Kelson 1959; McCarley and Carley 1978; Paradiso and Nowak 1972.

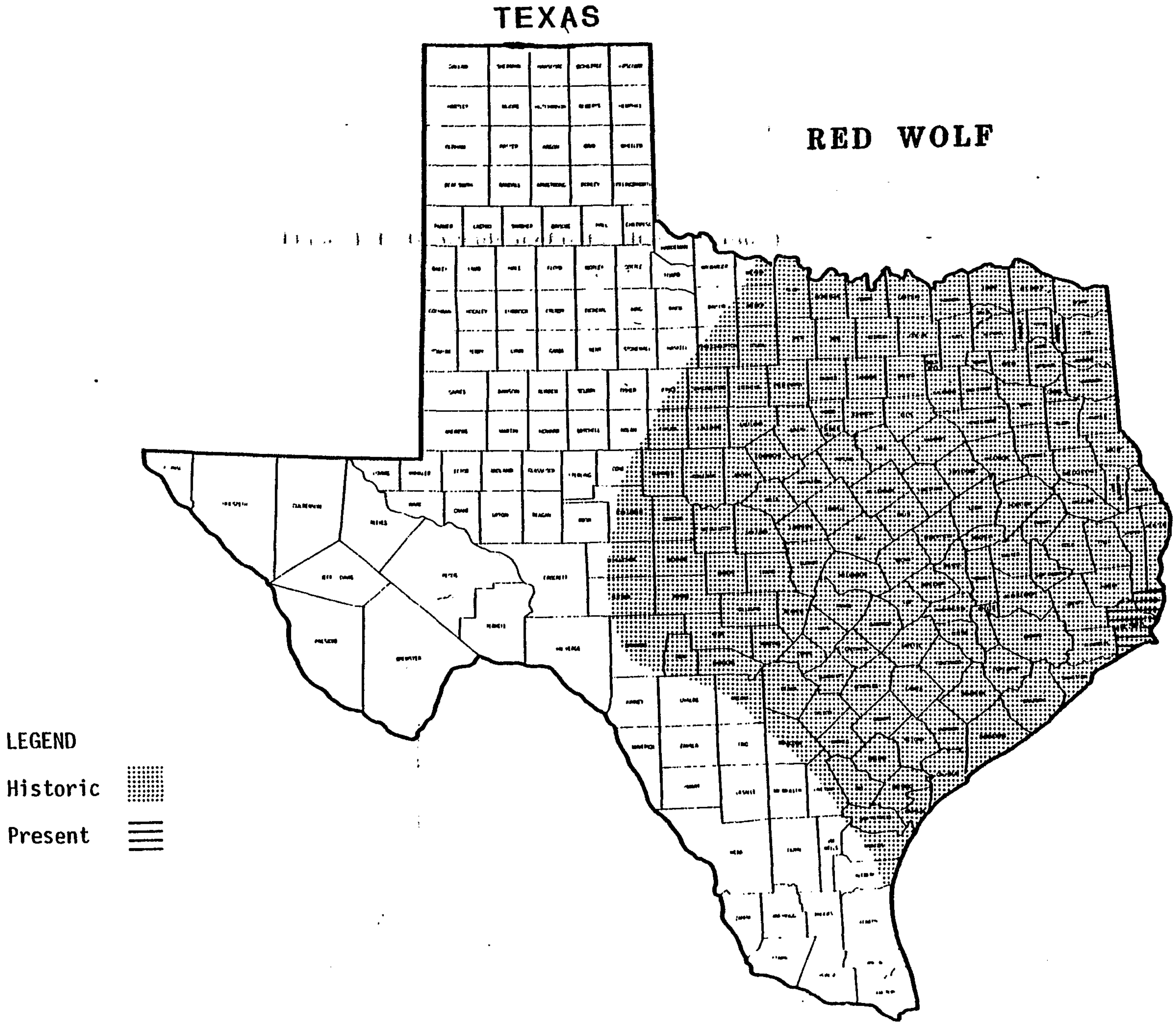
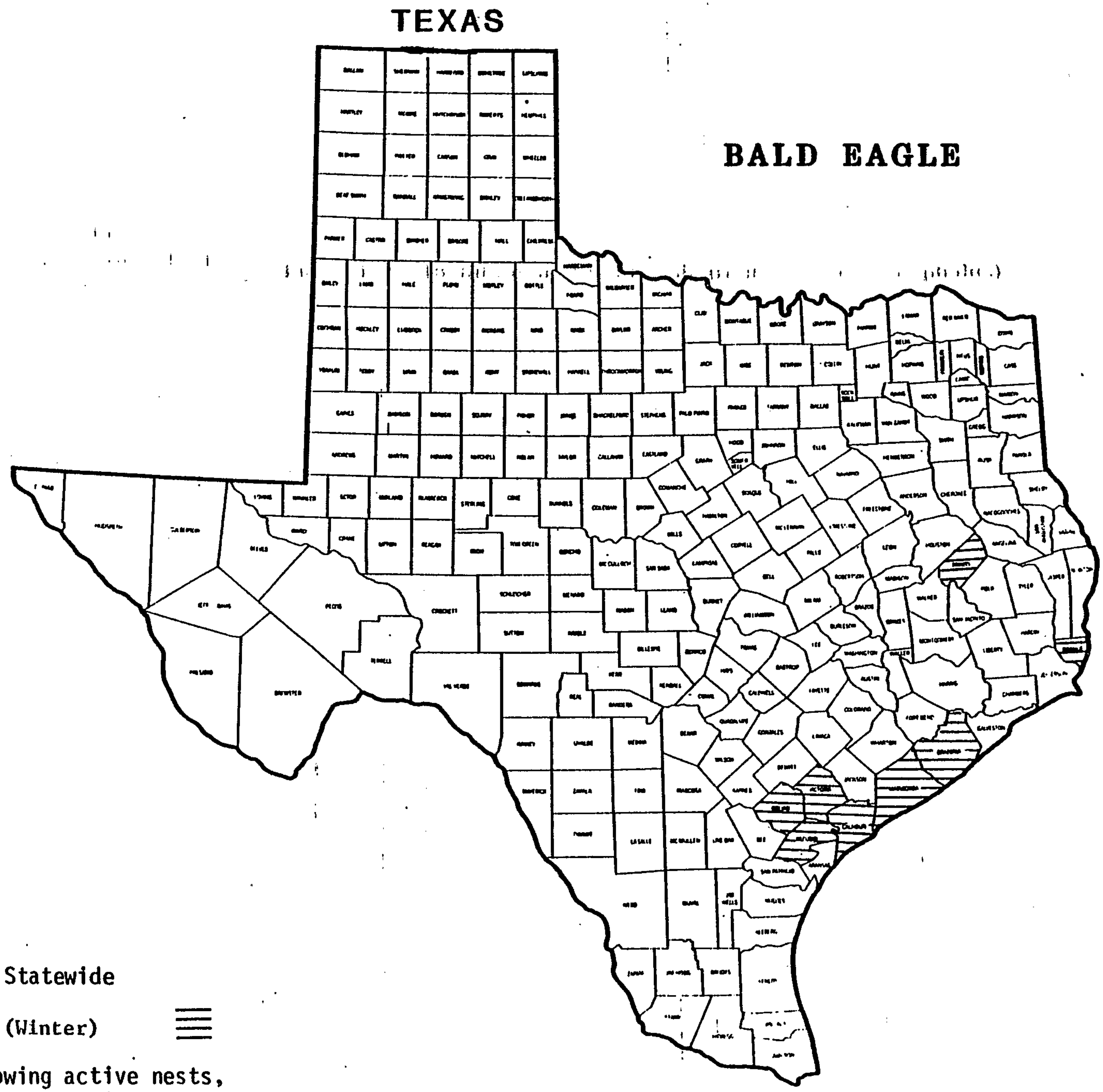


Figure E-1. Distribution of red wolf (<u>Canis</u> <u>rufus</u>).

Table E-4. Detailed description of bald eagle (Haliaeetus leucocephalus)

STATUS:	Endangered (32 FR 4001, March 11, 1967; 43 FR 6233, February 14, 1979).
SPECIES DESCRIPTION:	A large eagle with white head and tail in adult, wingspan 6 to 7.5 feet. Tarsi are bare of feathers (golden eagle legs are feathered to the toes). Immatures are dark.
HABITAT:	Nests near water, requires large trees or rock cliffs for nesting. Winters along major rivers and reservoirs. Fish provide primary food source.
DESTRIBUTION:	Found throughout the United States, Canada, and northern Mexico.
Historic:	Nationwide.
Present:	Wintering populations still may occur statewide. Counties shown as present distribution are those that contain substantial wintering populations. The birds winter around large bodies of water and the major concentrations generally occur from November-March.
REASONS FOR DECLINE:	Reproductive failure induced by pesticides. Human disturbance. Habitat loss.
OTHER INFORMATION:	The bald eagle is endangered in all but 5 of the lower 48 States. In Washington, Oregon, Minnesota, Wisconsin and Michigan, it is listed as threatened. Not listed in Alaska, Mexico, or Canada. Recovery Team appointed; Recovery Plan drafted.
REFERENCES:	Lish 1975; Oberholser 1974; Peterson 1963.



BALD EAGLE

LEGEND

Historic   Statewide

Present   (Winter)

Counties showing active nests, used at least once since 1971.

Figure E-2. Distribution of bald eagle (<u>Haliaeetus</u> <u>leucocephalus</u>).

Table E-5. Detailed description of brown pelican (*Pelecanus occidentalis*)

STATUS:	Endangered (35 FR 16047, October 13, 1970; 35 FR 18320, December 2, 1970).
SPECIES DESCRIPTION:	A large dark water bird (wingspan 6.5 ft.) with long pouched grayish bill. Adults with white head and neck, brownish black on breast and belly, silver grayish on most of upper parts.
HABITAT:	Sea coasts and coastal islands.
DISTRIBUTION:	Coastal waters of North and South America.
Historic:	Primarily along coast, but has been reported in the Trans-Pecos region, the Panhandle and north-central Texas.
Present:	Reduced to a small resident flock along the coast. Migrating flocks from the Mexican Gulf Coast frequently enter Texas waters.
REASONS FOR DECLINE:	Loss of habitat. Pesticides.
OTHER INFORMATION:	Recovery Team appointed; Recovery Plan approved. Protected by the State of Texas.
REFERENCES:	Oberholser 1974; Peterson 1963.

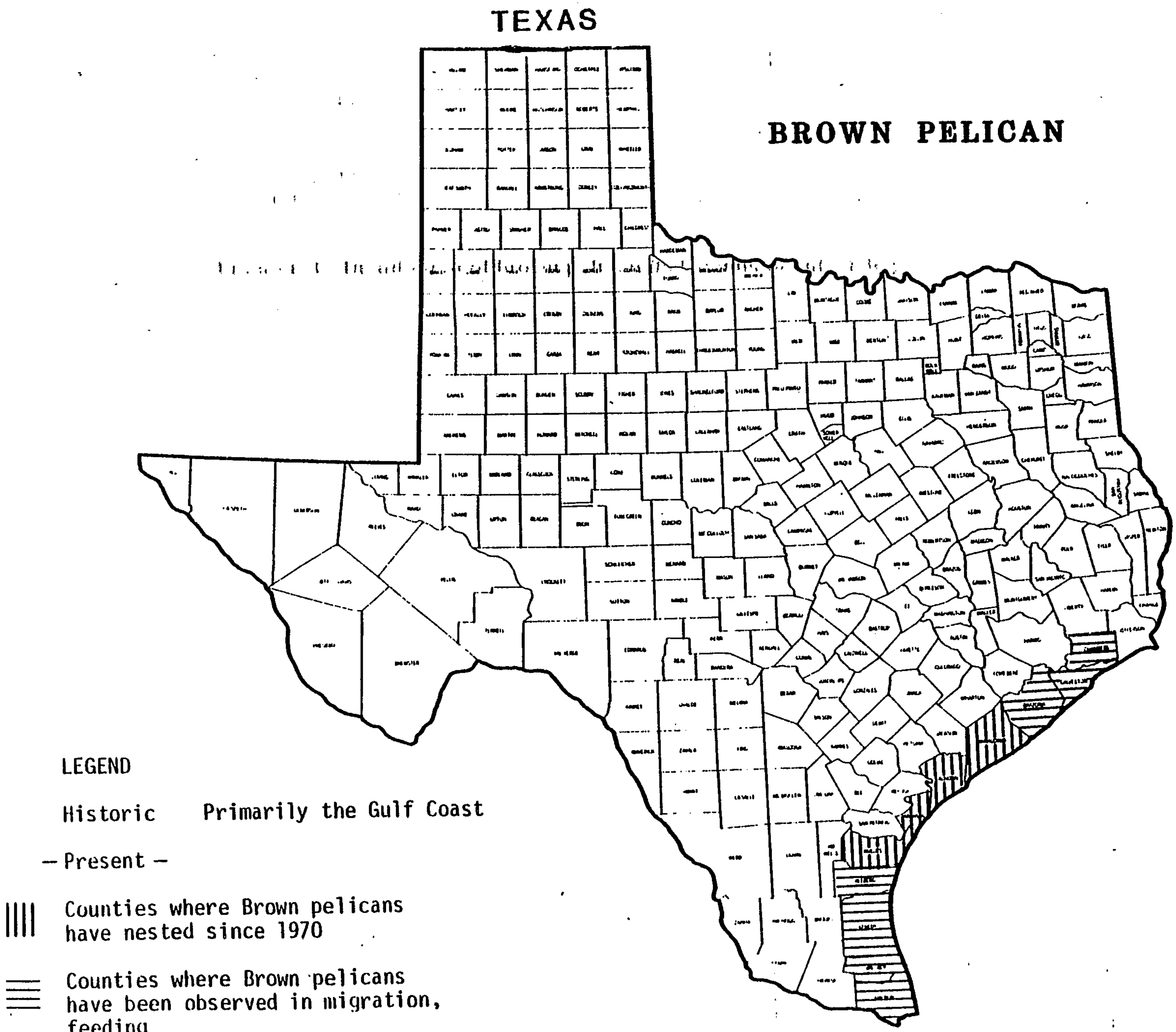
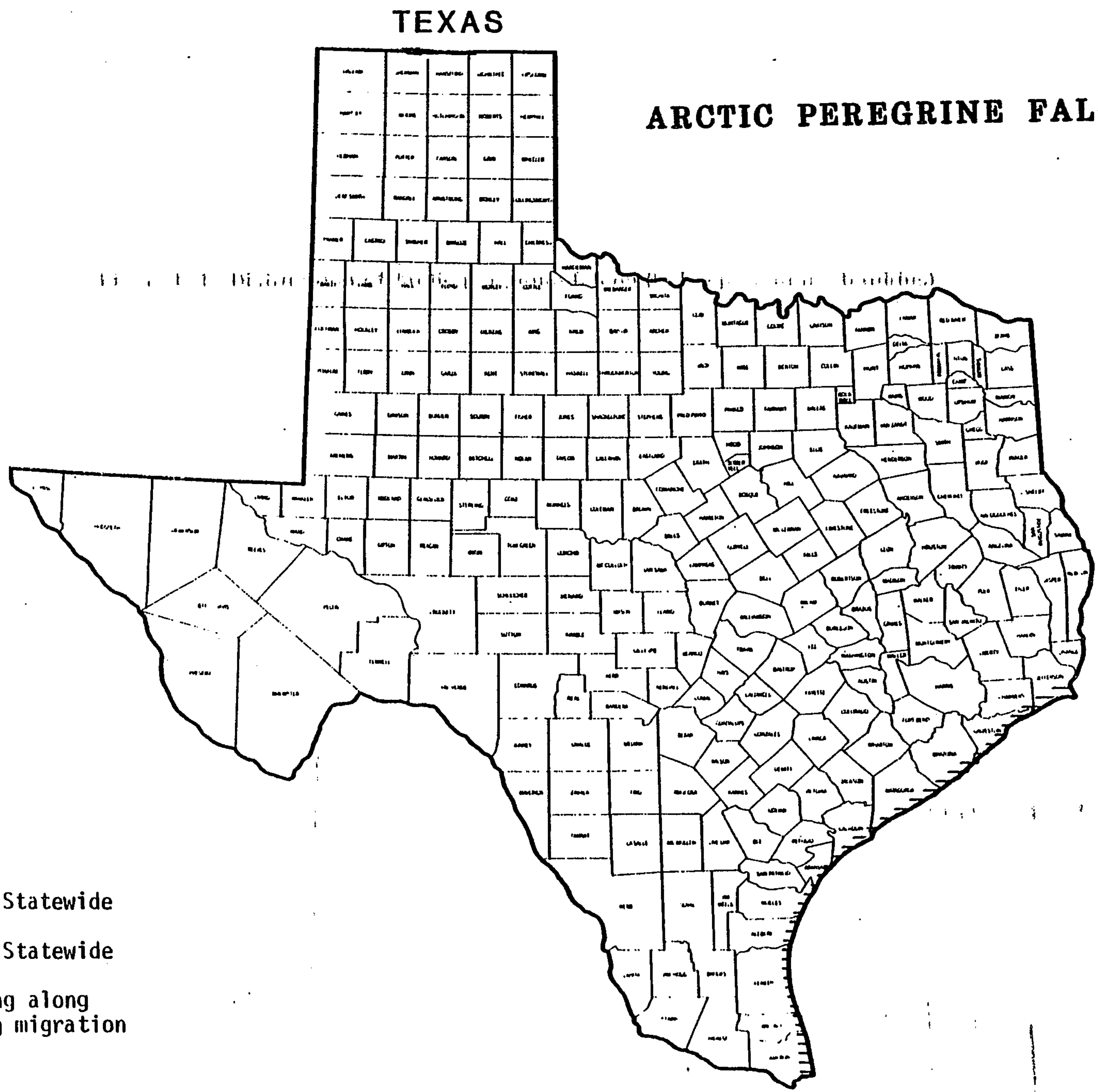


Figure E-3. Distribution of brown pelican (Pelecanus occidentalis).

Table E-6. Detailed description of Arctic peregrine falcon (Falco peregrinus tundrius)

STATUS:	Endangered (35 FR 16047, October 13, 1970; 35 FR 18320, December 2, 1970).
SPECIES DESCRIPTION:	Same as American peregrine except adults slightly smaller and paler in coloration.
HABITAT:	Nests in tundra, winters in Central and South America, especially along coastlines and in mountains.
DISTRIBUTION:	Breeds in the North American tundra and winters along the Gulf Coast from Florida west to the eastern Mexico coast and Baja California, south to mid-Chile and mid-Argentina.
Historic:	Statewide.
Present:	May occur statewide during their fall and spring migration. Concentrate along gulf coast, especially North and South Padre Island.
REASONS FOR DECLINE:	Reproductive failure due to pesticides.
OTHER INFORMATION:	Recovery Team appointed; Recovery Plan being implemented. Protected by the State of Texas.
REFERENCES:	Craig et al 1977; Johnson 1976; Oberholser 1974.

ARCTIC PEREGRINE FALCON



LEGEND

Historic Statewide

Present Statewide

Concentrating along coast during migration periods

Figure E-4. Distribution of Arctic peregrine falcon (<u>Falco peregrinus tundrius</u>).

Table E-7. Detailed description of Attwater's prairie chicken (*Tympanuchus cupido attwateri*)

STATUS:	Endangered (32 FR 4001, March 11, 1967).
SPECIES DESCRIPTION:	A medium-sized grouse of tall-grass coastal prairies. Males are brownish, strongly black-barred; has long winglike tufts (pinnates) on sides of neck, and has a short rounded blackish tail.
HABITAT:	Native tall-grass prairies of the coastal region.
DISTRIBUTION:	
Historic:	Formerly occupied some 8,000,000 acres of coastal prairie extending from Kleberg County, Texas northward to Bayou Teche, Louisana.
Present:	Reduced to several coastal counties in Texas. Total population in Texas estimated to be around 2,000 birds.
REASONS FOR DECLINE:	Loss of habitat due to conversion of native prairies to farmlands; industrial use and other agricultural uses incompatible with prairie chickens.
OTHER INFORMATION:	Recovery Team appointed; Recovery Plan in preparation. Protected by the State of Texas.
REFERENCES:	Lehmann 1941; Oberholser 1974; Peterson 1963.

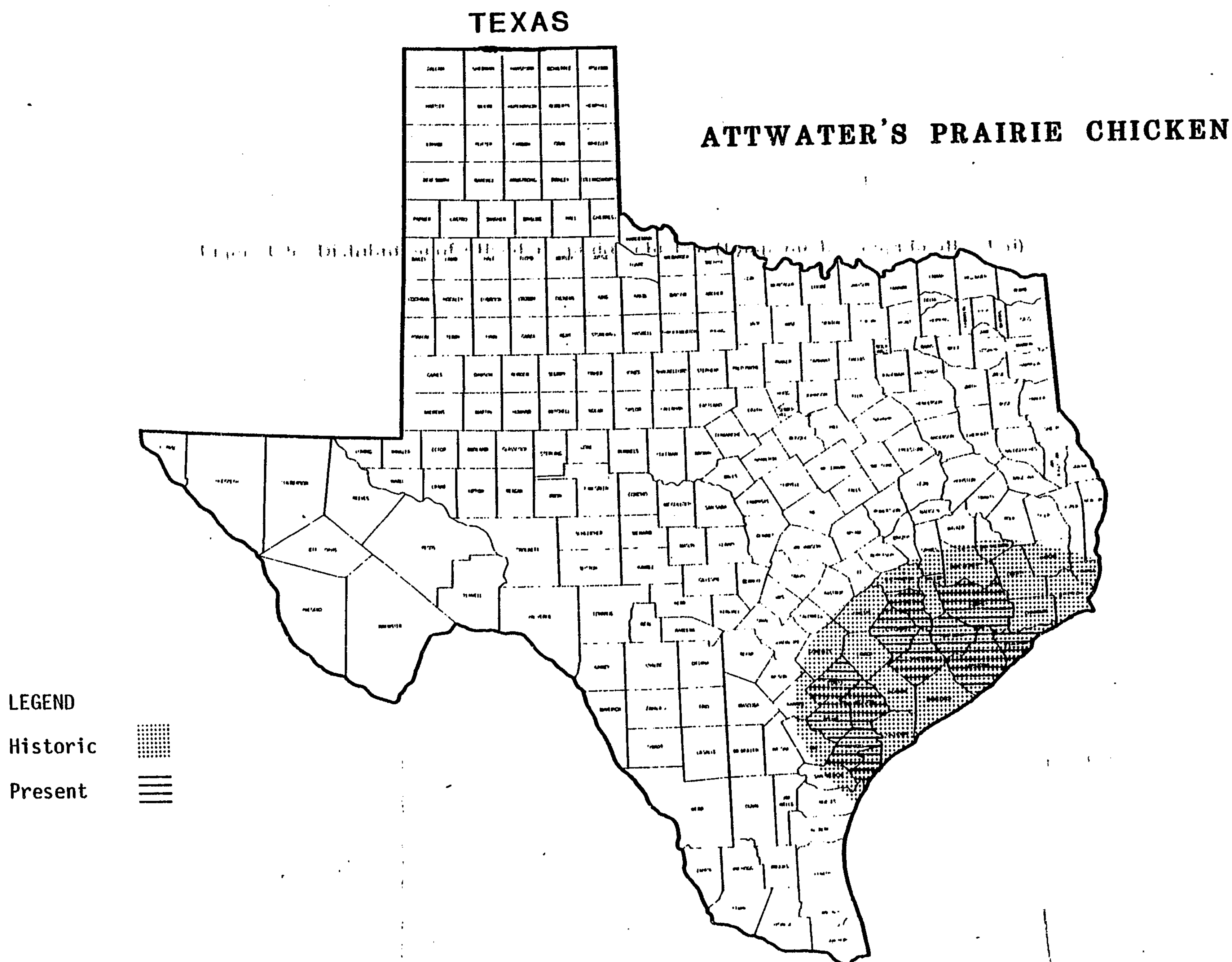


Figure E-5. Distribution of Attwater's prairie chicken (Tympanuchus cupido attwateri).

Table E-8. Detailed description of loggerhead sea turtle (*Caretta caretta*)

STATUS:	Threatened (43 FR 32808, July 28, 1978).
SPECIES DESCRIPTION:	Characterized by a large head with blunt jaws. Carapace and flippers are reddish-brown, the plastron yellow. Adults 170-350 lbs. and up to 45 inches.
HABITAT:	Widely distributed within its range. Found hundreds of miles out to sea as well as inshore areas such as bays, lagoons, salt marshes, ship channels and mouths of large rivers.
DISTRIBUTION:	Found in temperate and subtropical waters worldwide.
Historic:	Texas Gulf Coast.
Present:	Texas Gulf Coast. Rare visitor. One authenticated nesting record on South Padre Island in 1979.
REASONS FOR DECLINE:	Loss of nesting beaches due to recreational use and commercial development. Use of eggs as a food source.
OTHER INFORMATION:	Recovery Plan in preparation.
REFERENCES:	Conant 1975; Texas Parks and Wildlife Department 1978.

LOGGERHEAD SEA TURTLE

TEXAS

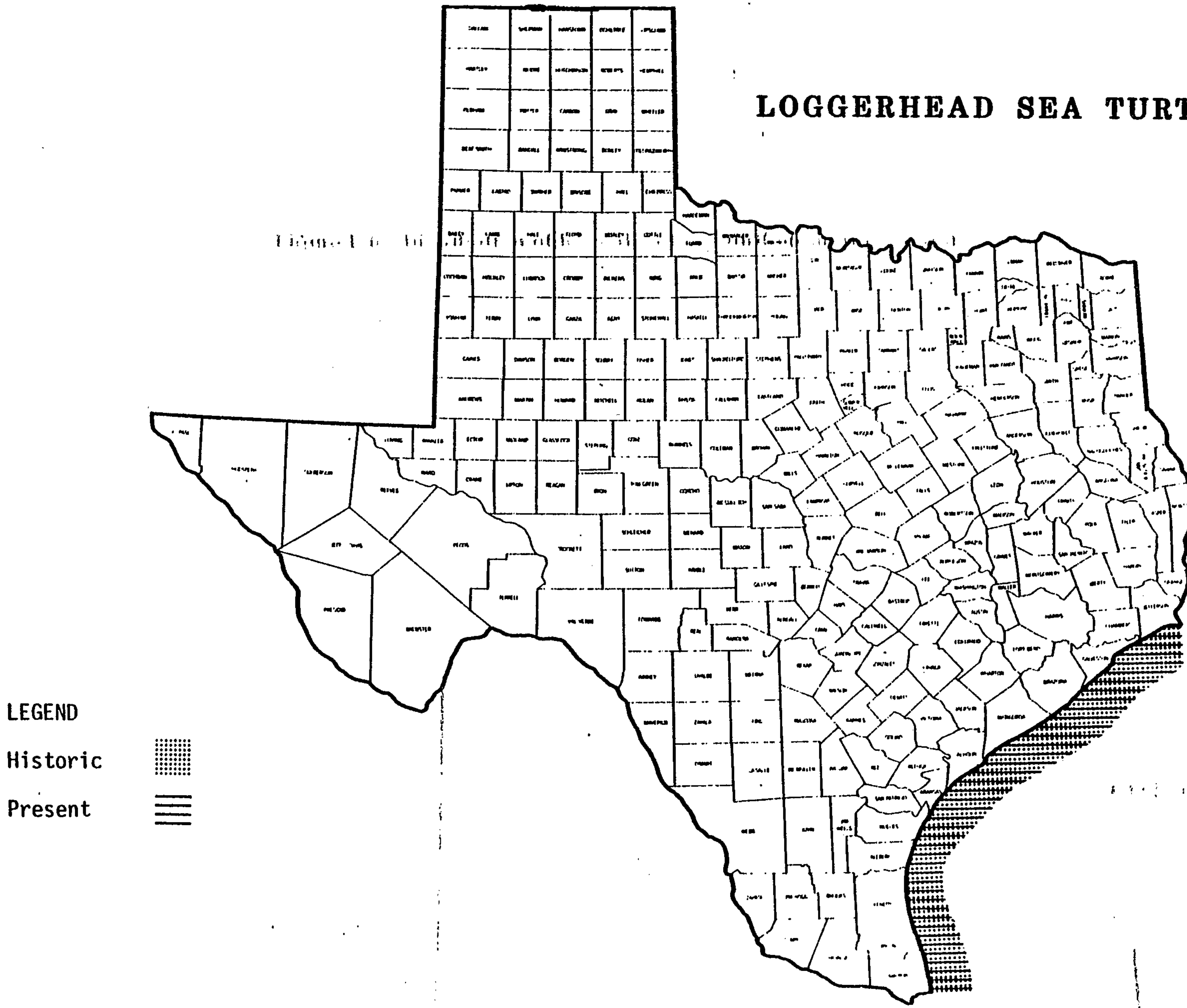


Figure E-6. Distribution of loggerhead sea turtle (*Caretta caretta*).

Table E-9. Detailed description of green sea turtle (Chelonia mydas)

STATUS:	Endangered (43 FR 32808, July 28, 1978) in Florida waters and the Pacific Coast of Mexico including the Gulf of California. Threatened elsewhere.
SPECIES DESCRIPTION:	Adults attain a length of 4 feet and range from 250-450 lbs. The adult carapace is smooth, keelless and light-to-dark brown with dark mottling.
HABITAT:	Generally found in shallow waters (except when migrating) inside reefs, bays and inlets. Open beaches with a sloping platform and minimal disturbance are required for nesting.
DISTRIBUTION:	Found throughout the world in tropical and temperate seas.
Historic:	The North American distribution is from Massachusetts to Mexico and from British Columbia to Baja California.
Present:	Occasionally occurs along the Texas Gulf Coast. Nesting in the United States is limited to Florida.
REASONS FOR DECLINE:	Over-utilization as a food source by humans, excessive natural predation in some areas, drowning in trawling operations.
OTHER INFORMATION:	Recovery plan in preparation.
REFERENCES:	Conant 1975; Texas Parks and Wildlife 1978.

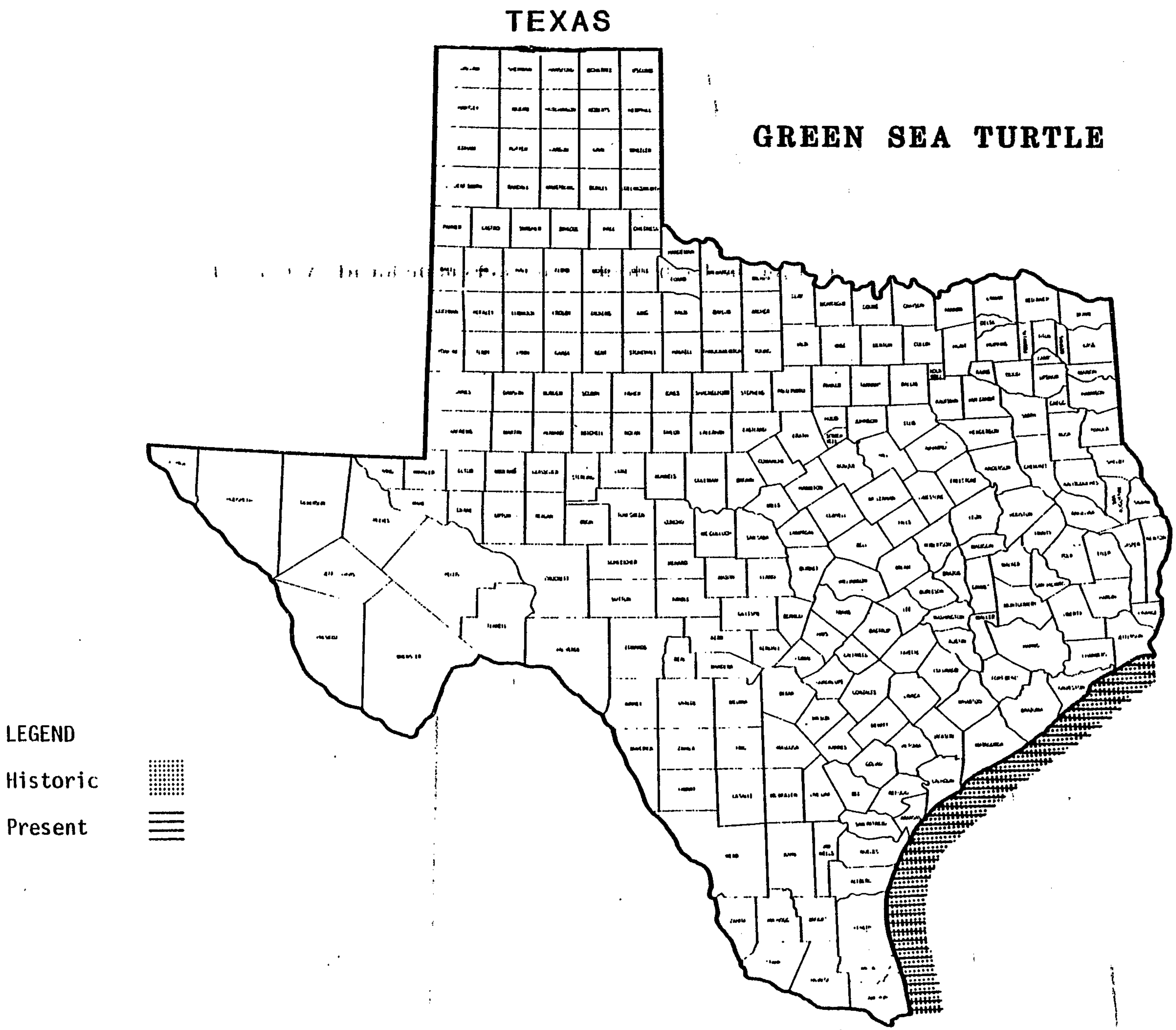


Figure E-7. Distribution of green sea turtle (Chelonia mydas).

Table E-10. Detailed description of leatherback sea turtle (*Dermochelys coriacea*)

STATUS:	Endangered (35 FR 8495, June 2, 1970).
SPECIES DESCRIPTION:	Largest of all living turtles. Adults 650-1200 lbs. Carapace and plastron have no scutes but are covered with smooth, slaty-black to dark bluish-black skin.
HABITAT:	Most pelagic of the sea turtles. Often found near the edge of the Continental Shelf.
DISTRIBUTION:	Tropical and semi-tropical Atlantic Ocean including Gulf of Mexico.
Historic:	Texas Gulf coast. Nesting in the U.S. is restricted to the Florida coast.
Present:	Texas Gulf coast. Very rare visitor.
REASONS FOR DECLINE:	Primarily the result of overutilization of eggs by humans.
OTHER INFORMATION:	Critical habitat has been established in the Virgin Islands. Recovery Plan in preparation. Protected by the State of Texas.
REFERENCES:	Brown 1950.

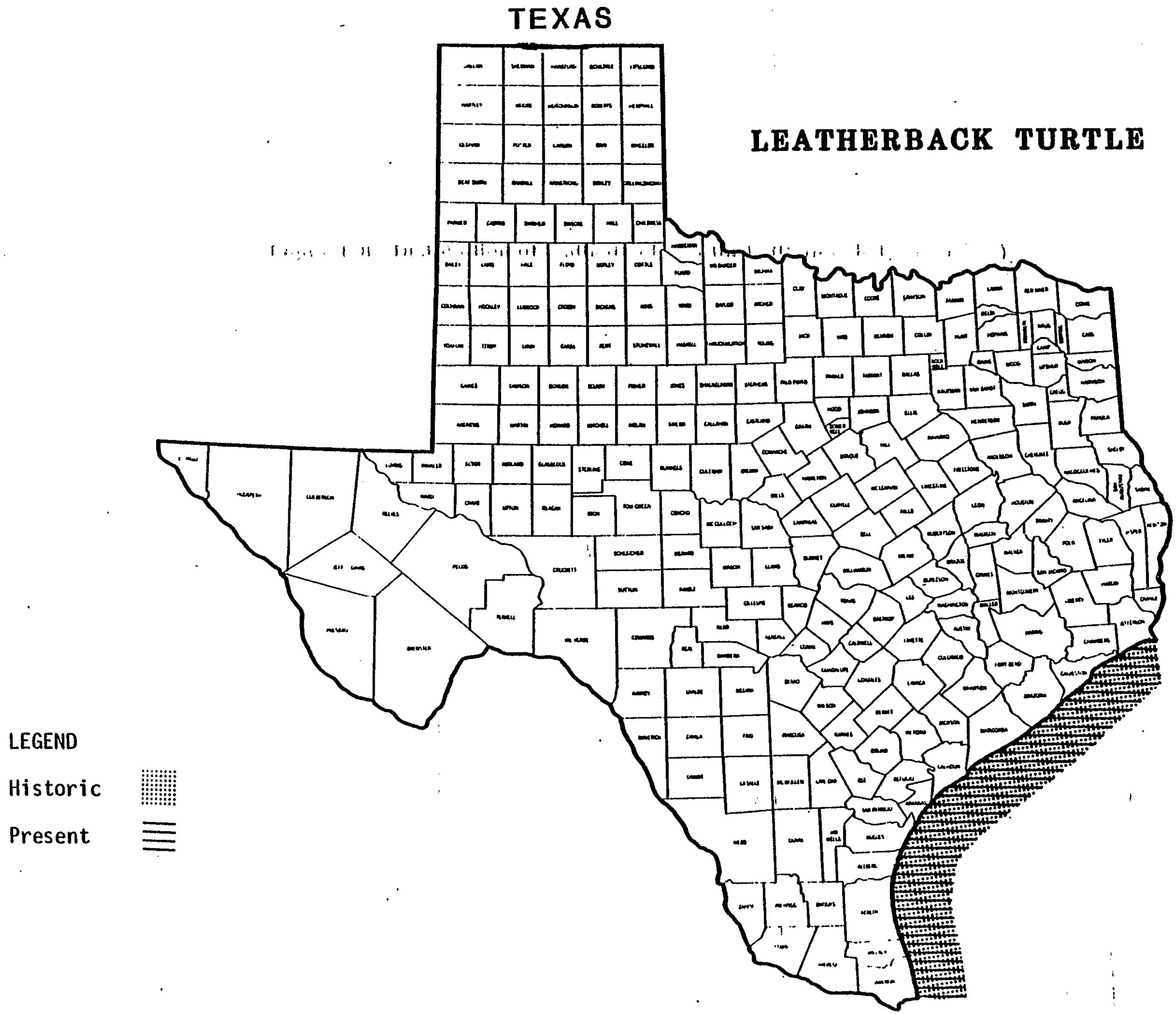


Figure E-8. Distribution of leatherback sea turtle (Dermochelys coriacea).

Table E-11. Detailed description of hawksbill sea turtle (*Eretmochelys imbricata*)

STATUS:	Endangered (35 FR 8495 June 2, 1970).
SPECIES DESCRIPTION:	One of the smaller sea turtles. Adults 95-165 lbs. Has elongated, oval shell. Carapace generally brown with splashes of yellow, orange or reddish-brown.
HABITAT:	Found in rocky areas, reefs, shallow coastal areas, lagoons of oceanic islands. Hatchlings often found in floating masses of sea plants.
DISTRIBUTION:	World-wide in tropical waters. Continental U.S. nesting is limited to Florida.
Historic:	Atlantic coast to Texas Gulf Coast.
Present:	Same. Very rare visitor along Texas coast.
REASONS FOR DECLINE:	Primary cause is harvesting for the shell. Some harvesting of eggs and meat occurs.
OTHER INFORMATIOIN:	Recovery Plan in preparation. Protected by the State of Texas.
REFERENCES:	Conant 1975.

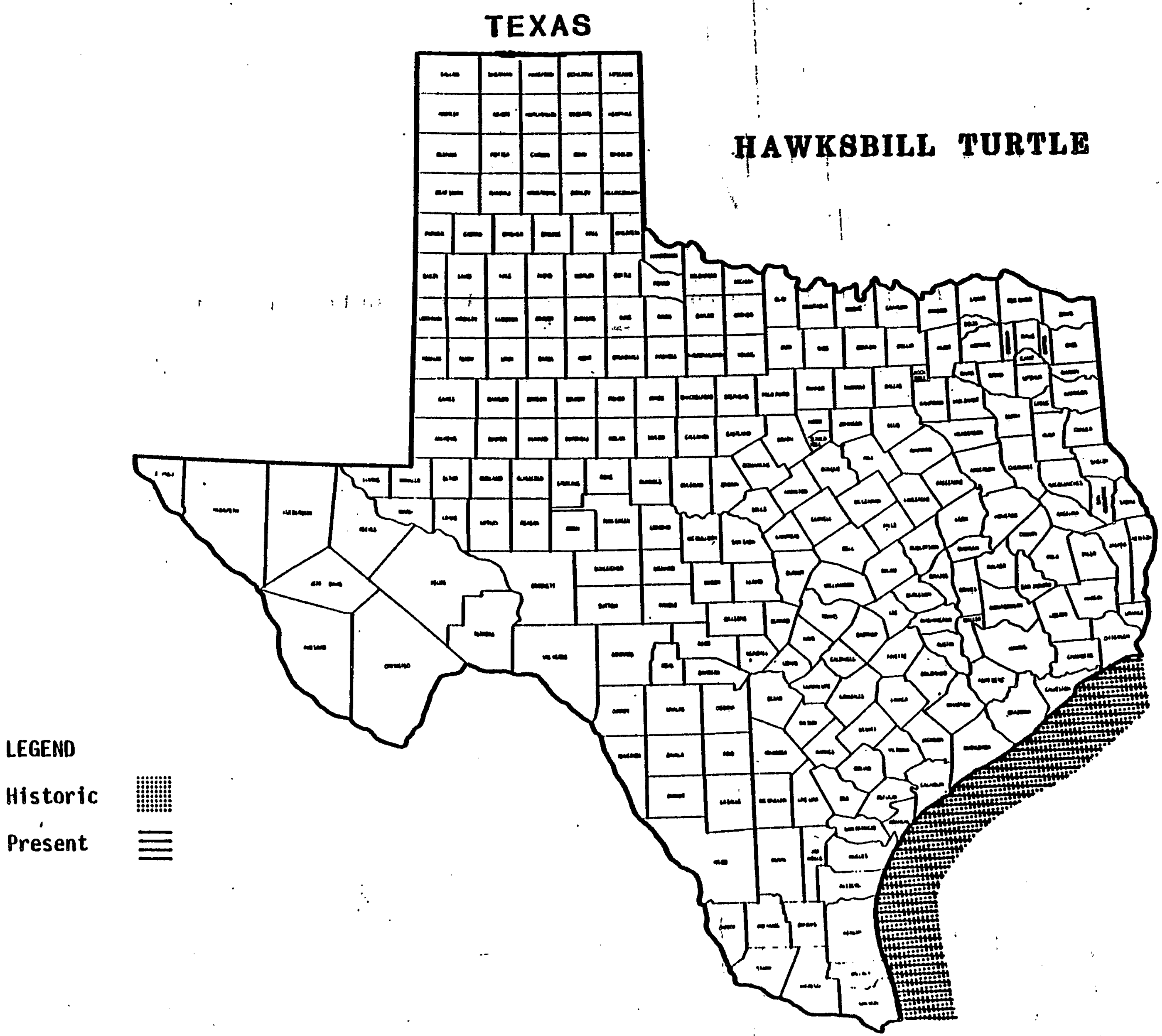


Figure E-9. Distribution of hawksbill sea turtle (<u>Eretmochelys imbricata</u>).

Table E-12. Detailed description of Kemp's ridley sea turtle (Lepidochelys kempii)

STATUS:	Endangered (35 FR 18320, December 2, 1970).
SPECIES DESCRIPTION:	One of the smallest sea turtles. Adults 80-100 lbs. The only sea turtle with a nearly circular carapace. Olive-green above and yellow below.
HABITAT:	Shallow coastal and estuarine waters.
DISTRIBUTION:	North Atlantic Ocean and Gulf of Mexico.
Historic:	Texas Gulf Coast.
Present:	The entire nesting population is currently limited to Rancho Nuevo, Tamaulipas, Mexico. A single female nested on Padre Island National Seashore in June 1979.
REASONS FOR DECLINE	Over-harvesting of eggs and adults for food and skins. Other factors include drowning in shrimp trawls and loss of eggs to predators.
OTHER INFORMATION:	Current population estimated at less than 3000. Recovery Team appointed; Recovery Plan in preparation. Joint U.S.-Mexican protection program underway, which includes protection and incubation of eggs, a hatchling "headstart" program (captive rearing for six months to a year), and establishment of a new nesting site. Protected by the State of Texas.
REFERENCES:	Brown 1950; Conant 1975.

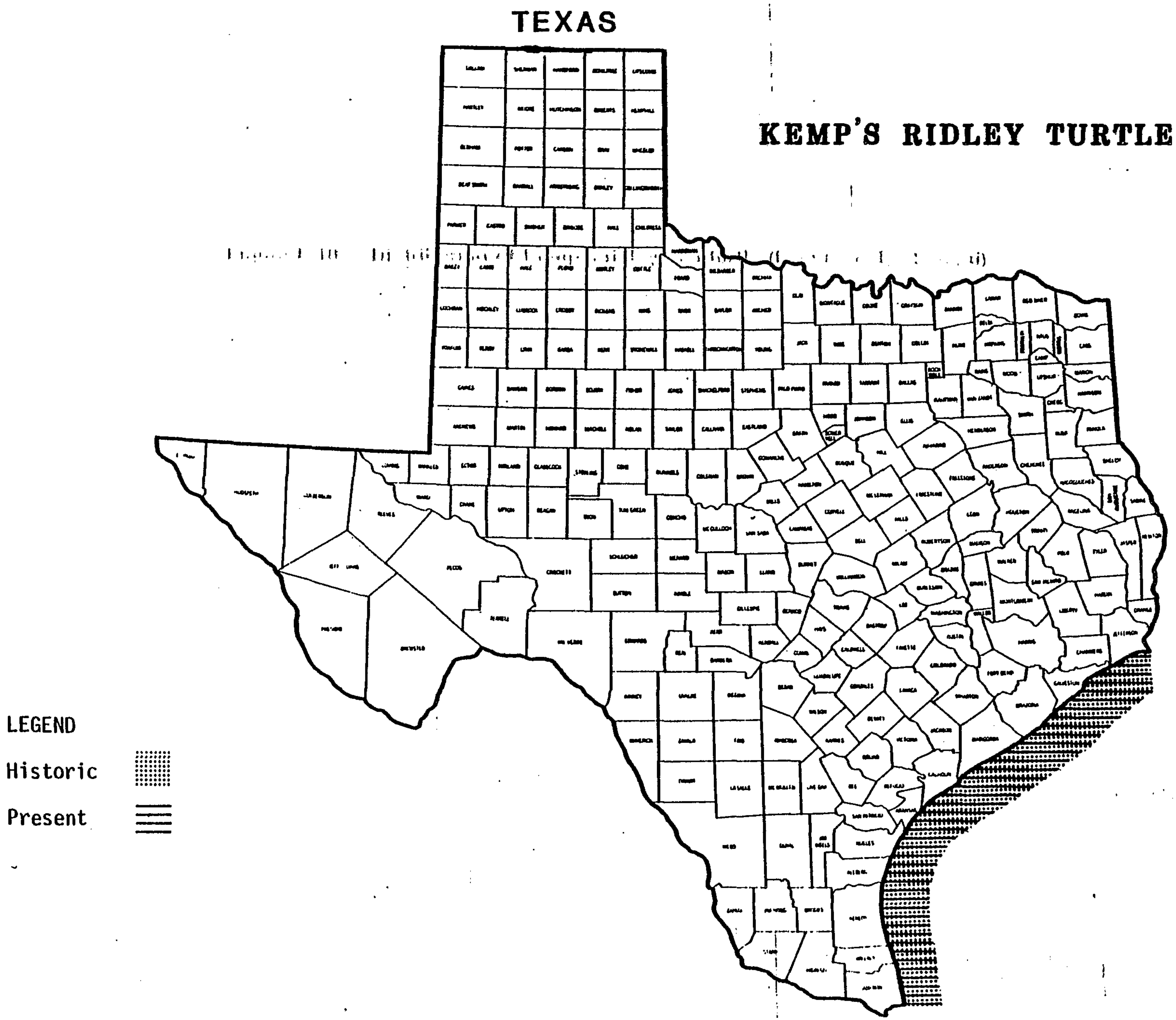


Figure E-10. Distribution of Kemp's ridley sea turtle (Lepidochelys kempii).

Table E-13. Detailed description of American alligator (*Alligator mississippiensis*)

STATUS:	Endangered Inland counties (40 FR 44418, September 26, 1975). Threatened Coastal counties (42 FR 2076, January 10, 1977).
SPECIES DESCRIPTION:	A large (up to 16 feet) lizard-like reptile with broadly rounded snout. General coloration of adults is grayish black.
HABITAT:	Rivers, swamps, estuaries, lakes and marshes.
DISTRIBUTION:	Southeastern United States from North Carolina to Texas.
Historic:	The eastern one-third of Texas in suitable marsh and water habitat.
Present:	Found along the Gulf Coast and eastern inland counties. Map depicts those counties where species is endangered or threatened.
REASONS FOR DECLINE:	Hunting, destruction of habitat. Young heavily subject to predation and human disturbance.
OTHER INFORMATION:	Recovery Team appointed; Recovery Plan drafted.
REFERENCES:	Conant 1975; Neill 1971; Rare and Endangered Species of Oklahoma Committee 1975; U. S. Fish and Wildlife Service 1973.

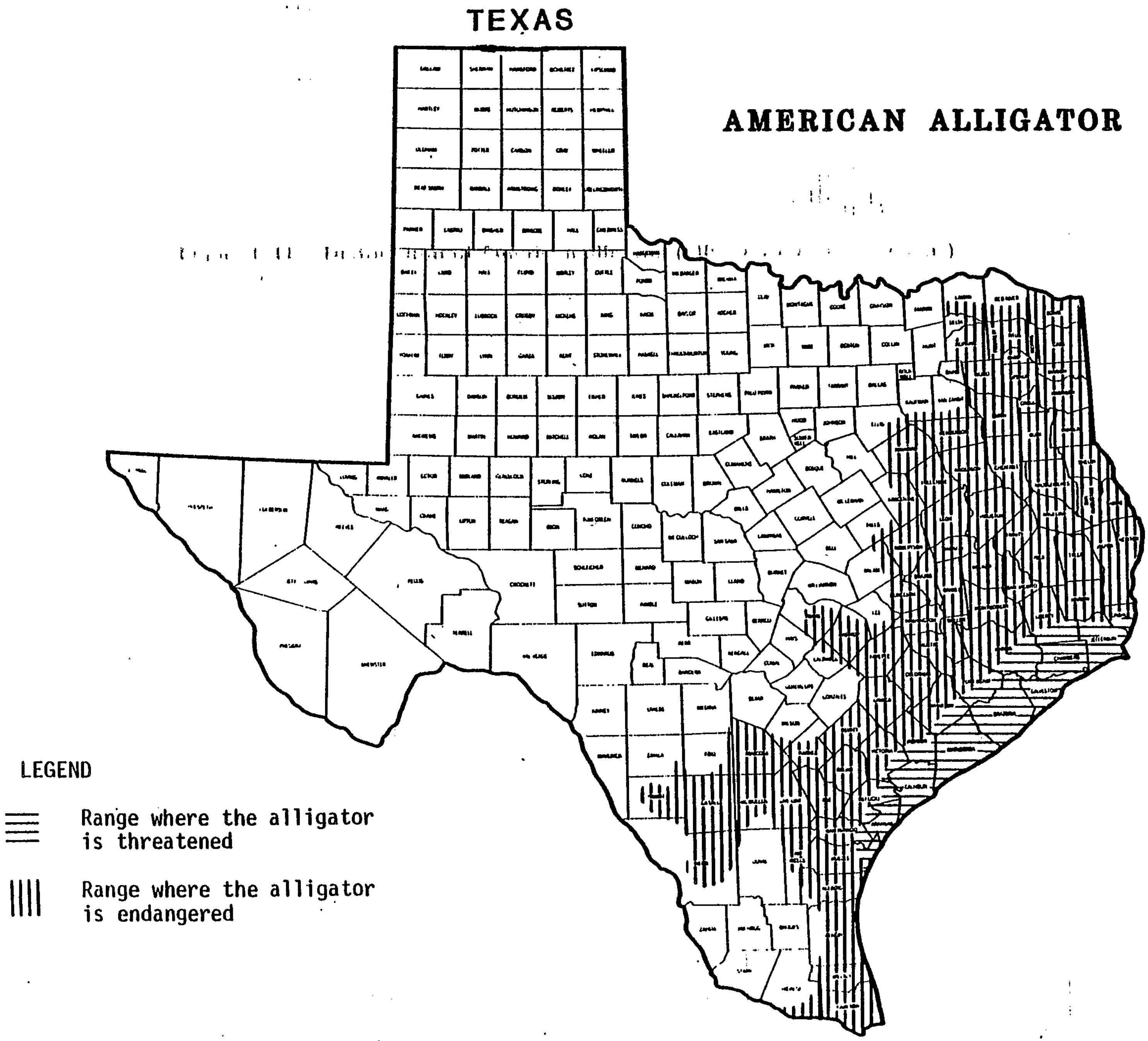


Figure E-11. Distribution of American alligator (Alligator mississippiensis).

APPENDIX E

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APPENDIX F

SUMMARY OF STRATEGIC PETROLEUM RESERVE (SPR) AND NON-SPR BASELINE DATA AT THE BIG HILL (TEXOMA) CANDIDATE BRINE DIFFUSER SITES

APPENDIX F

SUMMARY OF STRATEGIC PETROLEUM RESERVE (SPR) AND NON-SPR BASELINE DATA AT THE BIG HILL (TEXOMA) CANDIDATE BRINE DIFFUSER SITES

Introduction

The locations of the Texoma study sites and stations are discussed in Sect. 3.0. Tables F-1 and F-2 present the coordinates for the Big Hill (BH) and Big Hill Control (BHC) stations and a summary of the sampling chronology, respectively.

Methodologies

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

In-situ oxygen, conductivity, temperature, and pH as a function of depth (1-m intervals) were taken with a Hydrolab "Surveyor." Conductivity values were converted to salinities, and oxygen values were adjusted for temperature and salinity. Nutrients were analyzed according to Standard Methods (American Public Health Association, 1975).

Near-surface and near-bottom phytoplankton samples were obtained by using 6-L Van Dorn water bottles. A 1-L aliquot was drawn off each Van Dorn sample.

Phytoplankton samples were preserved in 5 percent buffered formalin with a methyl green stain. Enumerations were obtained by strip counting with a Sedgewick-Rafter cell. Phytoplankton counts were reported as units per liter, where unit refers to a simple cell or to a group of cells in species that form colonies or aggregates. Near-surface and near-bottom zooplankton tows were made by using 5-in.-diameter Clark-Bumpus plankton samplers. Zooplankton tows (#10 mesh) were made for 2.5 min at 1.5 knots. Zooplankton samples were fixed in 5 percent buffered formalin stained with rose bengal. Enumerations were obtained by the strip-counting method using a Sedgewick-Rafter cell.

Sediment subsamples were obtained from Van Veen grab samples, using 2.5-cm-diameter coring tube, taken to a depth of about 5.0 cm. In the laboratory, the cores were analyzed for sediment size distribution by sieve and hydrometer procedures described by Folk (1974).

Benthic megafauna were sampled with replicate 1/25-m^2 Van Veen grabs, and a meiofaunal core was taken from each grab in a manner similar to the sediment subsamples. Both megafaunal and meiofaunal samples were

Table F-1. Coordinates for sampling stations at the Big Hill and BHC brine disposal study sites

Station	Latitude	Longitude
<u>Big Hill</u>		
35	29° 33' 36" N	94° 07' 24" W
36	29° 36' 24" N	94° 07' 24" W
37	29° 35' 00" N	94° 07' 54" W
38	29° 34' 06" N	94° 09' 00" W
39	29° 35' 00" N	94° 09' 00" W
39E	29° 35' 00" N	94° 08' 48" W
39W	29° 35' 00" N	94° 09' 12" W
41	29° 35' 54" N	94° 09' 00" W
42	29° 35' 00" N	94° 10' 12" W
43	29° 33' 36" N	94° 10' 42" W
44	29° 36' 24" N	94° 10' 42" W
<u>BHC</u>		
50	29° 34' 18" N	93° 57' 36" W
50E	29° 34' 18" N	93° 57' 24" W
50W	29° 34' 18" N	93° 57' 48" W
51	29° 34' 18" N	93° 56' 36" W
52	29° 36' 30" N	93° 57' 36" W
53	29° 34' 18" N	93° 58' 36" W
54	29° 33' 24" N	93° 57' 36" W

Table F-2. **Spatial and temporal patterns of sample collection at the Big Hill study sites**

		A	A'	B	C	D	E	F
		PLANKTON*	CHLOROPHYLL	NUTRIENTS	DEMERSAL NEKTON	MEGAFAUNA** & CTD	MEIOFAUNA	SEDIMENTS***
		1234567890123	1234567890123	1234567890123	1234567890123	1234567890123	1234567890123	1234567890123
BIG HILL	35					XX X XXXXX	XXXX X XXXXX	XX X XXXXX
	36					XX X XXXXX	XXXX X XXXXX	XX X XXXXX
	37	XXXXXXXXXXXX	XXXXXXXXXXXXX	XXXXXXXXXXXXX	XXXXXXXXXXXXX	XXXXXXXXXXXXX	XXXXXXXXXXXXX	XXXXXXXXXXXXX
	38	XXX X XXXXX	X X XXXXXX	XX		XXXXXXXXXXXXX	XXXXXXXXXXXXX	XXXXXXXXXXXXX
	39			XXXX	XXXXXXXXXXXXX	XXXXXXXXXXXXX	XXXXXXXXXXXXX	XXXXXXXXXXXXX
	39E	XXXXXXXXXXXX	XXXXXXX XXXXX	XXXX XXXXX				
	39W	XXXXXXXXXXXX	XXXXXXX XXXXX	XXXX				
	41	XX X XXXXX	X X XXXXXX	XX		XXXXXXXXXXXXX	XXXXXXXXXXXXX	XXXXXXXXXXXXX
	42	XXXXXXXXXXXX	XXXXXXXXXXXXX	XXXXXXXXXXXXX	XXXXXXXXXXXXX	XXXXXXXXXXXXX	XXXXXXXXXXXXX	XXXXXX XXXXXX
	43	XXXXX	XXXXXX			XXXXXXXXXXXXX	XXXXXXXXXXXXX	XXXXXXXXXXXXX
	44	XXXXX	XXXXXX			XXXXXXXXXXXXX	XXXXXXXXXXXXX	XXXXXXXXXXXXX
BIG HILL CONTROL	50					XXXXXXXXXXXXX	XXXXXXXXXXXXX	XXXXXXXXXXXXX
	50E	XXXXXXXXXXXXX	XXXXX	XXXXXXXXXXXXX	XXXXXXXXXXXXX			
	50W	XXXXXXXXXXXX	XXXXX	XXXXXXXXXXXXX	XXXXXXXXXXXXX			
	51		XXXXXXXX			XXXXXXXXXXXXX	XXXXXXXXXXXXX	XXXXXXXXXXXXX
	52		XXXXXXXX			XXXXXXXXXXXXX	XXXXXXXXXXXXX	XXXXXXXXXXXXX
	53					XXXXXXXXXXXXX	XXXXXXXXXXXXX	XXXXXXXXXXXXX
	54					XXXXXXXXXXXXX	XXXXXXXXXXXXX	XXXXXXXXXXXXX

Source: Comiskey et al. (1979).

* Top and Bottom phytoplankton, chlorophyll a, and zooplankton.

** CTD: Conductivity, temperature, depth, dissolved oxygen, and ph.

*** Grain size distribution, % organic matter, % carbonate.

washed through screens. This study was actually comprised of two separate phases, September to December and February to October. During the first phase, megafauna were sieved through a 1-mm screen; during the second phase, a finer mesh (0.5-mm) screen was used. The meiofauna during the first phase represented the organisms from 1 mm to 250 µ; during the second phase, they were the 0.5-mm to 63-µ fraction of the benthos. These changes were made because of the small size of the megabenthos and increased interest in correctly ascertaining the composition of the true meiofaunal community. Samples were preserved with 10 percent buffered formalin and rose bengal stain. Rough sorting was performed in white pans under an illuminated magnifying glass, and fine sorting was done under a dissecting microscope. Meiofaunal organisms were floated in ethylene glycol solution to separate the animals from the debris.

Demersal fishes, larger demersal invertebrates, and larger and more mobile benthic animals were collected with a 4.3-m-wide otter trawl lined with a 4-mm stretched mesh sleeve net. The trawl was towed at a constant bow speed of 2 knots for 15 min in a direction perpendicular to the shoreline. The area covered by the trawl was calculated to be about 3,240 m^2. (No corrections have been made to account for variations in trawl distance due to the differences in hydrographic and meteorologic conditions.) Because prevailing currents flow parallel to the shoreline and are relatively weak (1 to 2 knots), it is thought that this source of error is minimal. All organisms in the sample were identified to the lowest possible taxon and counted. Each individual was measured, but not weighed.

Results

Currents and Winds

Currents and winds were sampled during the Texoma study, and the data are discussed in the context of four sampling periods with similar oceanographic conditions during 1978:

Sampling period 1: December 2 to February 28
Sampling period 2: March 10 to May 15
Sampling period 3: May 15 to July 12
Sampling period 4: July 12 to September 13.

Shorter current records are available for the period prior to December 2, but these records were not long enough for seasonal characterization.

Means and variance of the longshore (V) and onshore-offshore (U) component of the currents for the four sampling periods are given in Table F-3.

Sampling Period 1 (December 2 to February 28)

Mean near-bottom currents were predominantly to the west with a slight (an order of magnitude less) onshore component. Winds were easterly and offshore, with the transshelf component being larger. Longshore standard deviation for near-bottom currents was several times greater

Table F-3. Current meter and wind statistics for Texoma study (December 1977 to September 1978)

	Mean U	Mean V	S.D. U	S.D. V
December 2 - February 28				
BHC bottom	-0.26	-5.29	4.27	13.08
BHS	-0.77	-5.68	6.28	14.83
Wind BMNT[1]	1.22	-0.84	3.44	3.15
Wind SDMS[2]	2.13	-2.49	5.33	5.47
March 10 - May 15				
BHC bottom	0.68	-4.93	4.05	8.75
BHS	1.66	-6.39	5.22	10.85
Wind SDMS	-1.56	-2.88	4.14	3.04
May 15 - July 12				
BHC top	2.30	7.62	4.64	12.28
BHC bottom	0.82	3.49	2.75	6.20
BHS	0.60	1.39	3.86	8.76
Wind SDMS	-3.77	-2.51	2.57	3.07
July 12 - September 13				
BHC top	-2.61	-5.72	7.97	16.58
BHC bottom	-0.88	0.40	4.82	6.98
BHS	-1.09	-1.99	4.67	9.60
Wind SDMS	-2.76	-1.36	2.69	2.11

Current measurements units, cm/s; Wind measurement units, m/s.

[1]From Beaumont Airport observations.

[2]From NOAA's SADEM platform.

BHC = Big Hill Control.
BHS = Big Hill Secondary (Replacement of lost buoy).
U = Onshore-Offshore current component.
V = Longshore current component.

than transshelf standard deviation. Variation of the two components of wind were approximately equal.

Westward-directed currents dominated at BHC and Big Hill Secondary (BHS) (Fig. 3-3), being 72 percent and 67 percent of the records, respectively. Transshelf currents were approximately equal (52 percent offshore at BHC and 47 percent offshore at BHS). The dominant quadrant at BHC and BHS was to the SW with 41 percent and 40 percent of the daily means, respectively. In almost all cases, the maximum mean currents were to the northwest. Based on daily means, the maximum currents were on occasion greater than 30 cm/s.

Plots of daily mean currents at BHC and BHS have the "S" shape seen in many of the plots from this region. This configuration results because the lower-magnitude currents are predominantly to the SW or NE, while the larger-magnitude means are onshore and to the northwest.

Examination of current velocity components indicates strong coherence between longshore current records and moderate coherence between transshelf current records. Correlation between longshore winds and currents seems to be strong, with winds being associated with similarly directed near-bottom currents. Correlations between transshelf winds and currents are weak to moderate. If a variable lag of from 0 to 24 h is used, then somewhat better correspondence between wind and current episodes is attained.

Most sampling period 1 currents were directed toward the west with an occasional eastward-directed event lasting 2 to 3 d. Many times currents to the west exceeded 30 cm/s, and occasionally the filtered signal approached 40 cm/s.

<u>Sampling Period 2 (March 10 to May 15)</u>

During sampling period 2, the mean longshore current component remained the same as for sampling period 1. However, the transshelf component reversed directions of flow (to the offshore direction). The relative magnitudes of transshelf and longshore components remained approximately the same as those found in the previous sampling period. Mean winds also changed so the transshelf component was onshore and the longshore component was almost twice the transshelf component. The pattern and magnitude of variance remained approximately consistent with season 1.

BHC and BHS are statistically quite similar, being within 1 or 2 percentage points in the distribution of daily means. Approximately 64 percent of daily mean currents, V component, was directed longshore and easterly, and 59 percent of the U component was directed offshore. The dominant quadrant was to the SW, with 47 percent of mean vectors terminating there. Means of highest magnitude were generally directed onshore and to the west.

Dominant wind direction was onshore and easterly (54 percent of the means). Northwesterly and southeasterly winds accounted for 72 percent of the daily means. The orientation of the winds was at right angles to the near-bottom currents.

As seen in the first period, there was strong longshore correlation of currents and strong positive correlation between longshore winds and currents. Transshelf currents showed only moderate correlation.

The data indicate that winds were directed offshore only during significant wind events, which occurred at a fairly regular interval of 6 to 10 d and lasted 2 to 3 d. The offshore wind events were often associated with weaker northwesterly winds. The majority of the time, winds were directed onshore.

Sampling Period 3 (May 15 to July 12)

There was an important change in current patterns during sampling period 3. The longshore component of near-bottom currents was strongly directed to the east. This is the only period during which this occurred. The transshelf component was mainly to the offshore. Winds were consistent with those observed during sampling period 2, although relative magnitudes of transshelf and longshore components changed so that the transshelf component was approximately 50 percent larger than the longshore component.

Although the relative magnitude of transshelf and longshore variances remained similar to those in other seasons, the absolute magnitude of all current variances decreased.

During sampling period 3, a near-surface current meter was deployed at BHC, about 3 m below the water surface.

The mean current vectors of the upper and lower meters were oriented in approximately the same direction; however, near-bottom currents were 50 percent or more weaker than currents measured near the surface. The upper-current record had a root mean square (RMS) current magnitude about twice that of the lower meter, indicating greater variability at the upper-meter current.

At BHS, eastward-directed currents dominated slightly (58 percent), as did offshore currents (61 percent). Most currents were oriented approximately to the northeast or to the southwest. It is quite possible that the principal axis does not orient longshore and parallel to shore. At BHC, near-bottom currents were predominantly to the east (77 percent) and to the south (60 percent of U vectors). Mean current speeds were generally low, with most less than 10 cm/s. Symmetrical clustering around the longshore axis suggests that the principal axis aligns with the location isobaths.

By contrast, near-surface currents at BHC were predominantly to the east (77 percent), but 72 percent of the means were also directed offshore. Sixty-one percent of the means were oriented to the southeast and 12 percent to the northwest, so the principal axis probably had a cross-isobath component. Statistical comparison of near-surface and near-bottom mean currents showed that near-surface currents were oriented to the right of the near-bottom currents.

Winds were southeasterly for almost the entire sampling period. Only about 7 d had winds directed offshore. Excluding some weak westerly winds, only one short eastward-directed wind event occurred in 40 d. This type of persistent wind had not been measured previously.

Winds and currents were negatively correlated in the longshore (e.g., west-directed winds produced eastward-directed currents). This is contrary to expectation and normal conditions. Near-surface and near-bottom longshore currents had a strong positive correlation, as expected. It is difficult to identify the degree of correlation of transshelf currents at the two levels.

Sampling Period 4 (July 12 - September 13)

Winds were similar to those during sampling period 3; the mean vector was oriented easterly and onshore. The onshore component was approximately half the longshore component.

Near-bottom currents during this sampling period presented a confusing picture because the patterns at BHC and BHS differed. At BHS, the mean direction was to the west and onshore, and the longshore component was approximately twice the transshelf component. At BHC, mean direction was to the east and onshore, and the transshelf component was twice the longshore component. Transshelf components at both stations were similar in magnitude, differing by only 20 percent; however, longshore components were oriented in opposite directions.

On the average, there was considerable shear between the upper and lower current measurements at BHC. Over a distance of 5 m, the mean velocity differed by 6.1 cm/s.

During sampling period 4, winds were predominantly onshore (88 percent) and easterly (70 percent). Sixty percent of the mean vectors terminate in the northwest quadrant. Only 2 percent terminate in the southeast quadrant. As in most sampling periods, there was considerable scatter, even within quadrants.

Near-bottom currents at BHS cluster around the local isobath (54 percent offshore and 46 percent onshore) with slightly more than half of the vectors directed toward the west. Similarly, near-bottom currents at BHC were fairly uniformly distributed around the local isobath. Near-surface currents (U component) at BHC were approximately evenly distributed between onshore and offshore (46 and 54 percent, respectively). However, they were not evenly distributed longshore because only 11 percent of the mean vectors terminated in the northeast and southwest quadrants. There was a definite statistical trend indicating a cross-isobath transport. The cross-isobath trend was more pronounced for near-surface flows to the northwest.

During the latter part of August 1978, a severe storm moved through the study area, creating the most extreme currents measured during this study. These currents built and decayed rapidly. Half-hourly mean speeds of over 50 cm/s were recorded by the near-surface meter for over a day, and half-hourly speeds of 100 cm/s or greater existed for 3 to

Department of Energy
Washington, D.C. 20585

OCT 5 1981

Dear Colleague:

Enclosed is a copy of the Department of Energy's Final Supplement to the Final Environmental Impact Statements for the Strategic Petroleum Reserve Seaway and Texoma Groups of Salt Domes (DOE/EIS-0075). This Final Supplement, prepared in compliance with the National Environmental Policy Act, assesses the environmental implications of implementing the proposed Phase III expansion of the Strategic Petroleum Reserve program to provide an additional 212 million barrels of storage capacity, and to increase the Strategic Petroleum Reserve average drawdown capability from approximately 3.5 to 4.5 million barrels per day.

Copies of the Final Supplement are being provided to Federal, state and local agencies having jurisdiction by law and/or special expertise; and to organizations and individuals who commented on the Draft Supplement or requested a copy of the Final Supplement.

The review period for the Final Supplement ends 30 days after its availability is announced in the Federal Register weekly report of the Environmental Protection Agency.

Sincerely,

R. J. Stern

Robert J. Stern, Director
NEPA Affairs Division

Enclosure

4 h. A single large magnitude point in the northwest quadrant reflects these velocities. The near-surface currents exceeded 100 cm/s for several hours. The daily mean was approximately 65 cm/s. During this period, near-bottom half-hourly mean current speeds of 50 to 80 cm/s were measured. These extreme currents could have had significant impact on the sampling period means and variances. During the storm, currents at all depths were directed onshore, suggesting a large buildup along the coast or some kind of extensive horizontal circulation system.

This sampling period was characterized by weak and variable transshelf currents, although the corresponding winds were predominantly onshore. At times, near-surface and near-bottom currents were in phase, and at times, they were out of phase.

Near-bottom longshore currents were well correlated and displayed a reasonably positive correspondence with longshore winds and near-surface currents. Prior to the August storm, longshore currents showed no preferential direction. However, after the storm, currents were predominantly to the west, with only an occasional weak, short eastward event.

To visually portray the current regime at the Big Hill 3.5-mile site, onshore-offshore (U) and longshore (V) components of the near-bottom currents for exemplary periods are presented. Figures F-1 and F-2 show the "typical" and "storm front passage" current conditions at the site (January 21, 1978, to January 22, 1978), and Figs. F-3 and F-4 show the "sustained upcoast" (easterly) and "sustained low energy" current conditions (June 29, 1978, to July 14, 1978).

<u>Hydrography and Water Quality</u>

Mean temperatures for the five offshore Texoma sites are shown for the 13-month study period (September 1977 to October 1978) in Table F-4 and Fig. F-5. Highest mean values for temperature for the near-surface samples at Big Hill were found in July (30 to 31°C) and for the near-bottom samples in August (29.3 to 29.6°C). Lowest means (7 to 8°C) occurred for near-surface and near-bottom samples during the early February cruise. These temperatures were some of the lowest on record for the northwest Gulf and reflect the fact that they were collected during one of the coldest periods of the year in shallow water. Rapid warming occurred during the spring, which is consistent with other studies.

Except for July and August 1978, when temperatures were highest and little or no difference was seen in salinity of the near-surface and near-bottom waters, the near-bottom waters were consistently more saline (Table F-5 and Fig. F-6). The largest vertical differences in salinity occurred irregularly throughout the year, with December, April, and June showing especially large differences due largely to greatly reduced near-surface salinity (19.8 and 21.0 ppt during April and June 1978, respectively). This seasonal pattern of lowest salinities in the spring and highest salinities in the summer is consistent with previously reported findings (Murray, 1976).

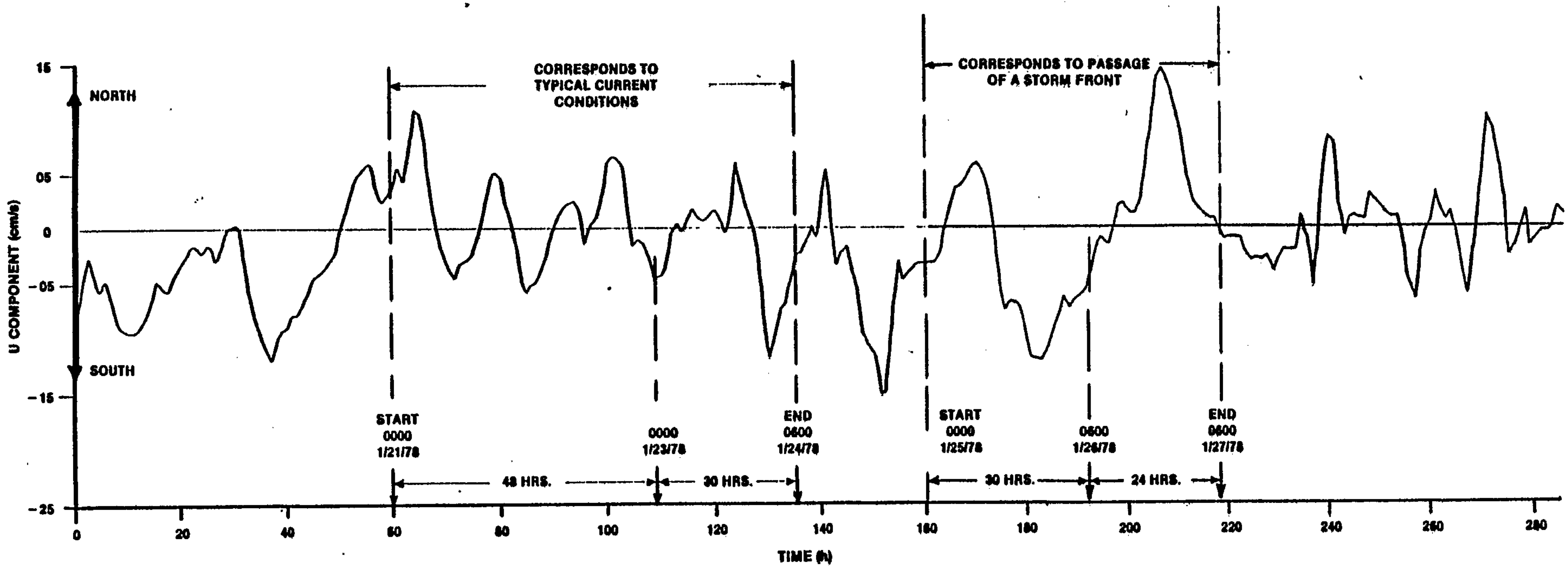


Figure F-1. Time series of observed offshore current component, U, from BHS current meter for typical and storm from passage conditions.

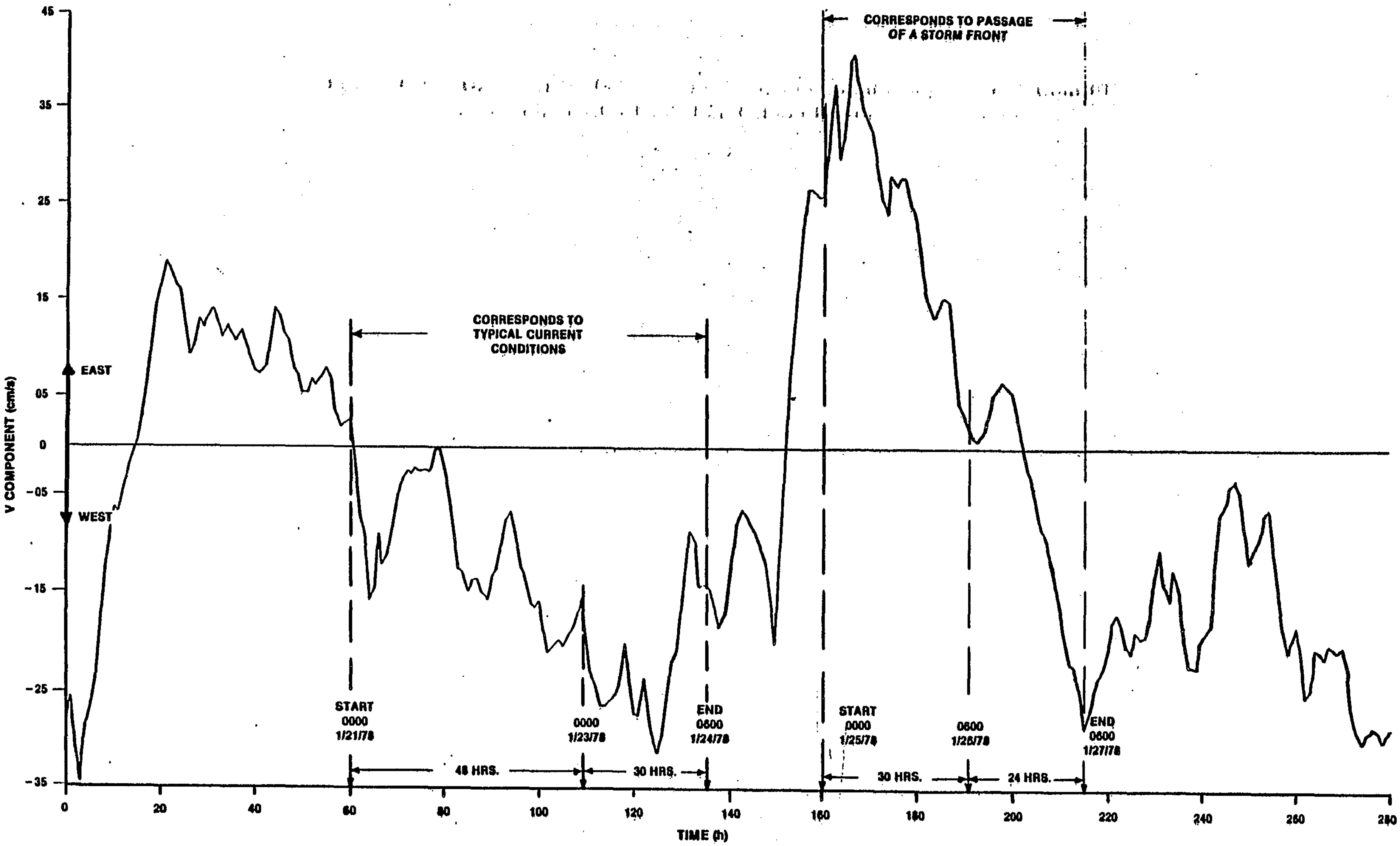


Figure F-2. Time series of observed longshore current component, V, from BHS current meter for typical and storm front passage conditions.

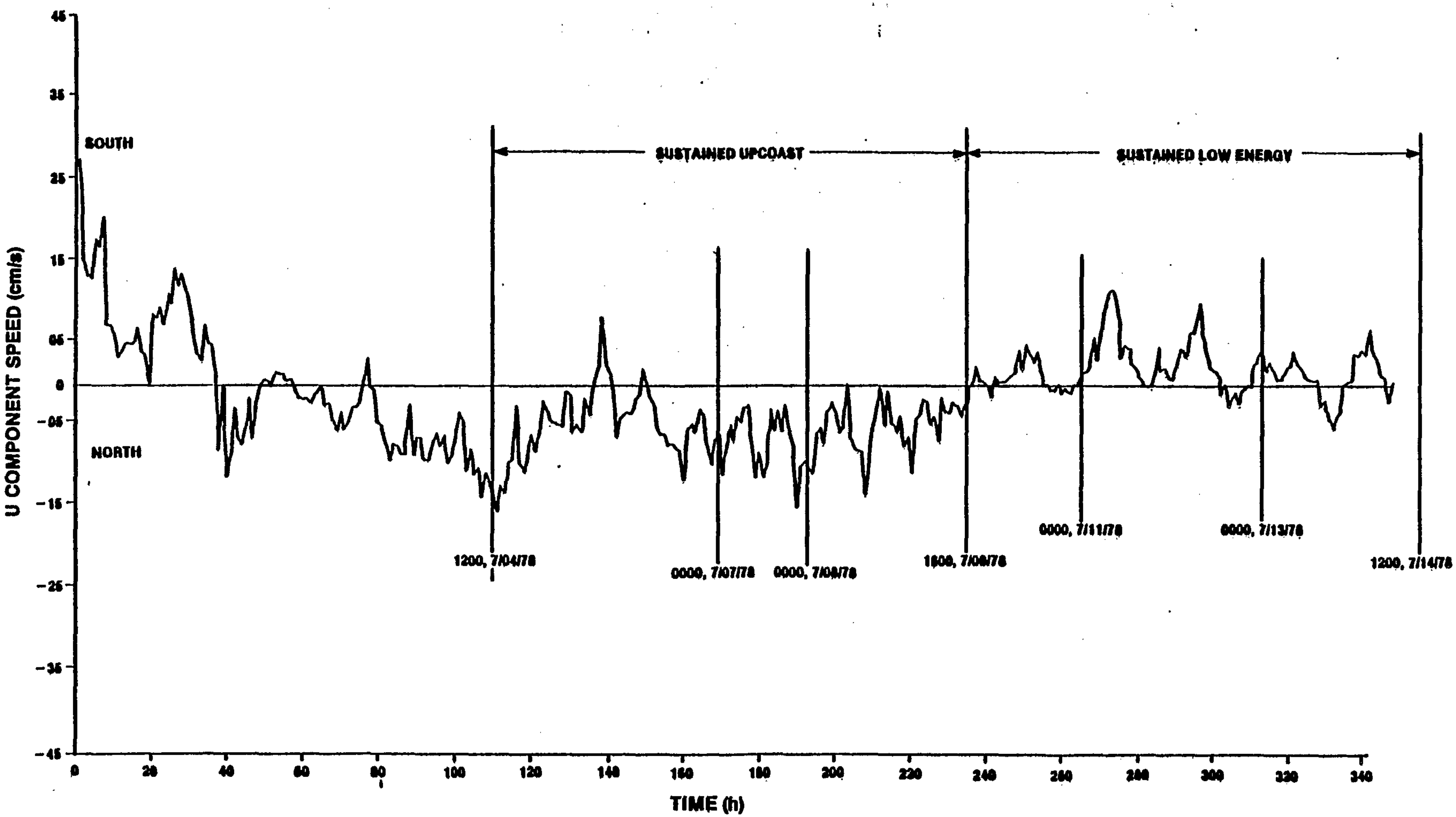


Figure F-3. Time series of observed offshore current component, U, from BHS current meter for sustained upcoast and sustained low energy current conditions.

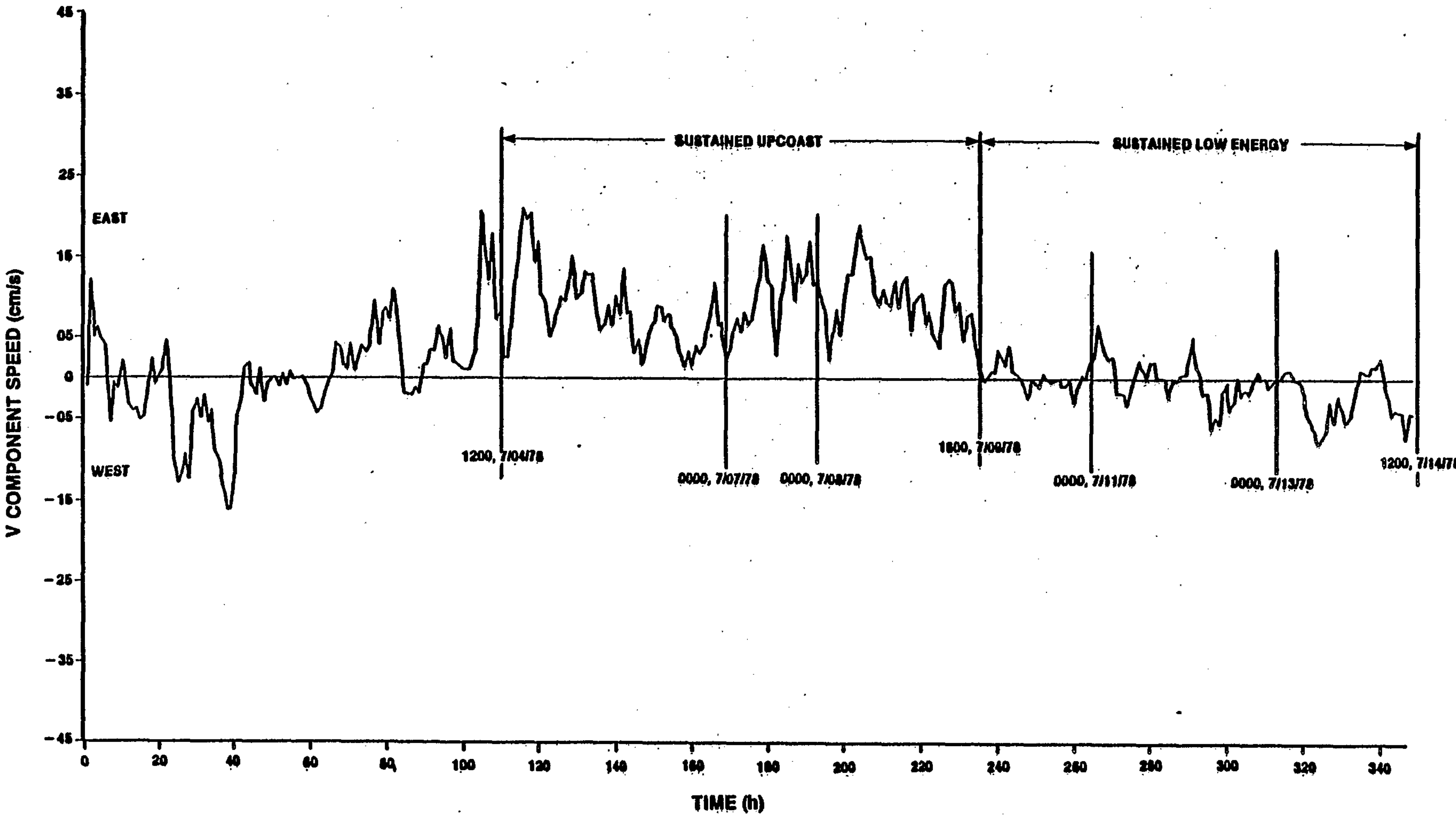
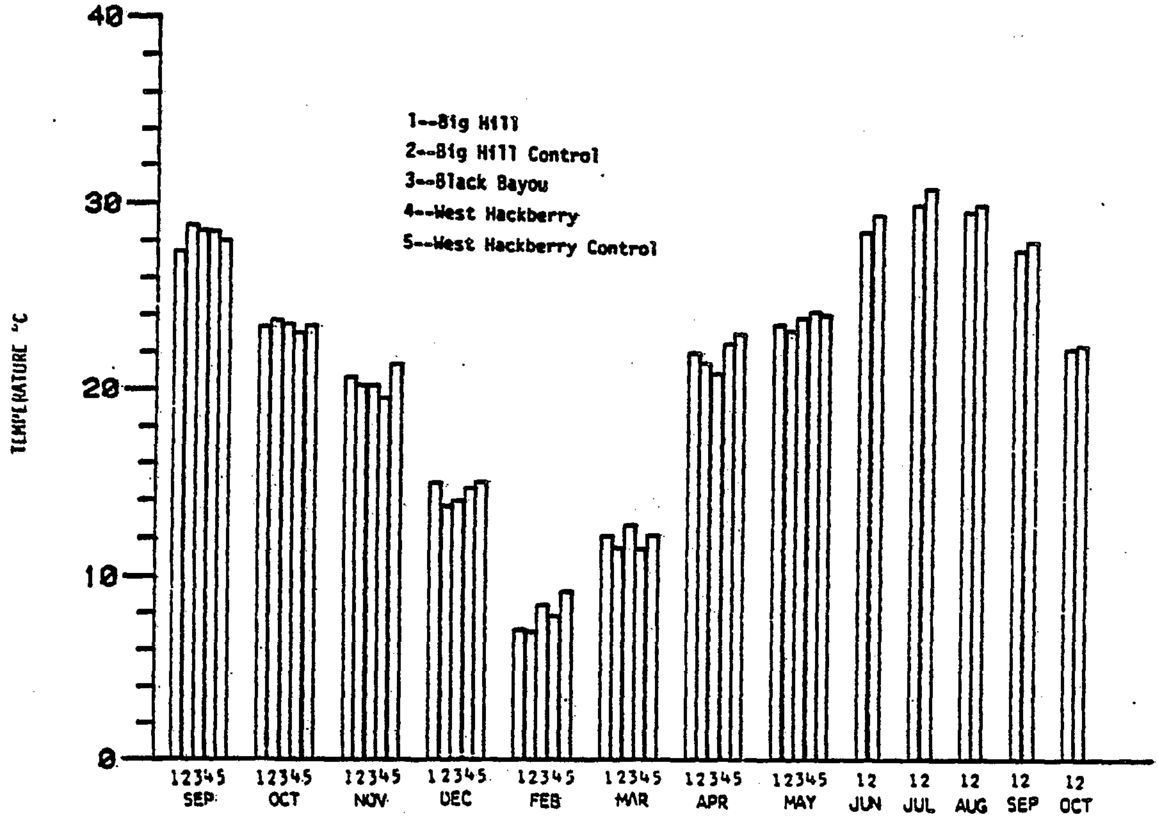


Figure F-4. Time series of observed offshore current component, V, from BHS current meter for sustained upcoast and sustained low energy current conditions.

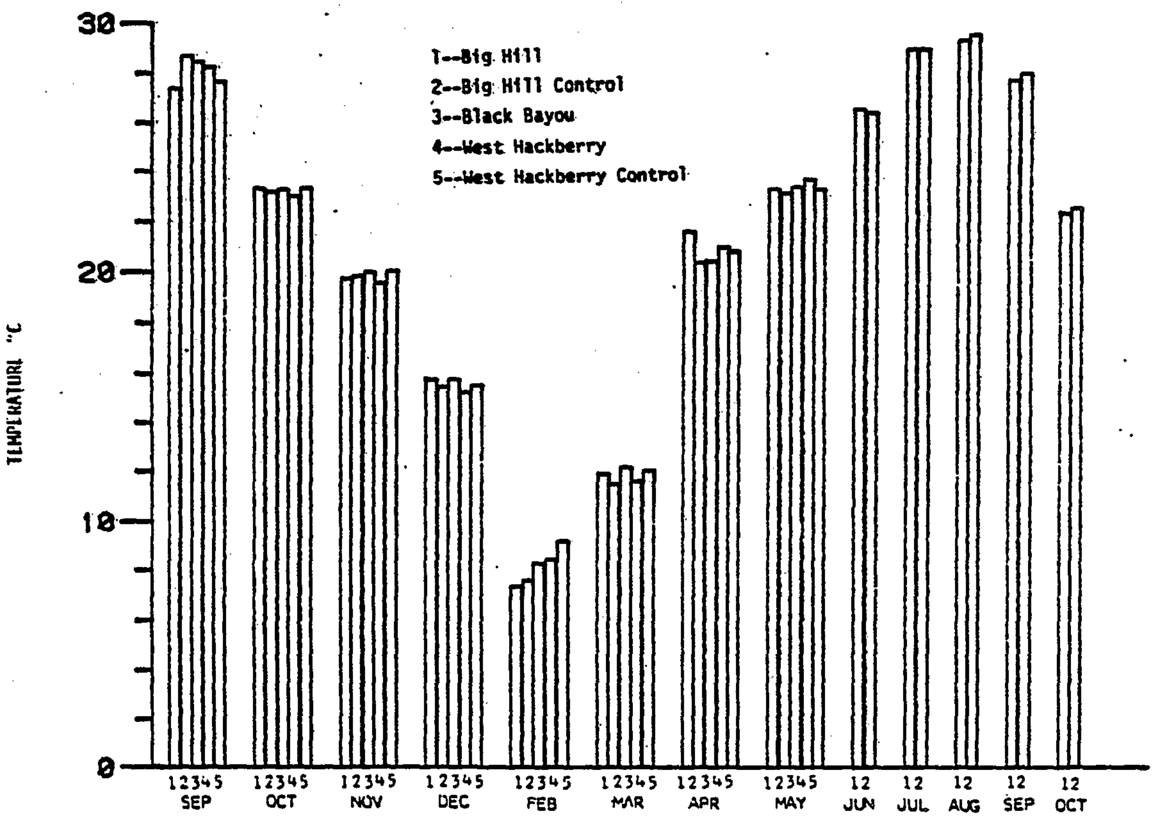
Table F-4. Mean values (± 1 standard error) for temperature (°C) by depth, site, and cruise in the Texoma study area (September 1977 - October 1978)

	Big Hill		Big Hill Control		Big Hill Cluster		Black Bayou		West Hackberry		West Hackberry Control		West Hackberry Cluster		Overall	
Month	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
SEP	27.30	27.30	28.90	28.90	27.92	27.85	28.60	28.45	28.53	28.20	28.05	27.65	28.38	28.06	28.24	28.00
SE	±0.11	±0.13	±0.10	±0.12	±0.21	±0.19	±0.06	±0.09	±0.10	±0.08	±0.08	±0.07	±0.07	±0.07	±0.08	±0.08
N	9	9	5	5	14	14	5	5	16	16	10	10	31	31	45	45
OCT	23.36	23.33	23.70	23.16	23.50	23.26	23.50	23.28	23.00	22.98	23.42	23.30	23.22	23.14	23.31	23.17
SE	±0.04	±0.05	±0.07	±0.13	±0.05	±0.06	±0.07	±0.06	±0.00	±0.01	±0.05	±0.07	±0.04	±0.03	±0.04	±0.05
N	9	9	6	6	15	15	7	7	17	17	10	10	34	34	49	49
NOV	20.60	19.71	20.20	19.80	20.43	19.75	20.15	19.99	19.50	19.54	21.37	20.05	20.13	19.77	20.23	19.76
SE	±0.18	±0.08	±0.12	±0.12	±0.13	±0.06	±0.10	±0.01	±0.00	±0.06	±0.17	±0.06	±0.17	±0.06	±0.12	±0.04
N	7	7	5	5	12	12	5	5	12	12	6	6	23	23	35	35
DEC	14.95	15.75	23.33	15.45	14.42	15.62	14.00	15.75	14.70	15.22	15.02	25.34	14.63	15.41	14.56	15.40
SE	±0.14	±0.05	±0.30	±0.12	±0.21	±0.07	±0.11	±0.07	±0.10	±0.07	±0.69	±0.15	±0.19	±0.07	±0.18	±0.05
N	7	7	5	5	12	12	5	5	12	12	6	6	23	23	35	35
JAN/FEB	7.10	7.32	7.00	7.55	7.06	7.41	8.50	8.25	7.85	8.41	9.18	9.18	8.45	8.70	7.69	8.00
SE	±0.09	±0.08	±0.00	±0.05	±0.06	±0.06			±0.15	±0.16	±0.06	±0.06	±0.22	±0.15	±0.18	±0.15
N	7	7	5	5	12	12	1	1	5	5	4	4	10	10	22	22
MAR	12.11	11.91	11.50	11.50	11.89	11.76	12.75	12.15	11.41	11.55	12.20	11.97	11.86	11.78	11.87	11.77
SE	±0.17	±0.14	±0.00	±0.00	±0.13	±0.10	±0.15	±0.12	±0.09	±0.06	±0.05	±0.02	±0.10	±0.05	±0.08	±0.05
N	9	9	5	5	14	14	5	5	17	17	10	10	32	32	46	46
APR	21.95	21.67	21.40	20.35	21.72	21.06	20.90	20.40	22.43	20.91	23.00	20.75	22.25	20.76	22.06	20.86
SE	±0.06	±0.15	±0.06	±0.16	±0.09	±0.21	±0.06	±0.10	±0.05	±0.11	±0.06	±0.06	±0.16	±0.07	±0.11	±0.08
N	7	7	5	5	12	12	5	5	12	12	6	6	23	23	35	35
MAY	23.50	23.25	23.15	23.10	23.35	23.18	23.85	23.35	24.14	23.66	24.00	23.25	24.04	23.48	23.80	23.38
SE	±0.09	±0.05	±0.06	±0.06	±0.07	±0.04	±0.12	±0.06	±0.05	±0.13	±0.09	±0.00	±0.05	±0.07	±0.07	±0.05
N	7	7	5	5	12	12	5	5	12	12	6	6	23	23	35	35
OVERALL	19.07	18.98	18.81	18.81	18.97	18.91	20.37	20.30	19.90	19.73	20.23	19.71	20.09	19.83	19.71	19.52
SE	±0.82	±0.80	±1.07	±1.00	±0.65	±0.62	±0.88	±0.85	±0.61	±0.58	±0.80	±0.77	±0.42	±0.40	±0.35	±0.34
N	62	62	41	41	103	103	38	38	103	103	58	58	199	199	302	302
JUN	28.55	26.52	29.45	26.35	28.87	26.46									28.72	26.50
SE	±0.26	±0.09	±0.12	±0.35	±0.20	±0.13	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		±0.16	±0.10
N	9	9	5	5	14	14									19	19
JUL	29.97	28.97	30.85	28.95	30.28	28.96									30.28	28.96
SE	±0.22	±0.05	±0.06	±0.05	±0.18	±0.03	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		±0.18	±0.03
N	9	9	5	5	14	14									14	14
AUG	29.66	29.33	29.95	29.55	29.76	29.41									29.76	29.41
SE	±0.10	±0.12	±0.05	±0.14	±0.07	±0.09	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		±0.07	±0.09
N	9	9	5	5	14	14									14	14
SEP	27.52	27.72	28.00	27.95	27.69	27.80									27.69	27.80
SE	±0.05	±0.13	±0.07	±0.26	±0.07	±0.12	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		±0.07	±0.12
N	9	9	5	5	14	14									14	14
OCT	22.22	22.27	22.40	22.50	22.28	22.35									22.28	22.35
SE	±0.08	±0.08	±0.18	±0.00	±0.08	±0.06	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		±0.08	±0.06
N	9	9	5	5	14	14									14	14
OVERALL	22.65	22.34	22.34	21.93	22.53	22.18									21.32	21.00
SE	±0.65	±0.62	±0.89	±0.82	±0.52	±0.49	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		±0.33	±0.32
N	107	107	66	66	173	173									377	377

Source: Comiskey et al. (1979).



(a)

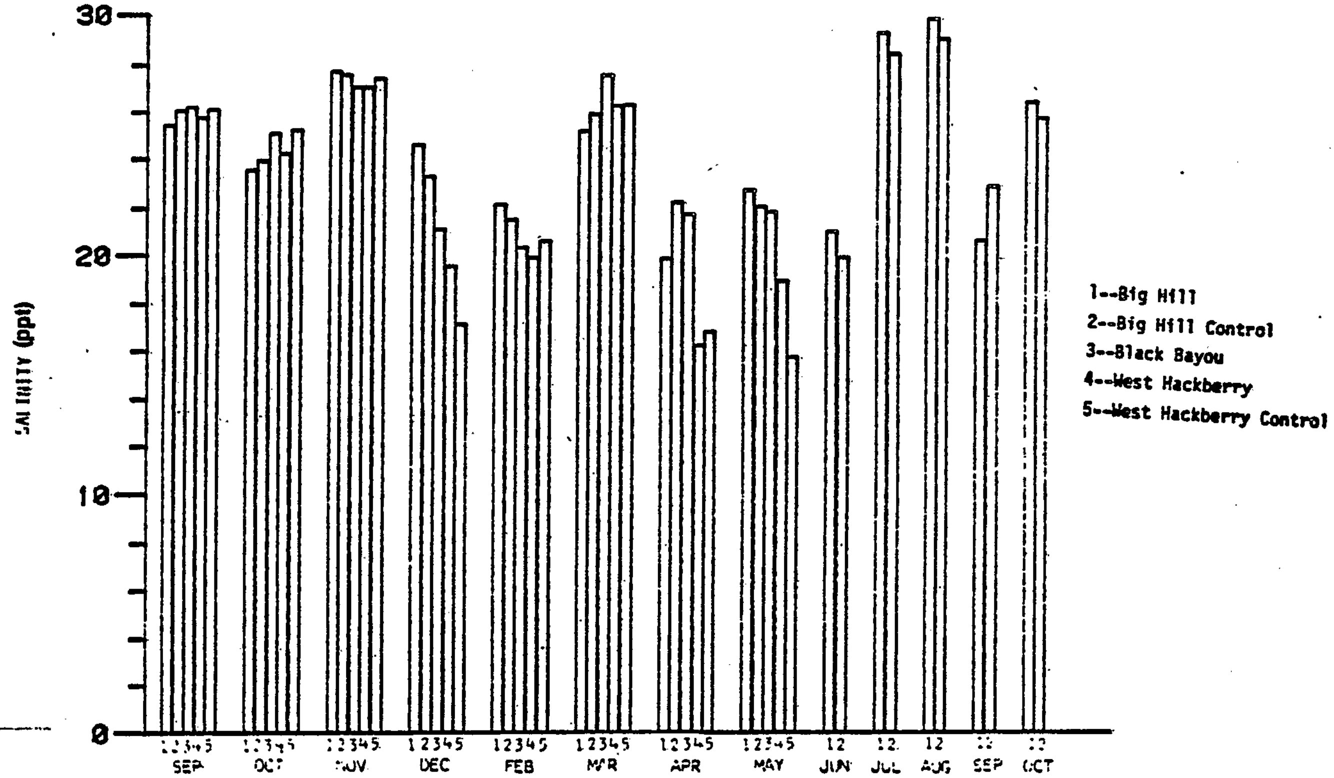


(b)

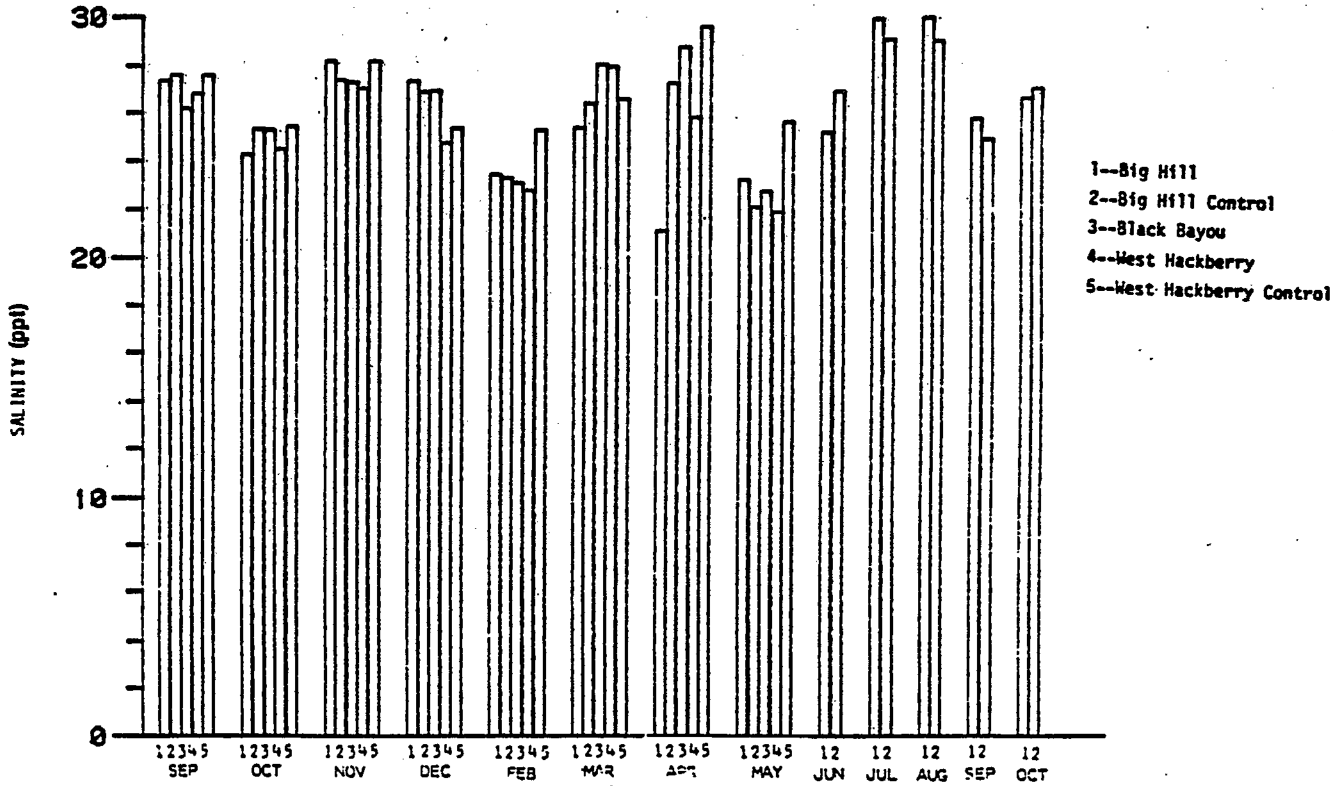
Figure F-5. Plot of mean temperature (°C) for the period September 1977 to October 1978 in the Texoma study area: (a) near-surface, (b) near-bottom.

Table F-5. Mean values (± 1 standard error) for salinity (ppt) by depth, site, and cruise in the Texoma study area

	Big Hill		Big Hill Control		Big Hill Cluster		Black Bayou		West Hackberry		West Hackberry Control		West Hackberry Cluster		Overall	
Month	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
SEP	25.40	27.30	26.00	27.50	25.69	27.45	26.22	26.21	25.70	26.03	26.12	27.62	25.96	26.99	25.00	27.13
SE	±0.20	±0.70	±0.34	±0.42	±0.22	±0.46	±0.19	±0.12	±0.26	±0.34	±0.31	±0.06	±0.17	±0.19	±0.13	±0.19
N	9	9	5	5	14	14	5	5	16	16	10	10	31	31	45	45
OCT	23.55	24.33	23.92	23.34	23.70	24.73	25.11	25.31	24.27	24.49	25.23	25.44	24.72	24.94	24.41	24.83
SE	±0.30	±0.29	±0.33	±0.19	±0.22	±0.23	±0.22	±0.16	±0.14	±0.13	±0.23	±0.26	±0.13	±0.13	±0.13	±0.11
N	9	9	6	6	15	15	7	7	17	17	10	10	34	34	49	49
NOV	27.76	28.16	27.59	27.37	27.69	27.83	27.00	27.30	27.06	27.83	27.42	28.19	27.16	27.39	27.34	27.54
SE	±0.29	±0.18	±0.72	±0.46	±0.32	±0.24	±0.29	±0.60	±0.16	±0.18	±0.12	±0.32	±0.11	±0.14	±0.13	±0.12
N	7	7	5	5	12	12	5	5	12	12	6	6	23	23	35	35
DEC	24.61	27.35	9.63	28.86	24.07	27.14	21.10	26.94	19.49	24.75	17.00	8.16	19.21	25.38	20.88	25.98
SE	±0.15	±0.09	±0.12	±0.17	±0.23	±0.11	±0.40	±0.16	±0.28	±0.31	±0.24	±0.65	±0.35	±0.24	±0.46	±0.22
N	7	7	5	5	12	12	5	5	12	12	6	6	23	23	35	35
JAN/FEB	22.10	23.45	21.51	23.26	21.85	23.37	20.27	23.06	19.86	22.71	20.53	25.25	20.17	23.79	21.00	23.56
SE	±0.23	±0.32	±0.26	±0.14	±0.18	±0.19			±0.75	±0.40	±0.00	±0.39	±0.37	±0.46	±0.26	±0.23
N	7	7	5	5	12	12	1	1	5	5	4	4	10	10	22	22
MAR	25.20	25.36	25.94	26.36	25.46	25.72	27.50	28.01	26.29	27.91	26.37	26.58	26.51	27.51	26.19	26.96
SE	±0.26	±0.22	±0.32	±0.14	±0.21	±0.20	±0.20	±0.11	±0.13	±0.33	±0.09	±0.24	±0.12	±0.23	±0.12	±0.20
N	9	9	5	5	14	14	5	5	17	17	10	10	32	32	46	46
APR	15.00	21.01	22.21	27.23	20.80	23.60	21.72	20.73	16.10	25.76	26.74	29.57	17.53	27.40	18.65	26.10
SE	±0.14	±0.52	±0.35	±0.00	±0.39	±1.02	±0.25	±0.25	±0.05	±0.64	±0.41	±0.15	±0.40	±0.49	±0.43	±0.56
N	7	7	5	5	12	12	5	5	12	12	6	6	23	23	35	35
MAY	27.75	23.15	22.00	22.00	22.43	22.67	21.70	22.70	18.09	21.79	15.69	25.57	18.69	22.97	19.97	22.87
SE	±0.16	±0.06	±0.26	±0.26	±0.17	±0.20	±0.13	±0.22	±0.96	±0.90	±0.86	±0.19	±0.70	±0.57	±0.55	±0.30
N	7	7	5	5	12	12	5	5	12	12	6	6	23	23	35	35
OVERALL	23.99	25.09	24.07	25.74	24.02	25.35	24.30	26.30	22.82	25.49	22.77	26.71	21.09	26.00	23.41	25.78
SE	±0.29	±0.31	±0.34	±0.32	±0.22	±0.23	±0.42	±0.31	±0.39	±0.24	±0.60	±0.19	±0.28	±0.15	±0.35	±0.13
N	62	62	41	41	103	103	30	30	103	103	58	58	199	199	302	302
JUN	20.98	25.16	19.89	26.85	20.59	25.76									19.91	26.19
SE	±0.23	±0.10	±0.28	±1.05	±0.22	±0.43	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		±0.31	±0.37
N	9	9	5	5	14	14									19	19
JUL	29.97	29.80	28.45	29.05	28.90	29.50									28.90	29.50
SE	±0.30	±0.20	±0.25	±0.39	±0.27	±0.21	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		±0.27	±0.21
N	9	9	5	5	14	14									14	14
AUG	29.86	29.97	29.00	29.00	29.55	29.62									29.55	29.62
SE	±0.14	±0.16	±0.22	±0.22	±0.16	±0.10	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		±0.16	±0.10
N	9	9	5	5	14	14									14	14
SEP	20.62	25.72	22.93	24.07	21.44	25.41									21.44	25.41
SE	±0.19	±0.30	±0.16	±0.71	±0.33	±0.35	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		±0.33	±0.35
N	9	9	5	5	14	14									14	14
OCT	26.44	26.63	25.75	27.00	26.19	26.76									26.19	26.76
SE	±0.15	±0.11	±0.22	±0.20	±0.15	±0.12	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		±0.15	±0.12
N	9	9	5	5	14	14									14	14
OVERALL	24.59	26.09	24.50	26.35	24.56	26.19									23.70	26.11
SE	±0.31	±0.25	±0.34	±0.27	±0.23	±0.18	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		±0.19	±0.11
N	107	107	66	66	173	173									377	377



(a)



(b)

Figure F-6. Plot of mean salinity (ppt) for the period September 1977 to October 1978 in the Texoma study area: (a) near-surface, (b) near-bottom.

It should be noted that vertical (near-surface to near-bottom) differences in mean monthly salinity were greater at the West Hackberry site than at the Big Hill site. For example, in April 1978, means for the near-surface and near-bottom samples at Big Hill were 19.8 and 21.0 ppt, respectively, compared with values of 16.2 and 25.8 ppt for West Hackberry. This difference is caused by the closer proximity of the West Hackberry site to Calcasieu Pass compared with the distance that the Big Hill site is downcoast of Sabine Pass.

Unlike the West Hackberry site (and also the BHC site), which exhibited obvious onshore-offshore salinity gradients, the Big Hill site appeared to be much more homogeneous hydrologically. This spatial homogeneity is also a result of the relatively greater distance of Big Hill from a local source of estuarine water. During several months, near-surface and/or near-bottom samples showed onshore-offshore gradients, with salinity usually increasing offshore. Longshore gradients in salinity were particularly lacking. Plots for representative months are shown in Figs. F-7 to F-9.

As can be seen in Figs. F-10 and F-11, a clear negative relationship existed between volume of river discharge (either local or regional) and salinity at the Texoma study sites. Therefore, large vertical differences in salinity occurred irregularly throughout the year, generally coinciding with pulses of freshwater input. There appears to be a significant time lag (up to 1 month) in the response of salinity in the study area to regional freshwater discharge.

The importance of the Mississippi and Atchafalaya River discharges to the seasonality of the salinities in the near-shore Gulf cannot be overstated. Figure F-11 (Gagliano et al., 1970) shows the relationship between the major river discharge and salinity levels at points along a transect perpendicular to the Louisiana coast off Calcasieu Lake. The magnitude of the salinity variation was inversely related to the distance off the coast.

During all months except March, when there was no significant difference in near-surface and near-bottom dissolved oxygen concentrations, means over all stations (cruise means) were higher near the surface (Table F-6, Fig. F-12). In general, dissolved oxygen levels were highest in the coldest months. In April, in conjunction with the greatly increased temperature, increased organic activity, and stratification, dissolved oxygen levels decreased considerably, especially for the near-bottom samples. In June, near-bottom dissolved oxygen levels dropped precipitously to levels lower than 0.5 parts per million (ppm), due again to renewed detrital input, stratification, and rising temperatures. There was gradual recovery in July and August.

Figures F-13 to F-16 and Tables F-7 to F-10 show the trends for important nutrients at the five sites in the Texoma study area. In general, nitrate, silicate, and phosphate showed similar behavior, with highest concentrations in the mid-winter and spring, especially in the near-surface water. Sulfate showed the opposite trend, with highest concentrations in summer and especially in the near-bottom waters.

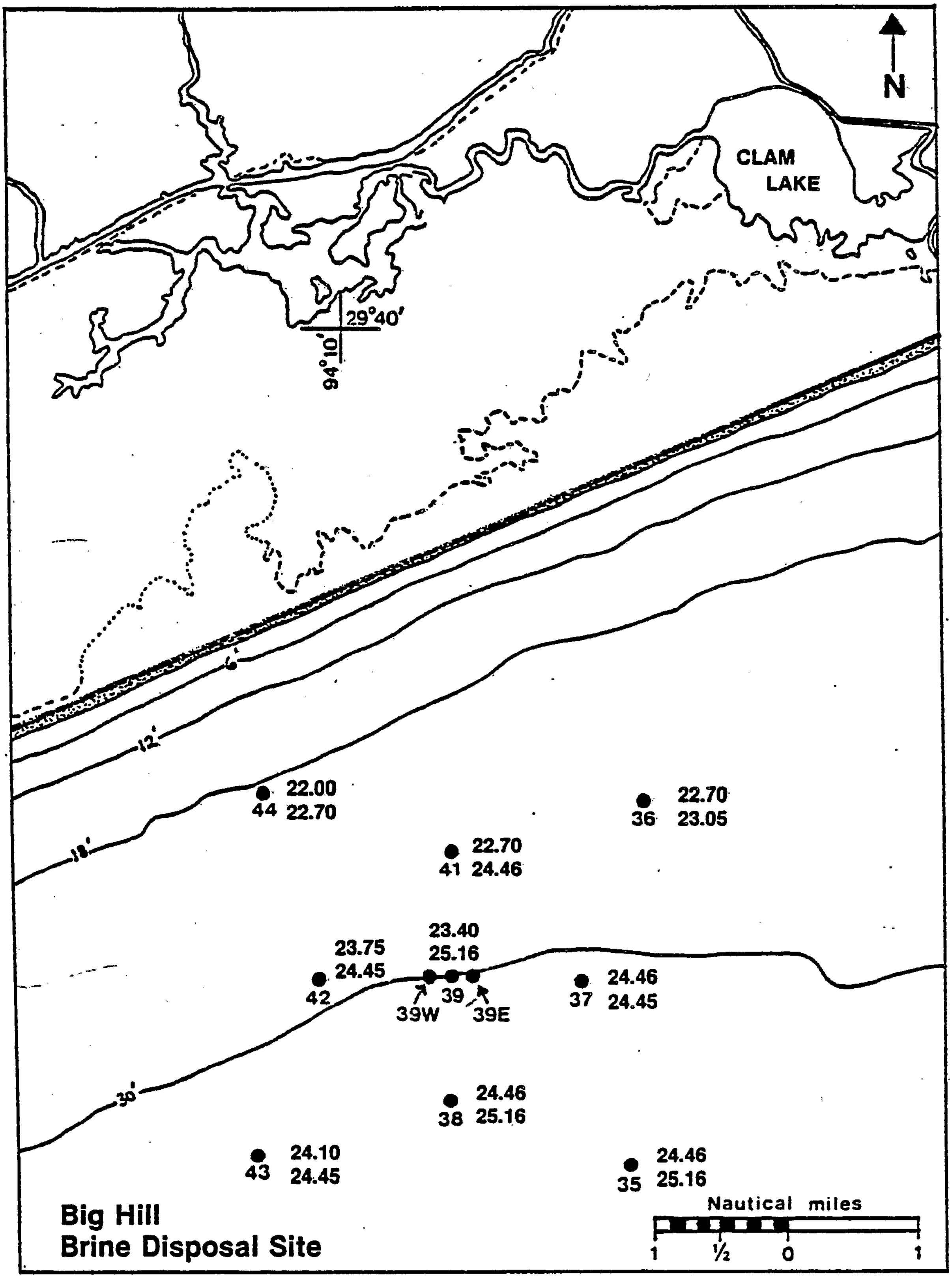


Figure F-7. Surface and bottom salinity plots (ppt) at Big Hill stations for cruise 2 (October 1977).

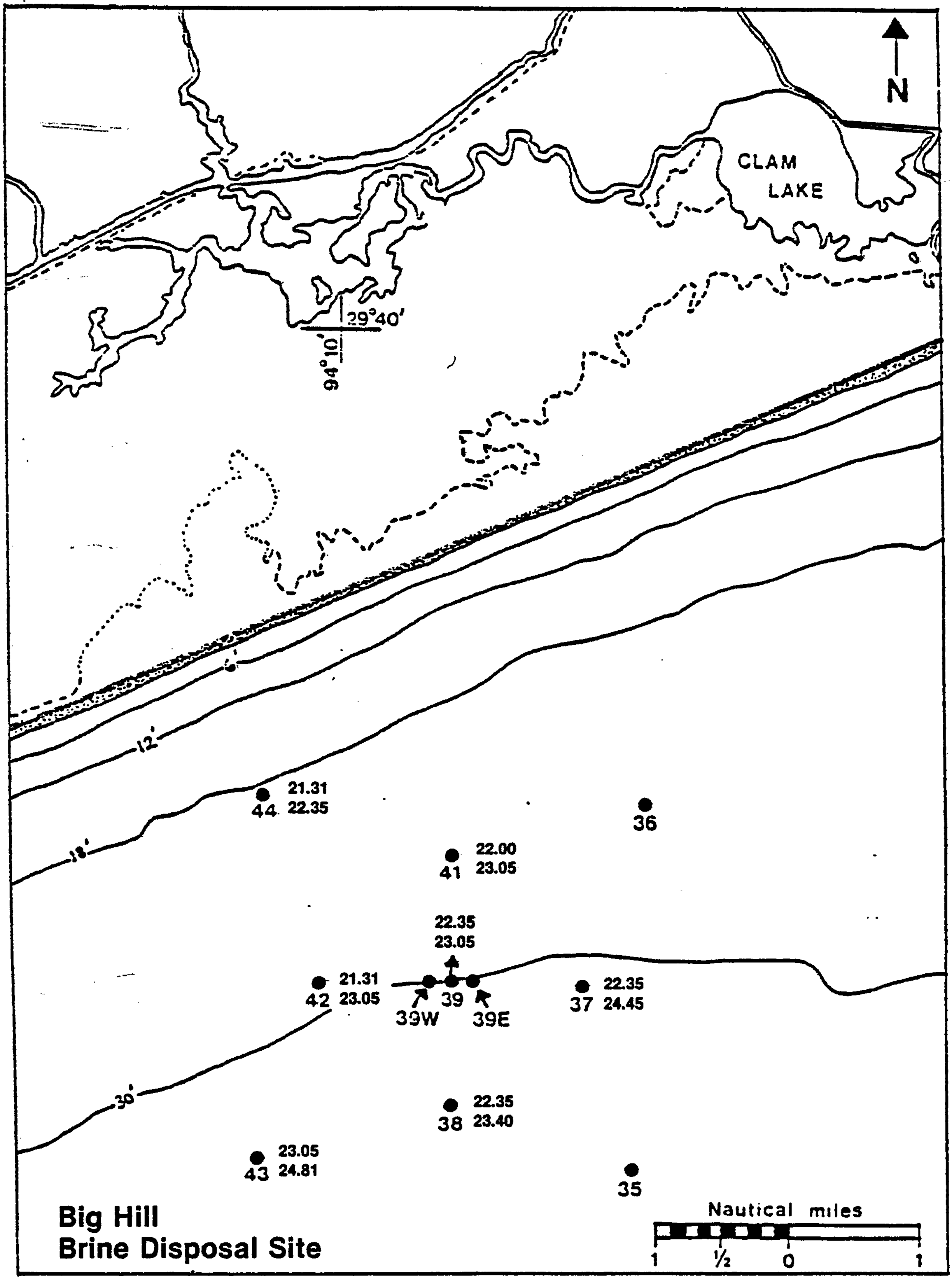


Figure F-8. Surface and bottom salinity plots (ppt) at Big Hill stations for cruise 5 (February 1978).

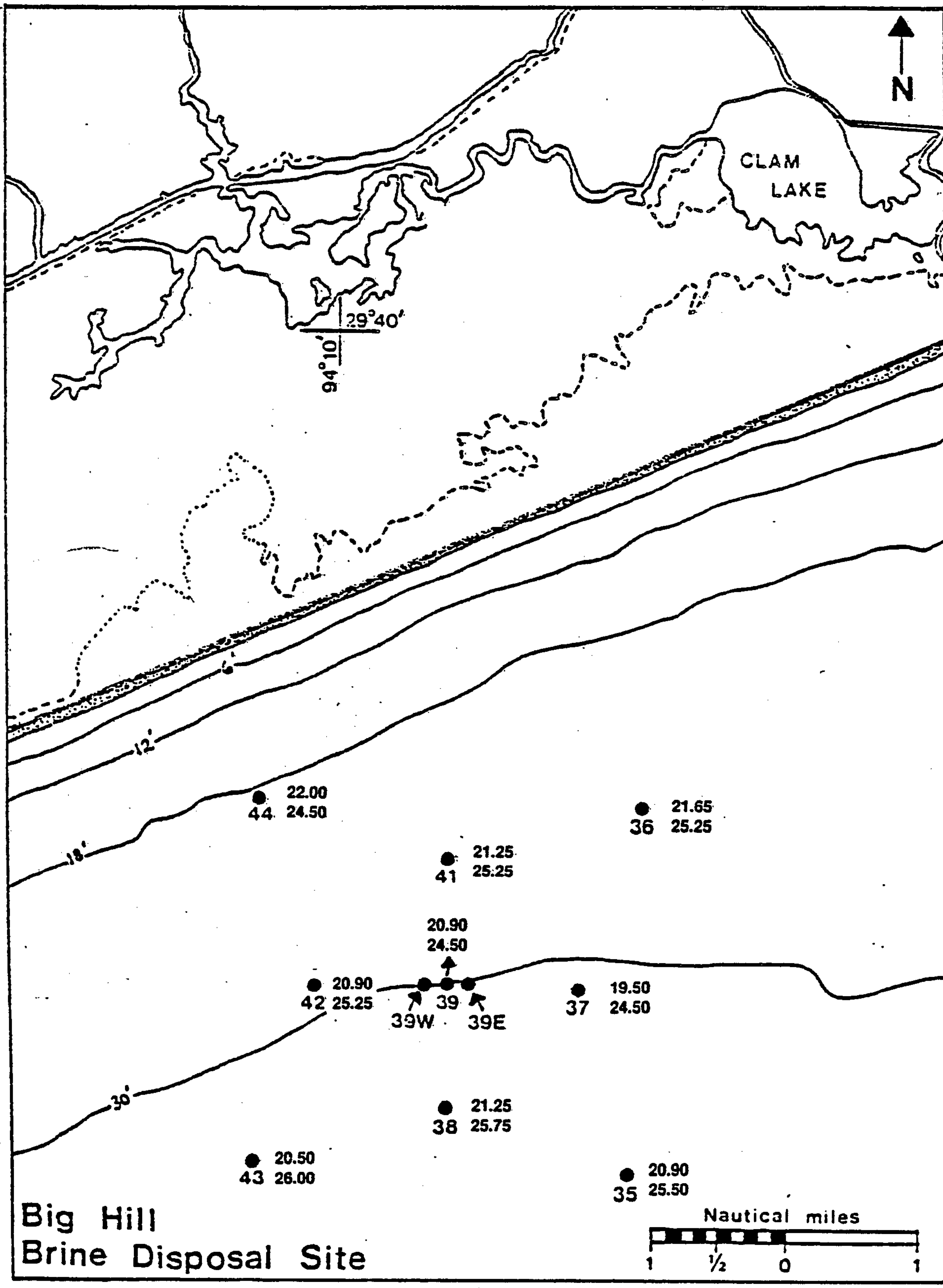


Figure F-9. Surface and bottom salinity plots (ppt) at Big Hill stations for cruise 9 (June 1978).

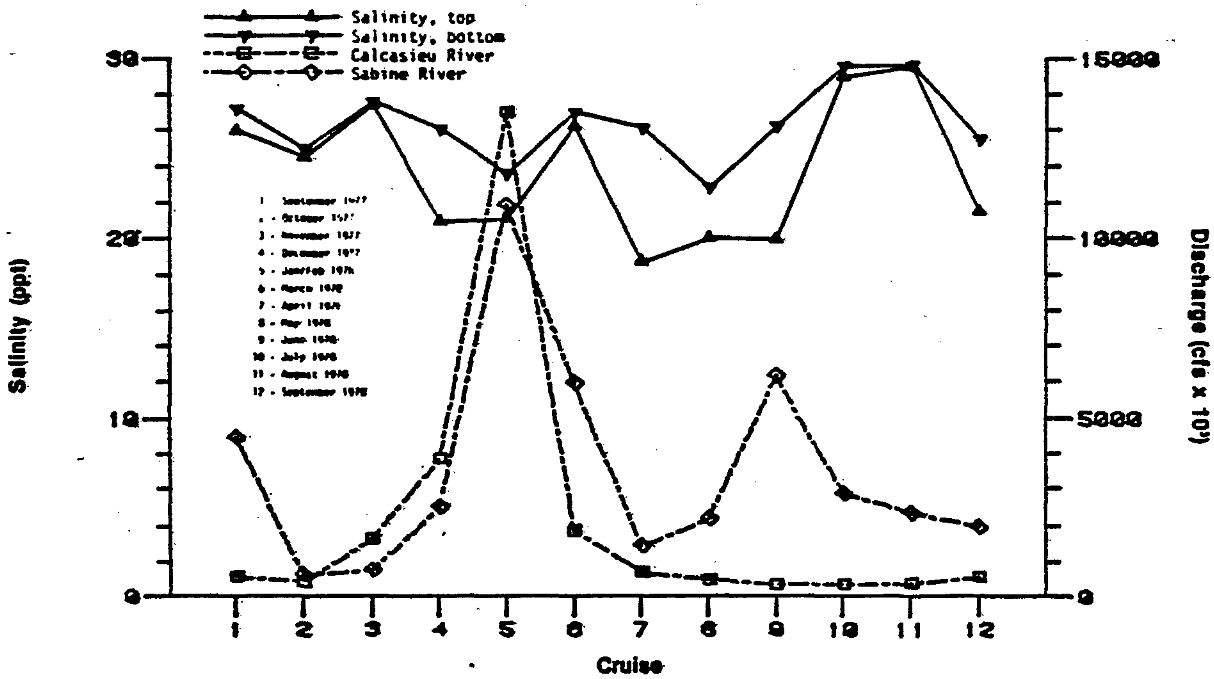


Figure F-10. **Plot of monthly mean values (over all sites) of salinity (ppt) and discharge from the Calcasieu and Sabine Rivers (cfs x 10^3) in the Texoma study region for the period September 1977 to September 1978.**

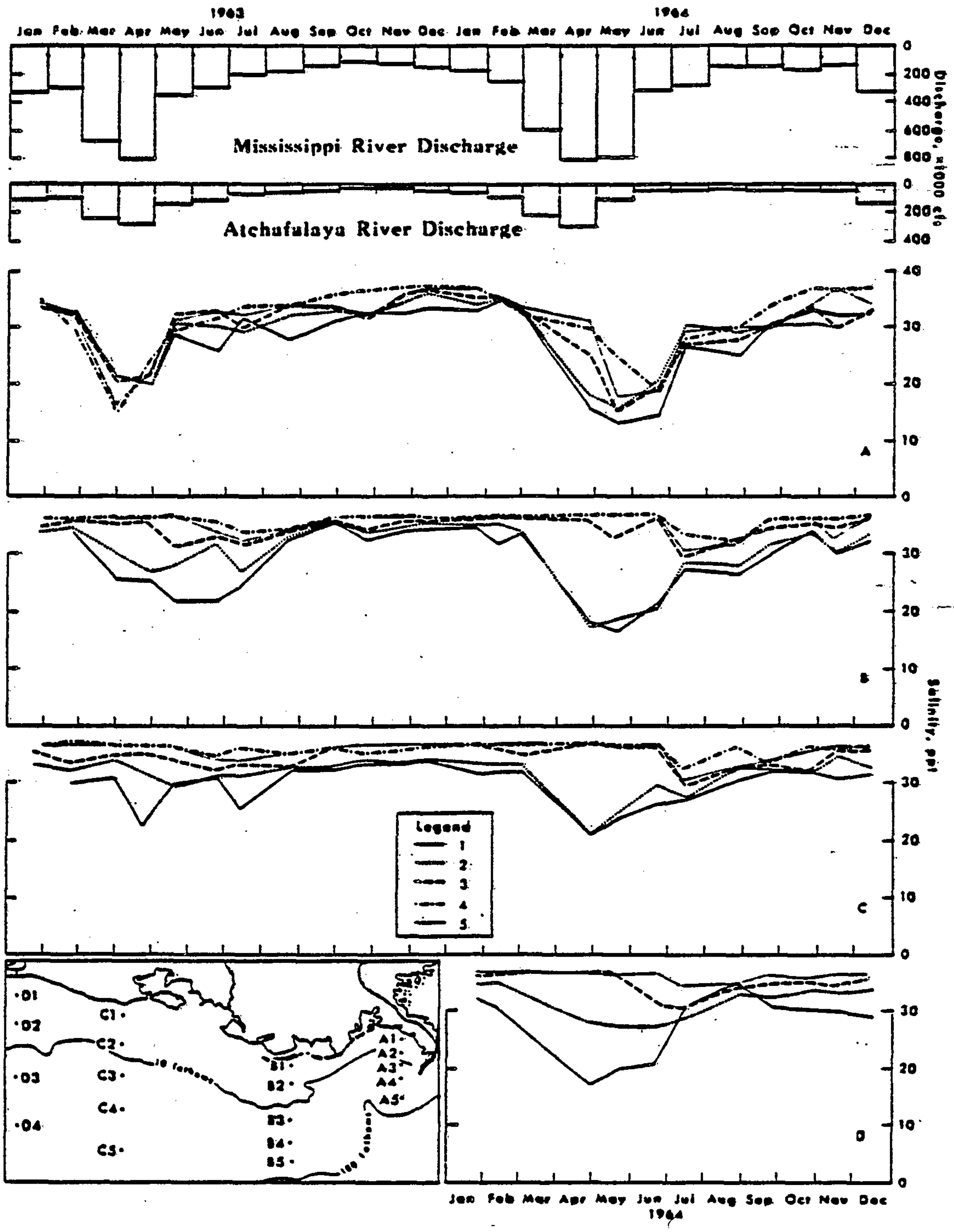
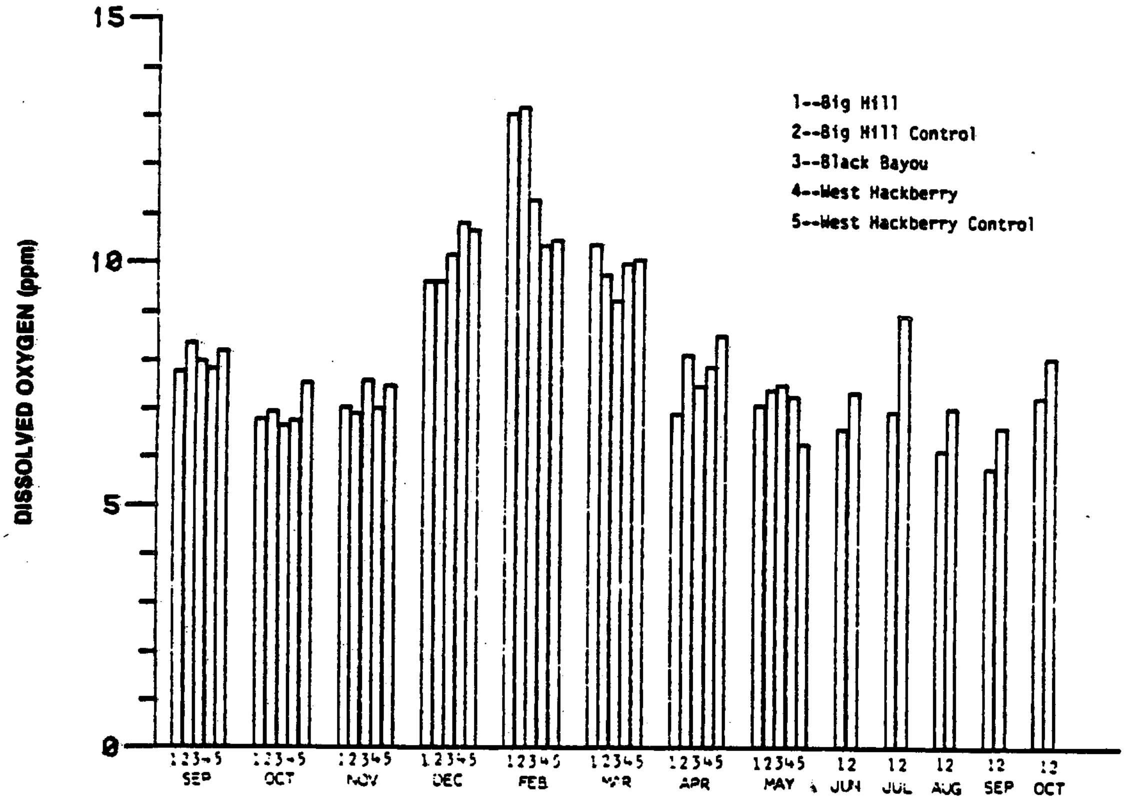


Figure F-11. Discharges of the Mississippi and Atchafalaya Rivers and seasonal salinity fluctuations of the adjacent open Gulf water. Source: Gagliano et al. (1970).

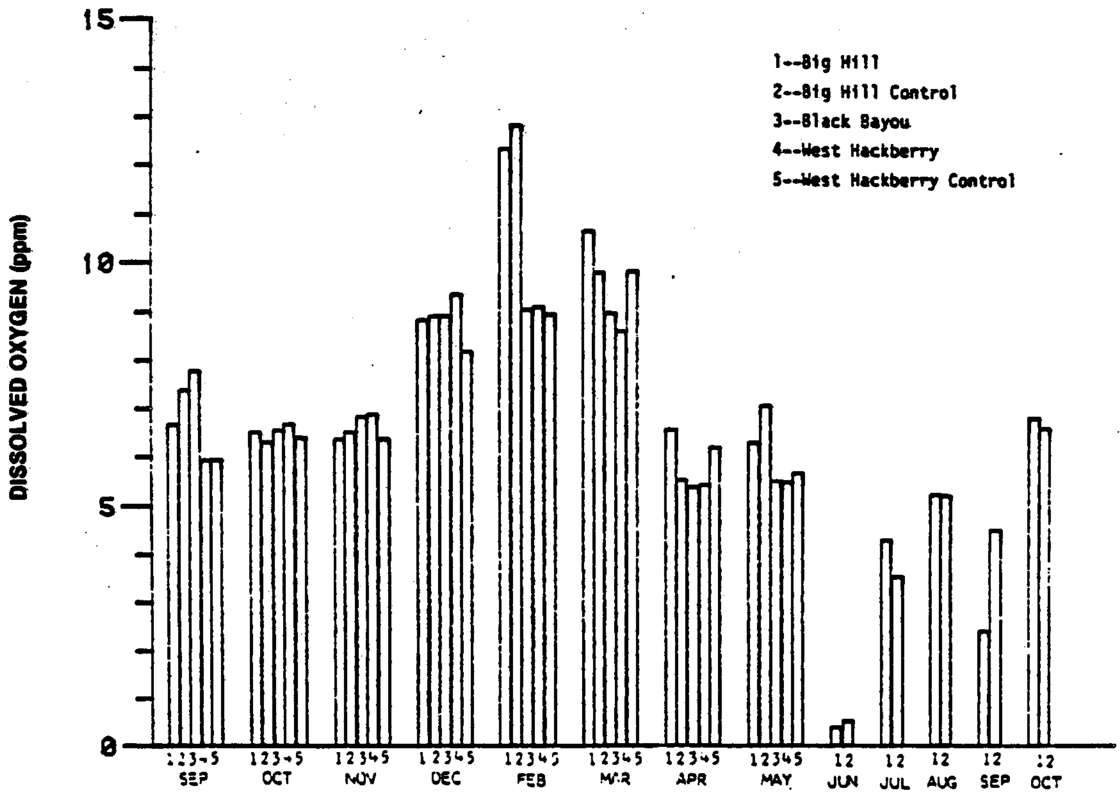
Table F-6. **Mean values (± 1 standard error) for dissolved oxygen (ppm) by depth, site, and cruise for five sites in the Texoma study area (September 1977 to October 1978)**

Month	Big Hill Top	Big Hill Bottom	Big Hill Control Top	Big Hill Control Bottom	Big Hill Cluster Top	Big Hill Cluster Bottom	Black Bayou Top	Black Bayou Bottom	West Hackberry Top	West Hackberry Bottom	West Hackberry Control Top	West Hackberry Control Bottom	West Hackberry Cluster Top	West Hackberry Cluster Bottom	Overall Top	Overall Bottom
SEP	7.76	6.68	8.35	7.39	7.97	6.93	7.97	7.78	7.82	5.95	8.20	5.93	7.96	6.24	7.47	6.45
SE	±0.09	±0.24	±0.08	±0.13	±0.10	±0.18	±0.12	±0.09	±0.11	±0.31	±0.23	±0.25	±0.10	±0.21	±0.07	±0.16
N	9	9	5	5	14	14	5	5	16	16	10	10	31	31	45	45
OCT	6.77	6.53	6.94	6.30	6.83	6.44	6.65	6.54	6.75	6.68	7.53	6.39	6.96	6.57	6.92	6.51
SE	±0.05	±0.05	±0.08	±0.08	±0.05	±0.05	±0.06	±0.06	±0.15	±0.07	±0.08	±0.22	±0.07	±0.07	±0.05	±0.05
N	9	9	6	6	15	15	7	7	17	17	10	10	34	34	49	49
NOV	7.03	6.35	6.91	6.52	6.98	6.42	7.59	6.83	[illegible]	6.87	7.48	6.36	7.26	6.73	7.16	6.62
SE	±0.08	±0.04	±0.30	±0.02	±0.13	±0.03	±0.04	±0.07	[illegible]	±0.04	±0.09	±0.13	±0.06	±0.06	±0.06	±0.05
N	7	7	5	5	12	12	5	5	12	12	6	6	21	21	15	15
DEC	9.63	8.82	13.70	8.90	9.63	8.85	10.17	8.90	10.81	9.34	10.67	15.49	10.64	8.94	10.29	8.91
SE	±0.04	±0.07	±0.20	±0.06	±0.05	±0.05	±0.19	±0.07	±0.07	±0.14	±0.11	±0.15	±0.08	±0.20	±0.10	±0.13
N	7	7	5	5	12	12	5	[illegible]	12	12	6	6	23	23	15	15
JAN/FEB	13.07	12.33	13.19	12.79	13.12	12.52	11.29	9.11	10.36	9.08	10.46	8.92	10.49	9.01	11.92	10.93
SE	±0.08	±0.04	±0.27	±0.03	±0.11	±0.07			±0.27	±0.10	±0.29	±0.00	±0.19	±0.05	±0.10	±0.08
N	7	7	5	5	12	12	1	1	5	5	4	4	10	10	22	22
MAR	10.39	10.61	9.75	9.79	10.16	10.32	9.24	8.55	9.98	8.59	10.07	9.81	9.89	9.01	9.97	9.42
SE	±0.08	±0.08	±0.05	±0.03	±0.10	±0.12	±0.16	±0.10	±0.07	±0.17	±0.03	±0.14	±0.06	±0.14	±0.05	±0.13
N	9	9	5	5	14	14	5	5	17	17	10	10	32	32	46	46
APR	6.91	6.54	8.10	5.53	7.40	6.12	7.48	5.36	7.88	5.41	8.51	6.17	7.96	5.61	7.77	5.78
SE	±0.15	±0.17	±0.15	±0.29	±0.20	±0.21	±0.12	±0.24	±0.10	±0.22	±0.09	±0.10	±0.09	±0.14	±0.10	±0.12
N	7	7	5	5	12	12	5	5	12	12	6	6	23	23	35	35
MAY	7.09	6.28	7.40	7.03	7.22	6.59	7.51	5.50	7.26	5.47	6.77	5.65	7.06	5.52	7.11	5.89
SE	±0.12	±0.10	±0.21	±0.25	±0.11	±0.16	±0.15	±0.16	±0.46	±0.43	±0.59	±0.48	±0.29	±0.25	±0.19	±0.19
N	7	7	5	5	12	12	5	5	12	12	6	6	21	23	35	35
OVERALL (Cruises 1-8)	8.55	8.01	8.74	7.99	8.61	8.00	8.10	7.14	8.12	7.04	8.57	7.16	8.35	7.09	8.44	7.40
SE	±0.26	±0.27	±0.31	±0.35	±0.20	±0.21	±0.20	±0.22	±0.15	±0.16	±0.20	±0.22	±0.10	±0.11	±0.09	±0.10
N	62	62	41	41	103	103	38	38	103	103	58	58	199	199	302	302
JUN	6.58	0.38	7.36	0.52	6.86	0.48	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		7.08	0.48
SE	±0.25	±0.05	±0.10	±0.44	±0.19	±0.15									±0.16	±0.17
N	9	9	5	5	14	14									19	19
JUL	6.96	4.28	8.94	3.53	7.67	4.01	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		7.67	4.01
SE	±0.24	±0.19	±0.23	±0.31	±0.31	±0.18									±0.31	±0.18
N	9	9	5	5	14	14									14	14
AUG	6.15	5.20	7.04	5.19	6.47	5.20	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		6.47	5.20
SE	±0.30	±0.34	±0.77	±0.60	±0.34	±0.29									±0.34	±0.29
N	9	9	5	5	14	14									14	14
SEP	5.79	2.40	6.65	4.49	6.10	3.14	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		6.10	3.14
SE	±0.12	±0.53	±0.18	±0.62	±0.15	±0.48									±0.15	±0.48
N	9	9	5	5	14	14									14	14
OCT	7.27	6.77	8.08	6.57	7.56	6.70	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		7.56	6.70
SE	±0.11	±0.08	±0.23	±0.07	±0.15	±0.06									±0.15	±0.06
N	9	9	5	5	14	14									14	14
OVERALL (Cruises 1-13)	7.71	6.24	8.31	6.50	7.94	6.34	8.10	7.14	8.12	7.04	8.57	7.16	8.35	7.09	8.15	6.66
SE	±0.18	±0.29	±0.22	±0.36	±0.14	±0.23	±0.20	±0.22	±0.15	±0.16	±0.20	±0.22	±0.10	±0.11	±0.08	±0.12
N	107	107	66	66	173	173	38	38	103	103	58	58	199	199	377	377

SE = One Standard Error
N = Number of Samples



(a)



(b)

Figure F-12. Plot of mean dissolved oxygen (ppm) for the period September 1977 to October 1978 in the Texoma study area: (a) near-surface, (b) near-bottom.

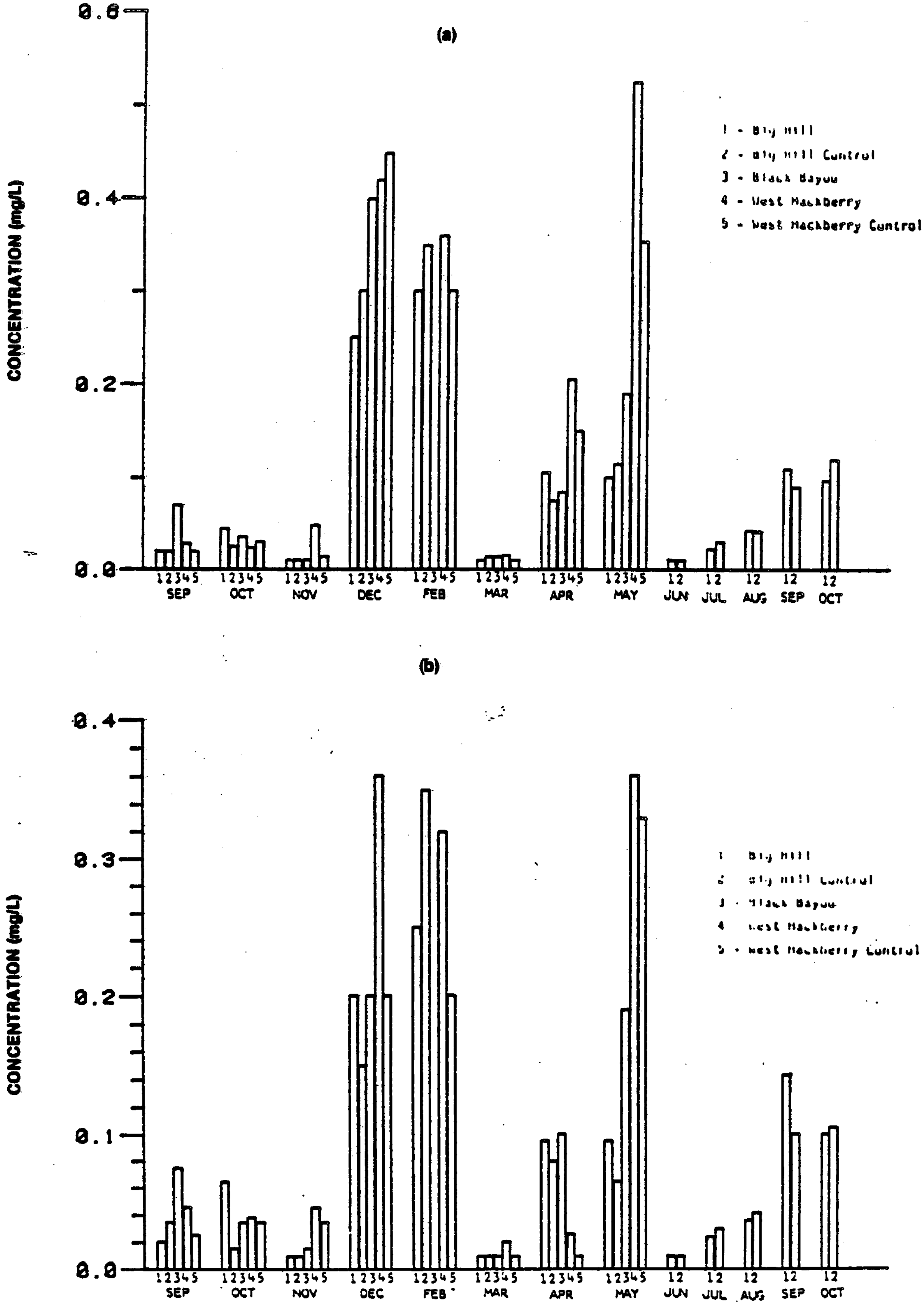


Figure F-13. Mean nitrate-nitrite concentration (mg/L) in the Texoma study area expressed by cruise for the period September 1977 to October 1978: (a) near-surface, (b) near-bottom.

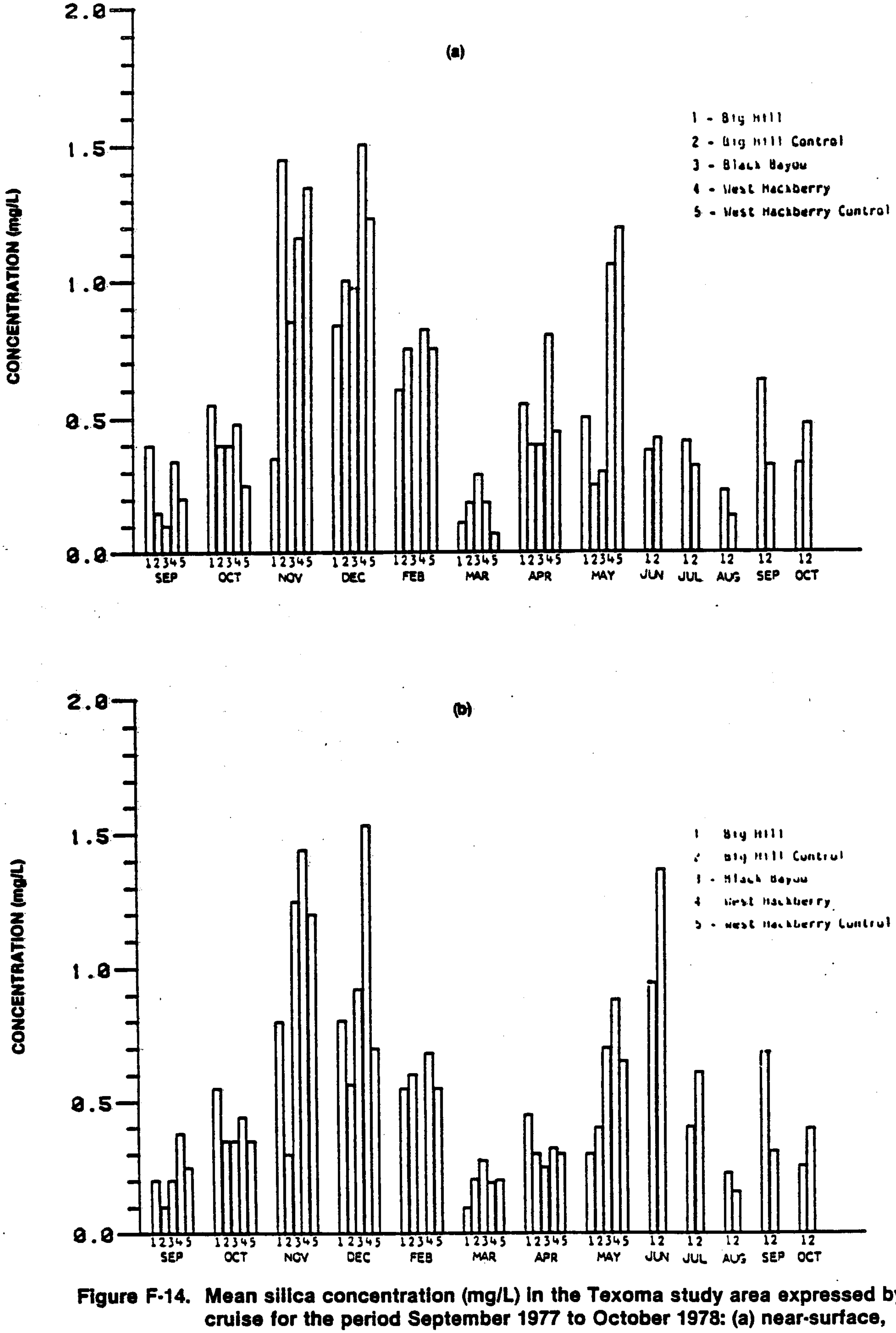
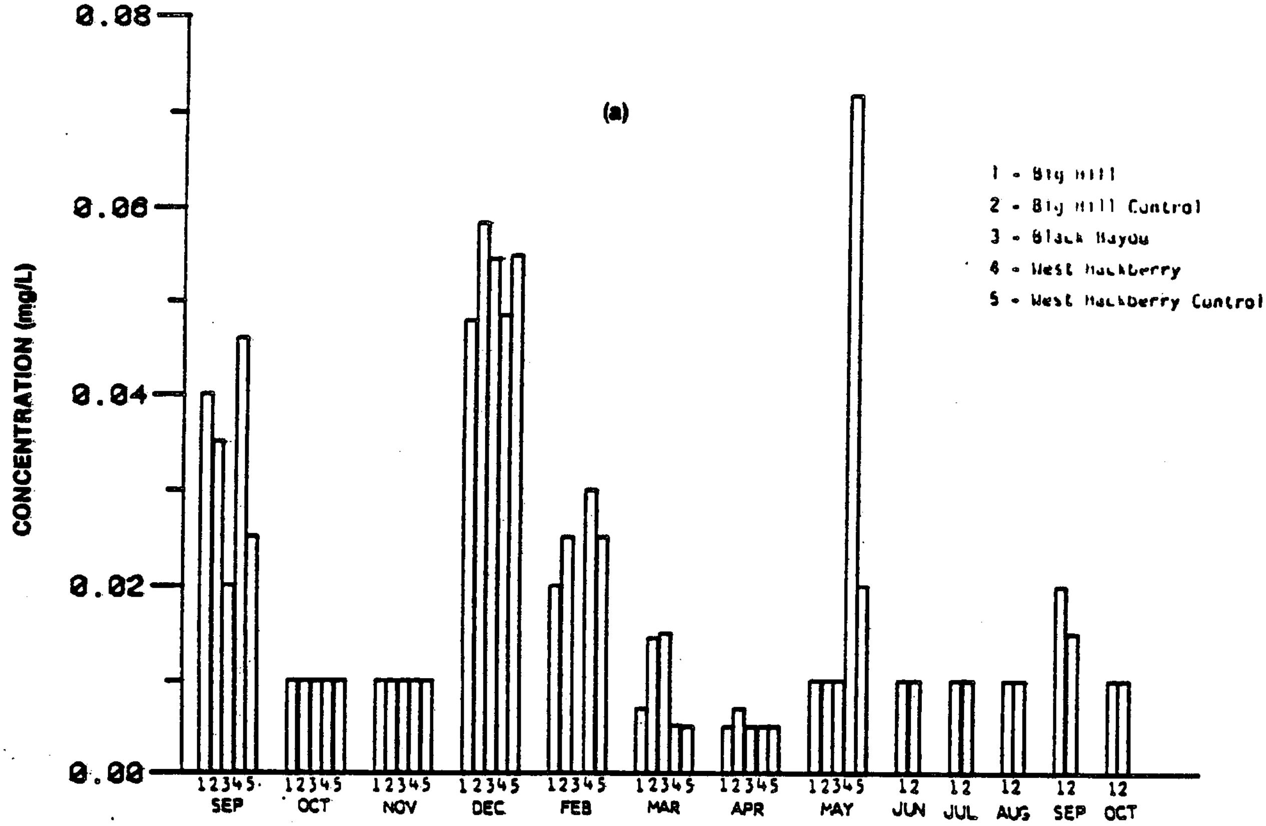


Figure F-14. Mean silica concentration (mg/L) in the Texoma study area expressed by cruise for the period September 1977 to October 1978: (a) near-surface, (b) near-bottom.



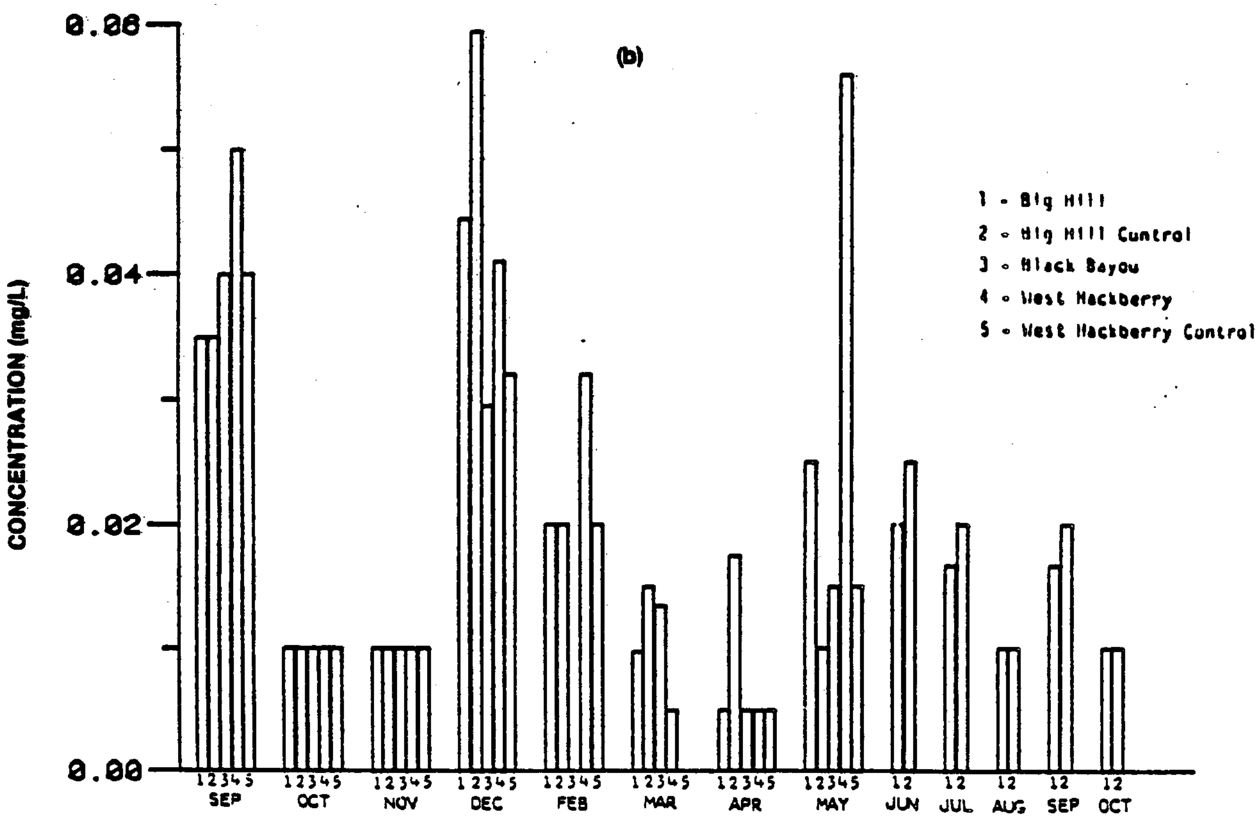


Figure F-15. **Mean phosphate concentration (mg/L) in the Texoma study area expressed by cruise for the period September 1977 to October 1978: (a) near-surface, (b) near-bottom.**

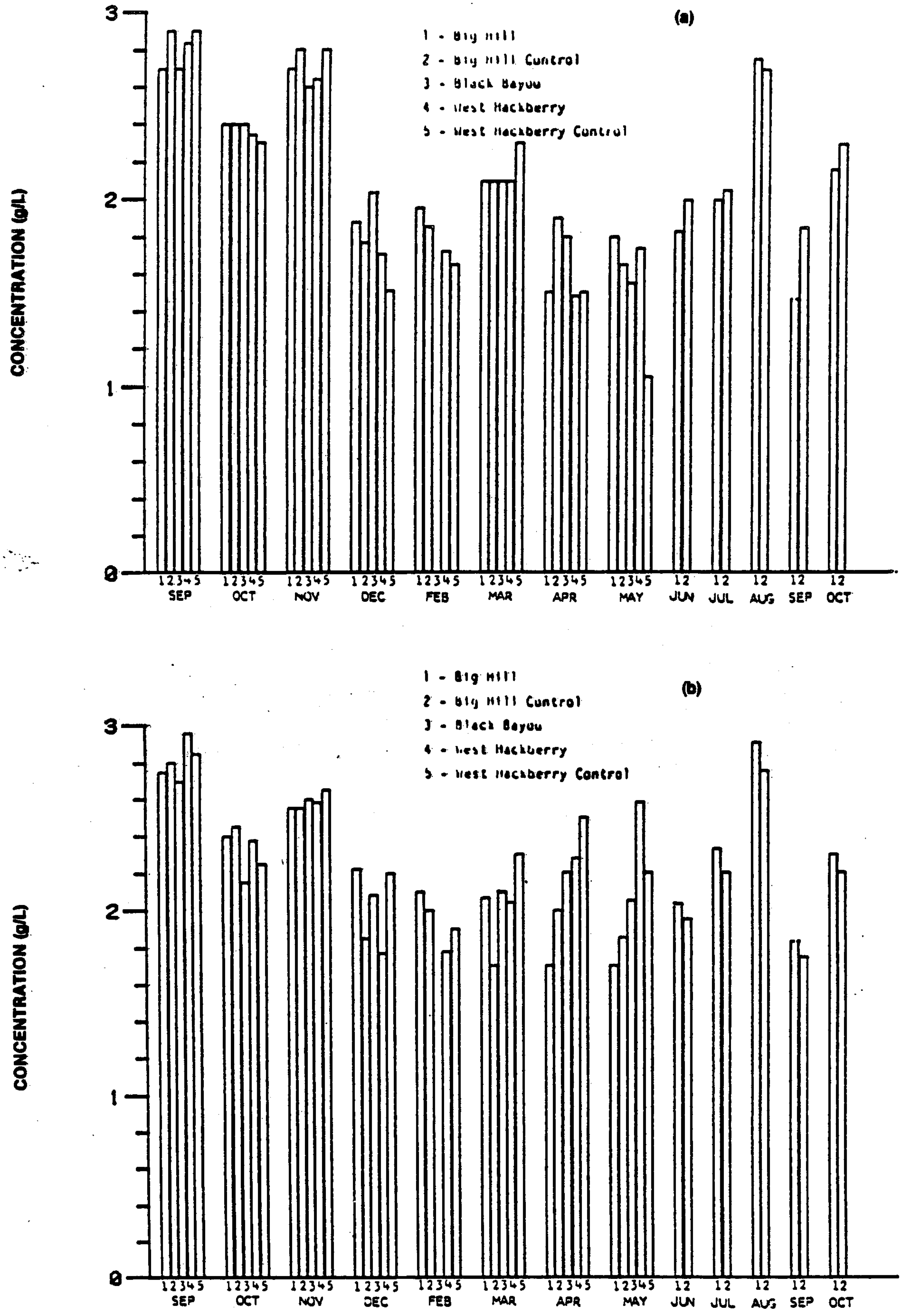


Figure F-16. Mean concentration of sulfate (g/L) in the Texoma study area expressed by cruise for the period September 1977 to October 1978: (a) near-surface, (b) near-bottom.

Table F-7. Mean value (± 1 standard error) for the silicate concentration (mg/L) by depth, site, and cruise for five sites in the Texoma study area during the period September 1977 to October 1978

Month	Big Hill		Big Hill Control		Big Hill Cluster		Black Bayou		West Hackberry		West Hackberry Control		West Hackberry Cluster		Overall	
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
SEP	0.40	0.20	0.15	0.05	0.23	0.15	0.10	0.20	0.34	0.38	0.20	0.25	0.25	0.31	0.25	0.26
SE	±0.00	±0.10	±0.05	±0.00	±0.09	±0.05	±0.00	±0.10	±0.09	±0.07	±0.00	±0.05	±0.06	±0.05	±0.05	±0.04
N	1	2	2	2	3	4	2	2	5	5	2	2	9	9	12	13
OCT	0.55	0.55	0.40	0.35	0.47	0.45	0.40	0.35	0.48	0.44	0.25	0.35	0.41	0.40	0.43	0.41
SE	±0.05	±0.15	±0.00	±0.05	±0.05	±0.09	±0.00	±0.05	±0.04	±0.05	±0.05	±0.05	±0.04	±0.03	±0.03	±0.03
N	2	2	2	2	4	4	2	2	5	5	2	2	9	9	13	13
NOV	0.35	0.80	1.45	0.30	0.90	0.55	0.85	1.25	1.16	1.44	1.35	1.20	1.13	1.34	1.06	1.10
SE	±0.05	±0.60	±0.15	±0.10	±0.32	±0.29	±0.15	±0.85	±0.23	±0.13	±0.35	±0.40	±0.15	±0.17	±0.14	±0.18
N	2	2	2	2	4	4	2	2	5	5	2	2	9	9	13	13
DEC	0.83	0.80	1.00	0.56	0.92	0.68	0.97	0.92	1.51	1.53	1.23	0.70	1.33	1.21	1.20	1.05
SE	±0.16	±0.10	±0.14	±0.16	±0.10	±0.10	±0.02	±0.20	±0.07	±0.04	±0.20	±0.04	±0.08	±0.17	±0.09	±0.14
N	2	2	2	2	4	4	2	2	5	5	2	2	9	9	13	13
JAN/FEB	0.60	0.55	0.75	0.60	0.67	0.57	NO SAMPLES		0.82	0.68	0.75	0.55	0.80	0.64	0.75	0.62
SE	±0.00	±0.05	±0.05	±0.00	±0.05	±0.02			±0.08	±0.05	±0.15	±0.05	±0.06	±0.04	±0.05	±0.03
N	2	2	2	2	4	4			5	5	2	2	7	7	11	11
MAR	0.11	0.10	0.18	0.20	0.14	0.14	0.29	0.27	0.18	0.19	0.07	0.20	0.20	0.21	0.17	0.18
SE	±0.03	±0.02	±0.05	±0.07	±0.03	±0.04	±0.00	±0.10	±0.02	±0.02	±0.00	±0.00	±0.03	±0.03	±0.02	±0.02
N	3	3	2	2	5	5	2	2	5	5	1	1	8	8	13	13
APR	0.55	0.45	0.40	0.30	0.47	0.37	0.40	0.25	0.80	0.32	0.45	0.30	0.63	0.30	0.58	0.32
SE	±0.05	±0.05	±0.00	±0.00	±0.05	±0.05	±0.10	±0.05	±0.04	±0.02	±0.05	±0.10	±0.07	±0.02	±0.05	±0.02
N	2	2	2	2	4	4	2	2	5	5	2	2	9	9	13	13
MAY	0.50	0.30	0.25	0.40	0.37	0.35	0.30	0.70	1.06	0.88	1.20	0.65	0.92	0.79	0.75	0.65
SE	±0.05	±0.20	±0.05	±0.10	±0.08	±0.09	±0.20	±0.20	±0.11	±0.20	±0.10	±0.15	±0.14	±0.12	±0.12	±0.10
N	2	2	2	2	4	4	2	2	5	5	2	2	9	9	13	13
OVERALL (Cruises 1-8)	0.47	0.45	0.57	0.35	0.50	0.49	0.47	0.56	0.79	0.73	0.73	0.55	0.71	0.68	0.60	0.58
SE	±0.06	±0.08	±0.11	±0.05	±0.05	±0.06	±0.09	±0.14	±0.07	±0.08	±0.13	±0.09	±0.05	±0.06	±0.04	±0.04
N	16	17	16	16	32	33	14	14	40	40	15	15	69	69	101	102
JUN	0.38	0.94	0.42	1.36	0.40	1.11	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		0.40	1.11
SE	±0.00	±0.19	±0.04	±0.04	±0.02	±0.15									±0.05	±0.09
N	3	3	2	2	5	5									5	5
JUL	0.41	0.40	0.32	0.61	0.38	0.49	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		0.38	0.49
SE	±0.04	±0.03	±0.04	±0.25	±0.03	±0.09									±0.03	±0.09
N	3	3	2	2	5	5									5	5
AUG	0.23	0.23	0.13	0.15	0.19	0.20	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		0.19	0.20
SE	±0.05	±0.03	±0.05	±0.03	±0.04	±0.03									±0.04	±0.03
N	3	3	2	2	5	5									5	5
SEP	0.64	0.68	0.32	0.31	0.51	0.53	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		0.51	0.53
SE	±0.06	±0.09	±0.01	±0.03	±0.08	±0.10									±0.08	±0.10
N	3	3	2	2	5	5									5	5
OCT	0.33	0.25	0.48	0.39	0.39	0.31	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		0.39	0.31
SE	±0.09	±0.12	±0.12	±0.03	±0.07	±0.08									±0.07	±0.08
N	3	3	2	2	5	5									5	5
OVERALL (Cruises 9-13)	0.43	0.47	0.48	0.43	0.46	0.45	0.47	0.56	0.79	0.73	0.73	0.55	0.71	0.68	0.60	0.57
SE	±0.04	±0.06	±0.07	±0.06	±0.04	±0.04	±0.09	±0.14	±0.07	±0.08	±0.13	±0.09	±0.05	±0.06	±0.04	±0.04
N	31	32	26	26	57	58	14	14	40	40	15	15	69	69	126	127

SE = One Standard Error.
N = Number of Samples.

Table F-8. Mean value (± 1 standard error) for phosphate concentrations (mg/L) by depth, site, and cruise for five sites in the Texoma study area for the period September 1977 to October 1978

Month	Big Hill		Big Hill Control		Big Hill Cluster		Black Bayou		West Hackberry		West Hackberry Control		West Hackberry Cluster		Overall	
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
SEP	0.04	0.03	0.03	0.03	0.04	0.03	0.02	0.04	0.05	0.05	0.02	0.04	0.03	0.04	0.03	0.04
SE	±0.00	±0.00	±0.05	±0.05	±0.00	±0.00	±0.02	±0.00	±0.01	±0.01	±0.00	±0.00	±0.01	±0.00	±0.00	±0.00
N	1	2	2	2	3	4	2	2	5	5	2	2	9	9	12	13
OCT	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
SE	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00
N	2	2	2	2	4	4	2	2	5	5	2	2	9	9	13	13
NOV	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
SE	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00
N	2	2	2	2	4	4	2	2	5	5	2	2	9	9	13	13
DEC	0.05	0.04	0.06	0.06	0.05	0.05	0.05	0.03	0.05	0.04	0.05	0.03	0.05	0.04	0.05	0.04
SE	±0.02	±0.00	±0.01	±0.02	±0.01	±0.01	±0.01	±0.01	±0.00	±0.00	±0.00	±0.01	±0.00	±0.00	±0.00	±0.00
N	2	2	2	2	4	4	2	2	5	5	2	2	9	9	13	13
JAN/FEB	0.02	0.02	0.02	0.02	0.02	0.02	NO SAMPLES		0.03	0.03	0.02	0.02	0.03	0.03	0.03	0.02
SE	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00			±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00
N	2	2	2	2	4	4			5	5	2	2	7	7	11	11
MAR	0.07	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01
SE	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00
N	3	3	2	2	5	5	2	2	5	5	1	1	8	8	13	13
APR	0.00	0.00	0.01	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
SE	±0.00	±0.00	±0.00	±0.01	±0.00	±0.01	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00
N	2	2	2	2	4	4	2	2	5	5	2	2	9	9	13	13
MAY	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.07	0.06	0.02	0.01	0.05	0.04	0.03	0.03
SE	±0.00	±0.01	±0.00	±0.00	±0.00	±0.01	±0.00	±0.00	±0.01	±0.01	±0.00	±0.00	±0.01	±0.01	±0.01	±0.01
N	2	2	2	2	4	4	2	2	5	5	2	2	9	9	13	13
OVERALL (Cruises 1-8)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02
SE	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00
N	16	17	16	16	32	33	14	14	40	40	15	15	69	69	101	102
JUN	0.01	0.02	0.01	0.02	0.01	0.02	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		0.01	0.02
SE	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00									±0.00	±0.00
N	3	3	2	2	5	5									5	5
JUL	0.01	0.02	0.01	0.02	0.01	0.02	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		0.01	0.02
SE	±0.00	±0.01	±0.00	±0.00	±0.00	±0.00									±0.00	±0.00
N	3	3	2	2	5	5									5	5
AUG	0.01	0.01	0.01	0.01	0.01	0.01	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		0.01	0.01
SE	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00									±0.00	±0.00
N	3	3	2	2	5	5									5	5
SEP	0.02	0.02	0.01	0.02	0.02	0.02	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		0.02	0.02
SE	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00									±0.00	±0.00
N	3	3	2	2	5	5									5	5
OCT	0.01	0.01	0.01	0.01	0.01	0.01	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		0.01	0.01
SE	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00									±0.00	±0.00
N	3	3	2	2	5	5									5	5
OVERALL (Cruises 9-13)	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02
SE	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00
N	31	32	26	26	57	58	14	14	40	40	15	15	69	69	126	127

SE = One Standard Error.
N = Number of Samples.

Table F-9. Mean values (± 1 standard error) for sulfate concentrations (g/L) by depth, site, and cruise for five sites in the Texoma study area during the period September 1977 to October 1978

Month	Big Hill		Big Hill Control		Big Hill Cluster		Black Bayou		West Hackberry		West Hackberry Control		West Hackberry Cluster		Overall	
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
SEP	2.70	2.75	2.90	2.80	2.83	2.77	2.70	2.70	2.84	2.96	2.90	2.85	2.82	2.88	2.82	2.85
SE	±0.00	±0.05	±0.30	±0.00	±0.18	±0.02	±0.00	±0.10	±0.08	±0.10	±0.20	±0.05	±0.06	±0.07	±0.06	±0.05
N	1	2	2	2	3	4	2	2	5	5	2	2	9	9	12	13
OCT	2.40	2.40	2.40	2.45	2.40	2.42	2.40	2.15	2.34	2.38	2.30	2.25	2.34	2.30	2.36	2.34
SE	±0.00	±0.00	±0.00	±0.05	±0.00	±0.02	±0.10	±0.35	±0.02	±0.02	±0.10	±0.05	±0.03	±0.07	±0.02	±0.05
N	2	2	2	2	4	4	2	2	5	5	2	2	9	9	13	13
NOV	2.70	2.55	2.80	2.55	2.75	2.55	2.60	2.60	2.64	2.58	2.80	2.65	2.67	2.60	2.69	2.58
SE	±0.00	±0.15	±0.00	±0.15	±0.03	±0.09	±0.00	±0.00	±0.04	±0.03	±0.10	±0.05	±0.04	±0.02	±0.03	±0.03
	2	2	2	2	4	4	2	2	5	5	2	2	9	9	13	13
DEC	1.88	2.22	1.77	1.84	1.82	2.03	2.03	2.08	1.71	1.77	1.51	2.19	1.73	1.93	1.76	1.96
SE	±0.25	±0.04	±0.16	±0.27	±0.12	±0.16	±0.23	±0.05	±0.03	±0.04	±0.12	±0.18	±0.08	±0.08	±0.06	±0.07
N	2	2	2	2	4	4	2	2	5	5	2	2	9	9	13	13
JAN/FEB	1.95	2.10	1.85	2.00	1.90	2.05	NO SAMPLES		1.72	1.78	1.65	1.90	1.70	1.81	1.77	1.90
SE	±0.05	±0.10	±0.05	±0.00	±0.04	±0.05			±0.09	±0.17	±0.05	±0.00	±0.06	±0.12	±0.05	±0.08
N	2	2	2	2	4	4			5	5	2	2	7	7	11	11
MAR	2.10	2.07	2.10	1.70	2.10	1.92	2.10	2.10	2.10	2.04	2.30	2.30	2.12	2.09	2.11	2.02
SE	±0.10	±0.09	±0.20	±0.00	±0.08	±0.10	±0.30	±0.10	±0.07	±0.09	±0	±0	±0.07	±0.07	±0.05	±0.06
N	3	3	2	2	5	5	2	2	5	5	1	1	8	8	13	13
APR	1.50	1.70	1.90	2.00	1.70	1.85	1.60	2.20	1.48	2.28	1.50	2.50	1.55	2.31	1.60	2.17
SE	±0.00	±0.10	±0.00	±0.00	±0.11	±0.09	±0.00	±0.20	±0.02	±0.06	±0.20	±0.00	±0.06	±0.06	±0.05	±0.08
N	2	2	2	2	4	4	2	2	5	5	2	2	9	9	13	13
MAY	1.80	1.70	1.65	1.85	1.72	1.77	1.55	2.05	1.74	2.58	1.05	2.20	1.54	2.38	1.60	2.19
SE	±0.10	±0.10	±0.15	±0.05	±0.08	±0.06	±0.05	±0.05	±0.14	±0.53	±0.15	±0.00	±0.12	±0.29	±0.09	±0.21
N	2	2	2	2	4	4	2	2	5	5	2	2	9	9	13	13
OVERALL (Cruises 1-8)	2.09	2.18	2.17	2.15	2.10	2.14	2.17	2.27	2.07	2.30	1.98	2.36	2.04	2.30	2.08	2.25
SE	±0.10	±0.09	±0.12	±0.10	±0.07	±0.06	±0.11	±0.08	±0.08	±0.09	±0.17	±0.08	±0.06	±0.05	±0.04	±0.04
N	16	17	16	16	32	33	14	14	40	40	15	15	69	69	101	102
JUN	1.83	2.03	2.00	1.95	1.90	2.00	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		1.90	2.00
SE	±0.09	±0.07	±0.20	±0.55	±0.09	±0.18									±0.04	±0.18
N	3	3	2	2	5	5									5	5
JUL	2.00	2.33	2.05	2.20	2.02	2.28	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		2.02	2.28
SE	±0.11	±0.07	±0.05	±0.10	±0.07	±0.06									±0.07	±0.06
N	3	3	2	2	5	5									5	5
AUG	2.76	2.91	2.70	2.75	2.74	2.85	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		2.74	2.85
SE	±0.10	±0.02	±0.03	±0.01	±0.06	±0.04									±0.06	±0.04
N	3	3	2	2	5	5									5	5
SEP	1.47	1.83	1.85	1.75	1.62	1.80	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		1.62	1.80
SE	±0.03	±0.22	±0.15	±0.25	±0.11	±0.14									±0.11	±0.14
N	3	3	2	2	5	5									5	5
OCT	2.17	2.30	2.30	2.20	2.22	2.26	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		2.22	2.26
SE	±0.09	±0.06	±0.00	±0.10	±0.06	±0.05									±0.06	±0.05
N	3	3	2	2	5	5									5	5
OVERALL (Cruises 9-13)	2.07	2.23	2.17	2.16	2.12	2.19	2.17	2.27	2.07	2.30	1.98	2.36	2.04	2.30	2.09	2.25
SE	±0.08	±0.07	±0.08	±0.08	±0.06	±0.05	±0.11	±0.08	±0.08	±0.09	±0.17	±0.08	± .06	±0.05	± .04	± .04
N	31	32	26	26	57	58	14	14	40	40	15	15	69	69	126	127

SE = One Standard Error,
N = Number of Samples.

Table F-10. Mean value (± 1 standard error) for nitrate-nitrite nitrogen concentration (mg/L) by depth, site, and cruise for five sites in the Texoma study area during the period September 1977 to October 1978

	Big Hill		Big Hill Control		Big Hill Cluster		Black Bayou		West Hackberry		West Hackberry Control		West Hackberry Cluster		Overall	
Month	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
SEP	0.02	0.02	0.02	0.03	0.02	0.03	0.07	0.07	0.03	0.05	0.02	0.02	0.03	0.05	0.03	0.04
SE	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.01	±0.00	±0.00	±0.01	±0.01	±0.00	±0.01	±0.43	±0.01	±0.01
N	1	2	2	2	3	4	2	2	5	5	2	2	9	9	12	12
OCT	0.04	0.06	0.02	0.01	0.03	0.04	0.03	0.03	0.02	0.04	0.03	0.03	0.03	0.04	0.03	0.04
SE	±0.00	±0.00	±0.00	±0.00	±0.01	±0.01	±0.00	±0.02	±0.01	±0.00	±0.02	±0.00	±0.00	±0.00	±0.00	±0.00
N	2	2	2	2	4	4	2	2	5	5	2	2	9	9	13	13
NOV	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.05	0.05	0.01	0.03	0.03	0.04	0.02	0.03
SE	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00	±0.01	±0.00	±0.00	±0.01	±0.00	±0.00	±0.00
N	2	2	2	2	4	4	2	2	5	5	2	2	9	9	13	13
DEC	0.25	0.20	0.30	0.15	0.27	0.17	0.40	0.20	0.42	0.36	0.45	0.20	0.42	0.29	0.38	0.25
SE	±0.05	±0.00	±0.10	±0.05	±0.05	±0.02	±0.00	±0.00	±0.02	±0.02	±0.05	±0.00	±0.01	±0.03	±0.02	±0.03
N	2	2	2	2	4	4	2	2	5	5	2	2	9	9	13	13
JAN/FEB	0.30	0.25	0.35	0.35	0.32	0.30	NO SAMPLES		0.36	0.32	0.30	0.20	0.34	0.28	0.34	0.29
SE	±0.00	±0.05	±0.05	±0.05	±0.02	±0.04			±0.02	±0.04	±0.00	±0.00	±0.02	±0.03	±0.01	±0.02
N	2	2	2	2	4	4			5	5	2	2	7	7	11	11
MAR	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.01	0.01
SE	±0.00	±0.00	±0.00	±0.00	±0.00	0.00	0.00	±0.01	±0.00	±0.01	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00
N	3	3	2	2	5	5	2	2	5	5	1	1	8	8	13	13
APR	0.10	0.09	0.07	0.08	0.09	0.09	0.08	0.10	0.21	0.03	0.15	0.01	0.17	0.04	0.14	0.05
SE	±0.02	±0.00	±0.01	±0.01	±0.01	±0.01	±0.00	±0.09	±0.01	±0.01	±0.01	±0.00	±0.02	±0.02	±0.02	±0.01
N	2	2	2	2	4	4	2	2	5	5	2	2	9	9	13	13
MAY	0.10	0.09	0.11	0.06	0.11	0.08	0.19	0.19	0.53	0.36	0.35	0.33	0.41	0.31	0.32	0.24
SE	±0.03	±0.02	±0.08	±0.03	±0.04	±0.02	±0.09	±0.09	±0.05	±0.04	±0.03	±0.11	±0.06	±0.04	±0.06	±0.04
N	2	2	2	2	4	4	2	2	5	5	2	2	9	9	13	13
OVERALL (Cruises 1-8)	0.10	0.09	0.11	0.09	0.09	0.08	0.11	0.09	0.20	0.15	0.18	0.11	0.17	0.12	0.13	0.10
SE	±0.03	±0.02	±0.03	±0.03	±0.02	±0.01	±0.04	±0.02	±0.03	±0.02	±0.04	±0.03	±0.02	±0.02	±0.01	±0.01
N	16	17	16	16	32	33	14	14	40	40	15	15	69	69	101	102
JUN	0.01	0.01	0.01	0.01	0.01	0.01	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		0.01	0.01
SE	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00									±0.01	±0.00
N	3	3	2	2	5	5									5	5
JUL	0.02	0.02	0.03	0.03	0.03	0.03	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		0.03	0.03
SE	±0.00	±0.00	±0.00	±0.00	±0.00	±0.00									±0.00	±0.00
N	3	3	2	2	5	5									5	5
AUG	0.04	0.04	0.04	0.04	0.04	0.04	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		0.04	0.04
SE	±0.00	±0.00	±0.01	±0.01	±0.00	±0.00									±0.00	±0.00
N	3	3	2	2	5	5									5	5
SEP	0.11	0.14	0.09	0.10	0.10	0.13	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		0.10	0.13
SE	±0.00	±0.02	±0.02	±0.01	±0.01	±0.02									±0.01	±0.02
N	3	3	2	2	5	5									5	5
OCT	0.10	0.10	0.12	0.10	0.11	0.10	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		0.11	0.10
SE	±0.00	±0.01	±0.00	±0.00	±0.01	±0.00									±0.01	±0.00
N	3	3	2	2	5	5									5	5
OVERALL (Cruises 9-13)	0.08	0.08	0.09	0.08	0.09	0.08	0.11	0.09	0.20	0.15	0.18	0.11	0.17	0.12	0.14	0.11
SE	±0.01	±0.01	±0.02	±0.02	±0.01	±0.01	±0.04	±0.02	±0.03	±0.02	±0.04	±0.03	±0.02	±0.02	±0.01	±0.01
N	31	32	26	26	57	58	14	14	40	40	15	15	69	69	126	127

SE = One Standard Error.
N = Number of Samples.

Results of simple correlation analyses for all pairwise comparisons of nutrient and hydrographic variables for near-surface and near-bottom samples are presented in Table F-11 for the Big Hill and BHC sites for the period September 1977 to October 1978. These results are very similar to those for the entire Texoma area. The strong negative correlation of temperature and dissolved oxygen is quite evident, indicating the higher dissolved oxygen values in the winter. Of particular note for the near-surface samples are (1) the mutual bivariate correlations of 0.40 to 0.61 for silicate, nitrate, and phosphate concentrations; (2) the strong positive correlation of salinity and sulfate; and (3) the negative correlations between sulfate and nitrate and between silicate and salinity. These relationships are not nearly as strong for the near-bottom samples, although the trends for the near-bottom samples are generically similar to those for the near-surface samples. The near-bottom samples, with less freshwater influence, showed less distinct trends regarding salinity/nutrient relationships, except for salinity and sulfate. Nor are the relationships shown for the near-surface samples as strong for the Big Hill group of sites as they were for the samples from the West Hackberry group because of the close proximity of the West Hackberry site to Calcasieu Pass. These results are consistent with the terrestrial (freshwater) source of phosphate, nitrate, and silicate in the coastal zone and the oceanic source of higher sulfate levels.

These major trends seen in the Texoma study are shown in Figs. F-17 to F-20. Figure F-17 shows the strong negative relationship between dissolved oxygen and temperature, especially for the near-surface samples. The extreme situation for the near-bottom samples in June 1978 is noted. Sulfate is shown to be most closely related to salinity in Fig. F-18, while Figs. F-19 and F-20 show the positive relationship between nitrate concentrations and local and regional discharge, with two peaks noted.

Results of the factor analysis for CTD/nutrient data collected at the Big Hill and BHC sites for the period September 1977 to October 1978 are shown in Table F-12 in the form of the rotated factor pattern matrix. The three factors define three major trends in hydrologic-nutrient dynamics, which explain most of the variance in the data. Factor 1 highlights the distinct winter period with high dissolved oxygen, low temperature, and especially high nitrate levels. Factor 2 defines those water masses where silicate, phosphate, and nitrate are in highest concentration (late winter to spring), while factor 3 defines those water masses with high salinity and sulfate. Since salinity and sulfate levels have a bimodal distribution over the sampling period, no strong relationship was seen with temperature. Factor 3 represents the encroachment of saline Gulf water into the near-shore area.

Phytoplankton

Figures F-21 to F-23 show the response of the primary producers (phytoplankton) to nutrient enrichment associated with freshwater discharge. Table F-13 and Fig. F-24 show the cruise and site means for phytoplankton density. Particularly sharp increases in phytoplankton standing stock were seen in December 1977 and May 1978, coinciding with

Table F-11. Results of simple correlation analyses for CTD and nutrient variables for the Big Hill group during the period September 1977 to October 1978

Near-surface

	Sulfate	Phosphate	Nitrate	Silicate	Temperature	Salinity
Dissolved Oxygen	NS*	NS	0.52	NS	-0.80	NS
Salinity	0.67**	NS	NS	-0.48	0.23	
Temperature	NS	NS	-0.55	NS		
Silicate	NS	0.40	0.45			
Nitrate	-0.38	0.61				
Phosphate	NS					

Near-bottom

	Sulfate	Phosphate	Nitrate	Silicate	Temperature	Salinity
Dissolved Oxygen	NS	NS	NS	-0.38	-0.81	-0.27
Salinity	0.72	NS	NS	NS	0.38	
Temperature	NS	NS	-0.42	NS		
Silicate	NS	0.27	NS			
Nitrate	NS	0.29				
Phosphate	NS					

* NS = Not Significant at $p = 0.05$.
**All values significant at $p = 0.05$.

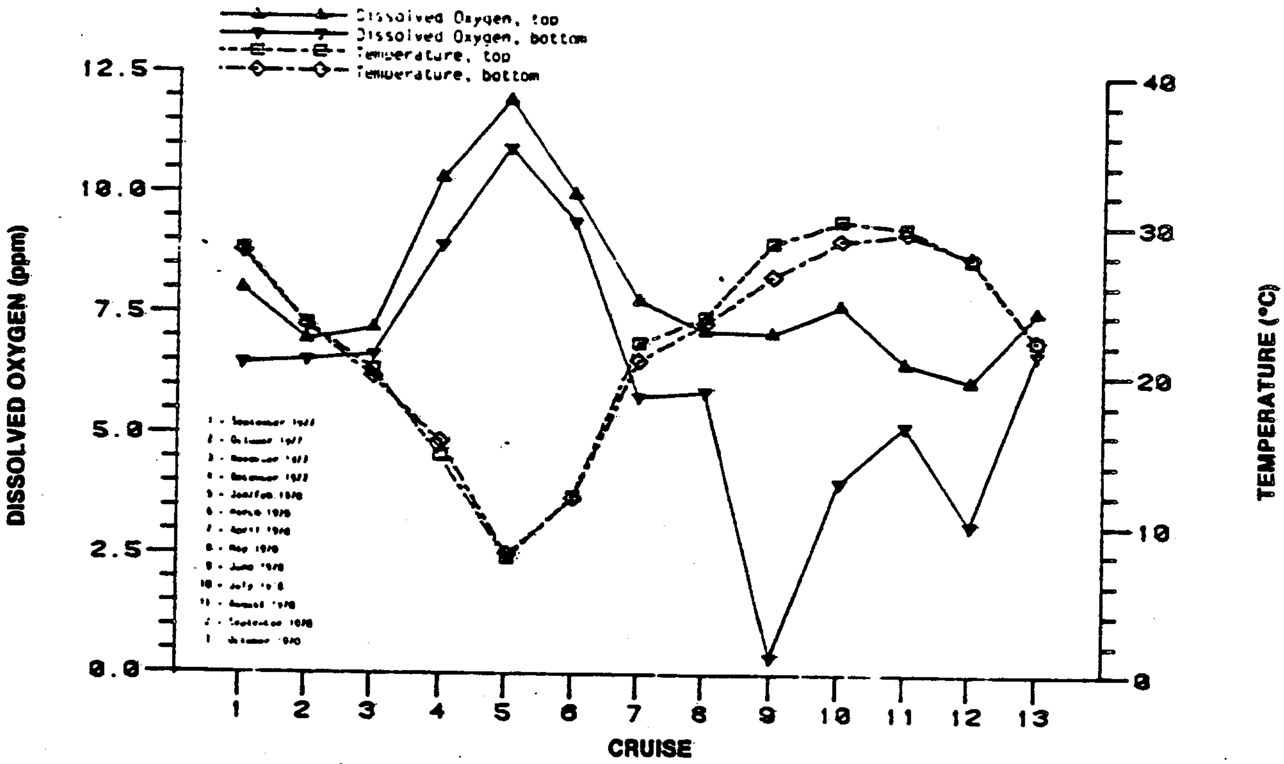


Figure F-17. Plot of monthly mean values (over all sites) of dissolved oxygen (ppm) and temperature (°C) in the Texoma study region for the period September 1977 to October 1978.

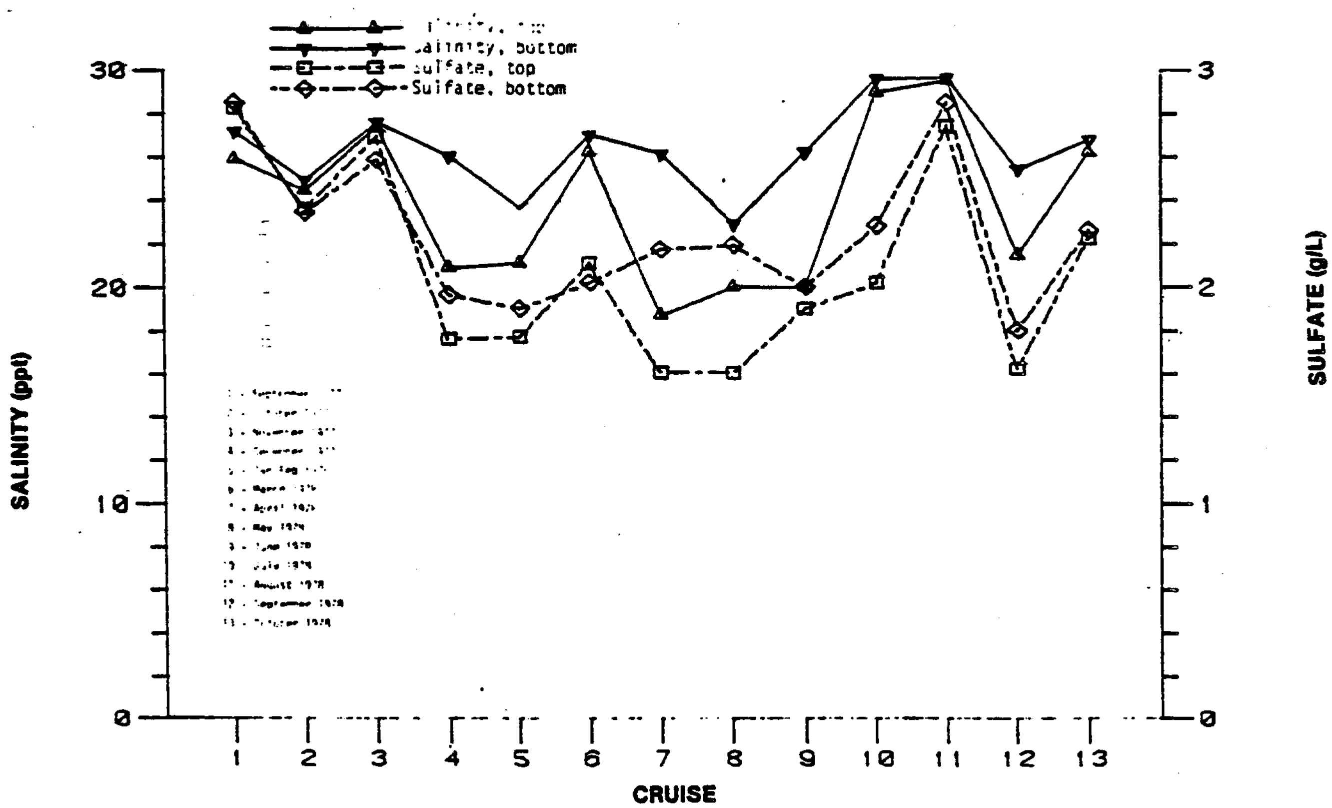


Figure F-18. Plot of monthly mean values (over all sites) of salinity (ppt) and sulfate concentration (g/L) in the Texoma study region for the period September 1977 to October 1978.

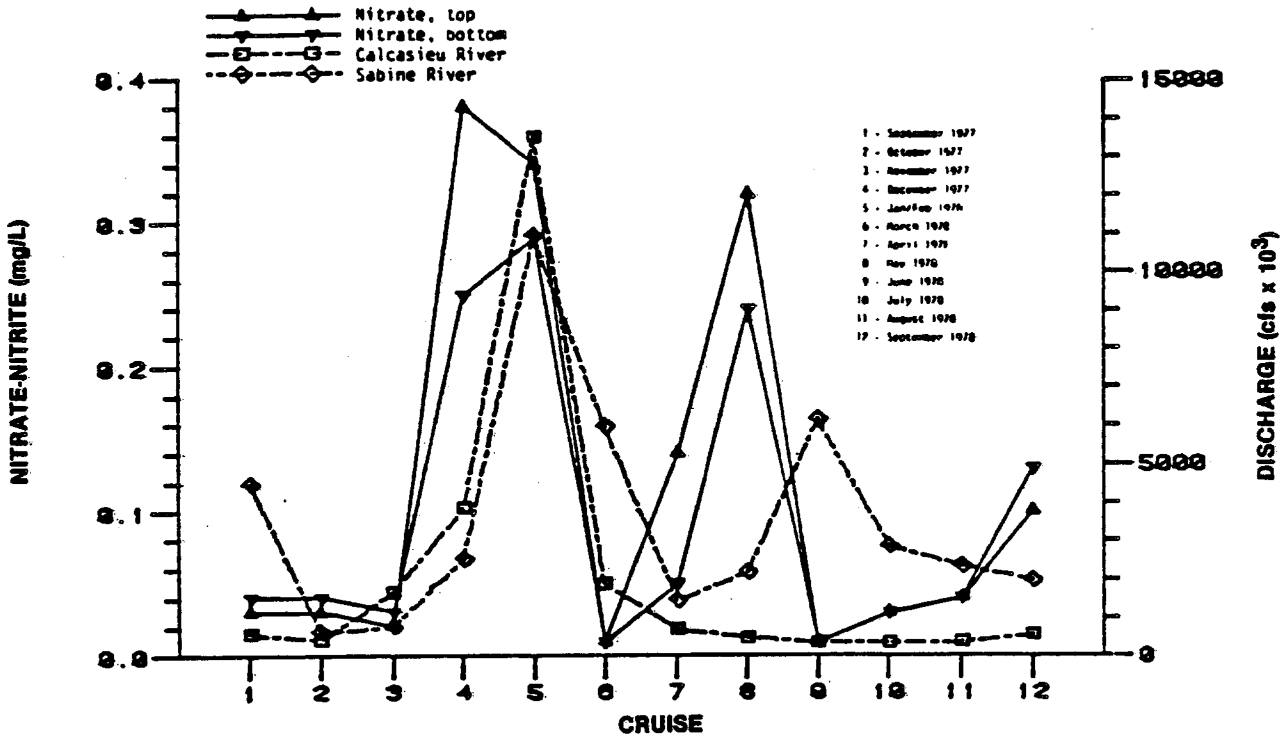


Figure F-19. Plot of monthly mean values (over all sites) of nitrate-nitrite concentration (mg/L) and discharge from the Calcasieu and Sabine Rivers (cfs x 10^3) in the Texoma study region for the period September 1977 to September 1978.

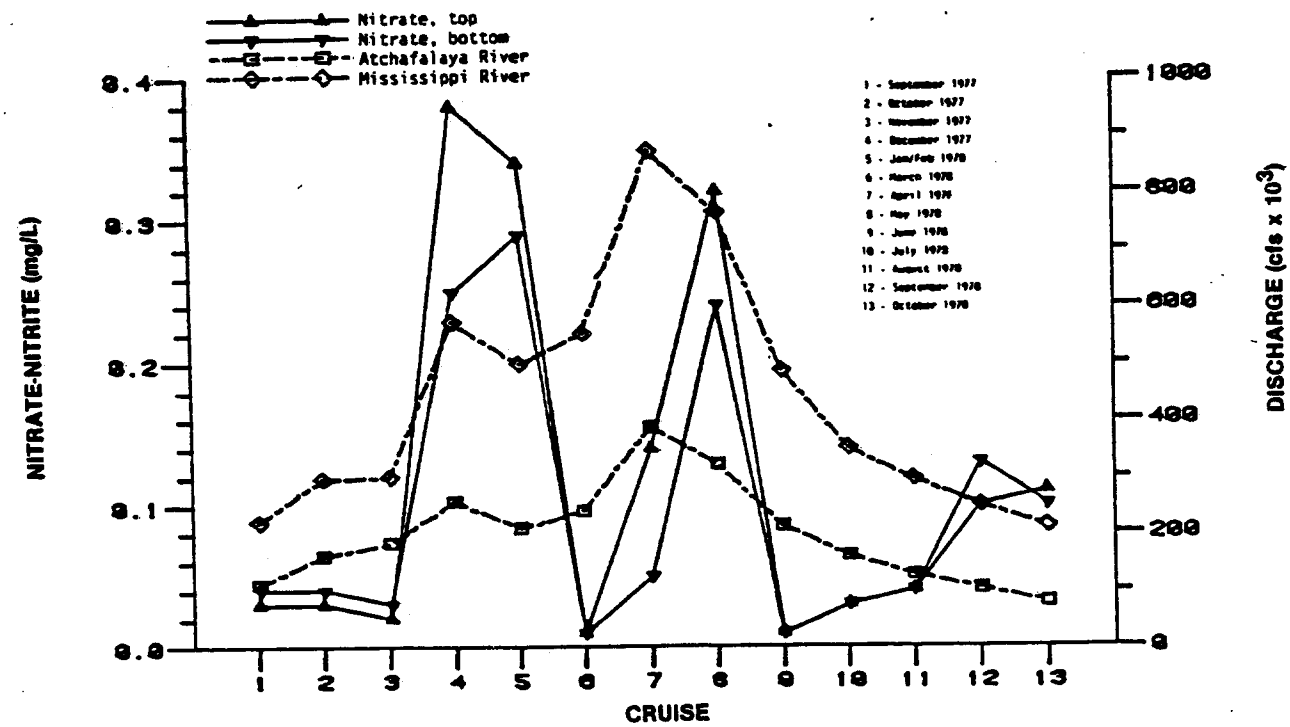


Figure F-20. Plot of monthly mean values (over all sites) of nitrate-nitrite concentration (mg/L) and discharge from the Mississippi and Atchafalaya Rivers (cfs x 10^3) in the Texoma study region for the period September 1977 to October 1978.

Table F-12. Rotated factor pattern matrix for the CTD/nutrient data set for the Big Hill sites (September 1977 to October 1978)

	Rotation Method: VARIMAX		
	Factor 1	Factor 2	Factor 3
Temperature	-0.84065	-0.16172	0.18763
Salinity	-0.21370	0.01894	0.86932
Dissolved Oxygen	0.94460	-0.13921	-0.04348
Sulfate	-0.06211	-0.08922	0.89471
Silicate	-0.20359	0.82040	-0.20726
Phosphate	0.26453	0.77107	0.19252
Nitrate	0.61439	0.54437	-0.29336
Proportional Contributions to Common Variances by Rotated Factors			
	2.137377	1.617800	1.759391

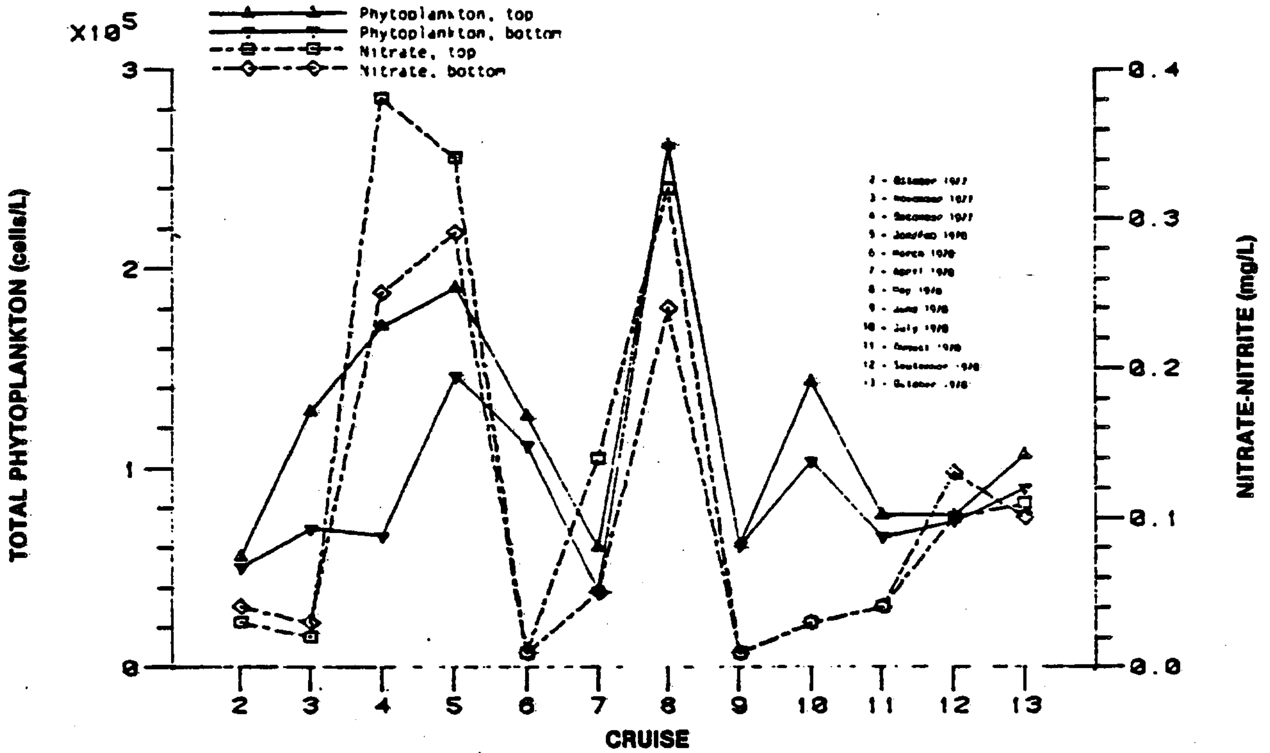


Figure F-21. Plot of monthly mean values (over all sites) of total phytoplankton (number of cells/L) and nitrate-nitrite concentrations (mg/L) in the Texoma study region for the period October 1977 to October 1978.

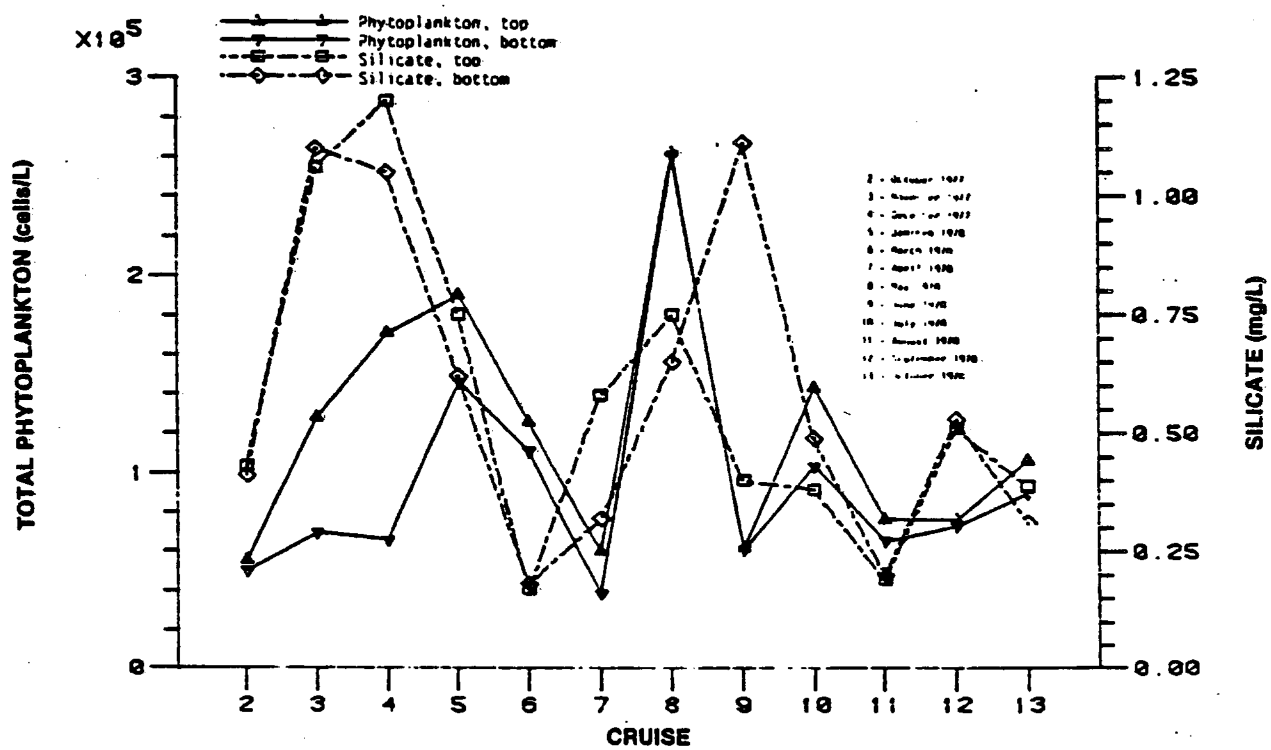


Figure F-22. Plot of monthly mean values (over all sites) of total phytoplankton (number of cells/L) and silicate concentration (mg/L) in the Texoma study region for the period October 1977 to October 1978.

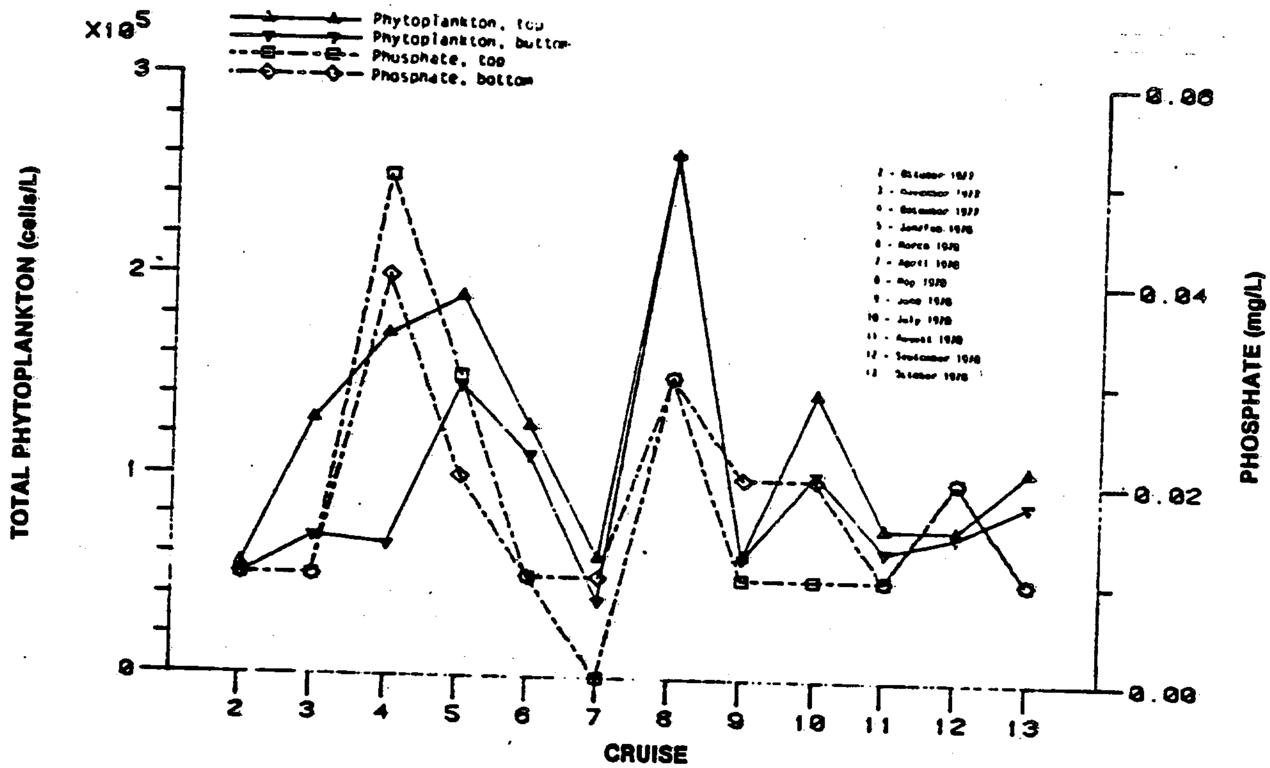


Figure F-23. Plot of monthly mean values (over all sites) of total phytoplankton (number of cells/L) and phosphate concentrations (mg/L) in the Texoma study region for the period October 1977 to October 1978.

Table F-13. Mean number of phytoplankton individuals for five sites in the Texoma region by depth, site, and cruise (October 1977 to October 1978)

Month	Big Hill		Big Hill Control		Big Hill Cluster		Black Bayou		West Hackberry		West Hackberry Control		West Hackberry Cluster		Overall	
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
OCT	115388	29914	39354	44719	75750	35218	20577	29920	89907	68685	24539	41904	50608	54995	55305	49999
CI*					(21853-237605)	(2536-208692)							(30954-80937)	(34406-86288)	(36124-83355)	(30995-78972)
N**	3	3	3	3	5	5	2	2	10	10	6	6	18	18	23	23
NOV	251960	95648	107337	29920	191040	71918	217441	76000	103550	90745	80691	36290	107410	68516	127821	69520
CI					(92022-391073)	(41112-123386)							(71284-160554)	(43471-106403)	(90537-179738)	(49810-96319)
N	4	4	2	2	6	6	2	2	8	8	4	4	14	14	20	20
DEC	128726	60641	150423	37612	135600	51837	312861	28305	118439	110333	362071	49204	187918	72845	170451	65835
CI					(94645-193515)	(30885-84978)							(121368-289527)	(43024-121272)	(124266-233098)	(44872-95549)
N	4	4	2	2	6	6	2	2	8	8	4	4	14	14	20	20
JAN FEB	126137	177751	----	----	126139	107753	121484	88319	263214	213668	179628	112338	217443	160251	189916	145371
CI					(88698-182532)	(72372-159310)							(165810-284475)	(123070-208996)	(149805-240286)	(116395-181319)
N	4	4	0	0	4	4	1	1	7	7	4	4	12	12	16	16
MAR	118258	108180	86148	101208	106463	105806	120348	89450	147056	138277	119243	81445	134623	113450	125449	111213
CI					(82650-136604)	(88872-125642)							(110563-163792)	(91775-139898)	(107783-145958)	(95428-129421)
N	4	4	2	2	6	6	2	2	8	8	4	4	14	15	20	20
APR	85726	16482	151086	145373	103714	36099	137021	35506	25275	31124	73822	62857	57601	48556	60252	38488
CI					(69236-154032)	(7174-133558)							(37018-88562)	(34853-67000)	(50941-96277)	(28448-66792)
N	4	4	2	2	6	6	2	2	7	7	4	4	12	12	19	19
MAY	881807	714303	372590	206999	711359	52494	344091	424788	669907	333127	24748	85012	196472	213123	262082	260696
CI					(409104-1234737)	(248620-1101428)							(82176-460253)	(126501-356975)	(130995-519420)	(168377-402147)
N	3	3	1	1	4	4	2	2	7	7	5	5	14	14	18	18
OVERALL	163753	80513	109850	71020	145511	77574	142772	72616	131425	110060	76288	61709	116061	96880	120477	84582
CI	(123031-217353)	(50959-125529)	(66015-180577)	(39456-125007)	(114121-185256)	(54620-109231)	(84341-239204)	(40725-126824)	(107017-182888)	(93450-145639)	(54140-106753)	(46754-80934)	(94702-141972)	(76040-106427)	(105847-144054)	(74281-100563)
N	26	26	11	11	37	37	13	13	55	55	31	31	98	99	116	116
JUN	66351	68141	46797	38455	61794	61154	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES	
CI					(54424-70144)	(51704-71880)										
N	8	8	2	2	10	10										
JUL	156189	110792	98805	77924	142756	103313	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES	
CI					(119100-170813)	(84034-126811)										
N	8	8	2	2	10	10										
AUG	85146	67728	48579	56871	76238	65414	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES	
CI					(62610-92560)	(55232-77263)										
N	8	8	2	2	10	10										
SEP	86791	81436	46725	47630	76129	73272	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES	
CI					(60349-95733)	(58969-90755)										
N	8	8	2	2	10	10										
OCT	109310	96087	96006	71277	106210	89955	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES	
CI					(91167-123549)	(68027-118406)										
N	8	8	2	2	9	9										
OVERALL	119163	82051	84694	63835	109686	77201	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES	
CI	(104057-136256)	(68355-98230)	(62811-113575)	(47162-85895)	(96779-124232)	(66153-89956)										
N	66	66	21	21	86	86										

*95% Confidence Limits

**N Number of Samples.

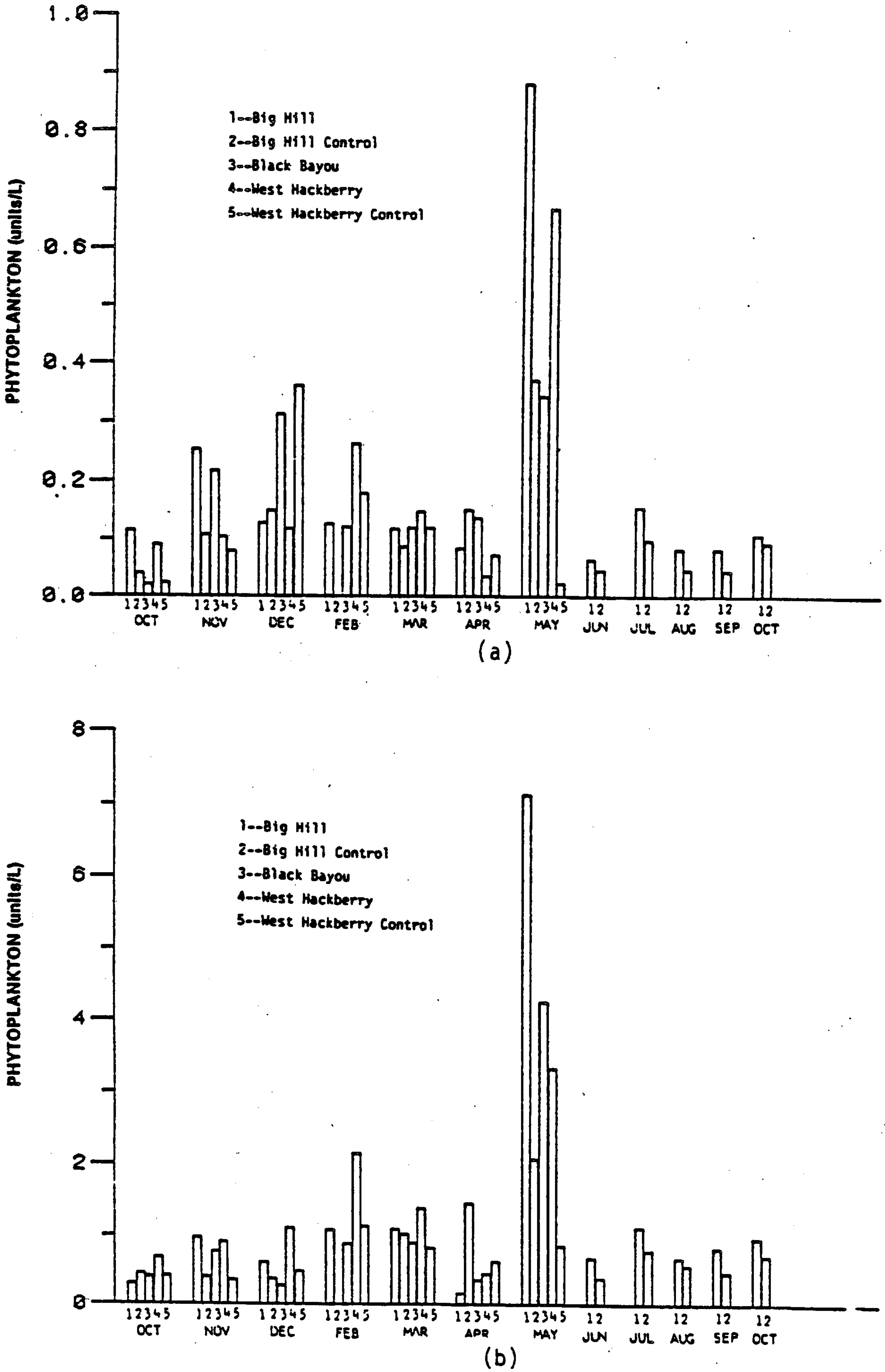


Figure F-24. Total abundance of phytoplankton (units/L): (a) Top samples, (b) bottom samples.

peaks in nutrient concentrations. The precipitous decrease in phytoplankton density in June 1978 paralleled decreases in nutrient levels. The consequences of this decline in phytoplankton standing crop (and, therefore, increase in phytoplankton-derived and labile organic detritus) on water quality are seen in Fig. F-25. It appears that the very low dissolved oxygen concentrations in the near-bottom waters of the Big Hill area in June 1978 were caused by aerobic decomposition of this organic detritus. Near-surface dissolved oxygen concentrations did not decrease because the near-surface water mass was not cut off from the atmosphere. The near-bottom layer, however, received little or no regeneration from atmospheric sources during the time due to the strong stratification that was apparent during the entire spring and especially in June (Fig. F-25).

During the course of the study, 42 diatom and 4 dinoflagellate taxa of phytoplankton were found in the Texoma study region (Table F-14). Most of the species were ubiquitous over the region. During the period when samples were taken at both West Hackberry and Big Hill clusters, only one taxon, Surirella sp., was not found at both sites. This species was taken only rarely at West Hackberry, and its absence at Big Hill is probably attributable to lower sampling intensity. Site-specific differences in taxonomic composition of the phytoplankton were not evident.

Marked seasonal changes in community composition (Table F-15) were noted during the course of the study. The community appeared to pass through three distinct phases, more or less characteristic of all sites at a given time. During the fall and early winter period, Skeletonema costatum, Chaetoceros curvisetus, and Rhizosolenia robusta dominated the community. During midwinter and early spring, the community was characterized by Coscinodiscus centralis. Other species, notably Asterionella japonica, Ceratium tripos, and Thalassiothrix mediterranea, were of significance for relatively brief periods. From early summer to early fall, a third set of species became important. These included C. tripos, Rhizosolenia alata, Rhizosolenia acuminata, Biddulphia granulata, and Biddulphia mobiliensis. Most of the dominant species were approximately coequal from early summer to early fall, with any one taxon seldom contributing more than 10 percent of the numbers of individuals in the various samples. An exception to this is C. tripos, which comprised about 15 percent of the community in June, but was thereafter of modest importance.

In general, the number of species detected in the samples decreased from an October maximum of 28 to an April minimum of 5, then rose to a late summer peak of 27. A local maximum in species numbers may have been present in the February to March period. These changes in species numbers roughly correlate with the changes in composition discussed in the above paragraphs. That is, the maxima and minima of species numbers appear to be related to the periods of transition between the fall, winter-spring, and summer flora. The decline in species numbers from August to October closely parallels the decline previously noted from October to December. Despite the fact that these two periods were slightly offset in the seasonal sequence, the patterns of species composition during these periods are similar.

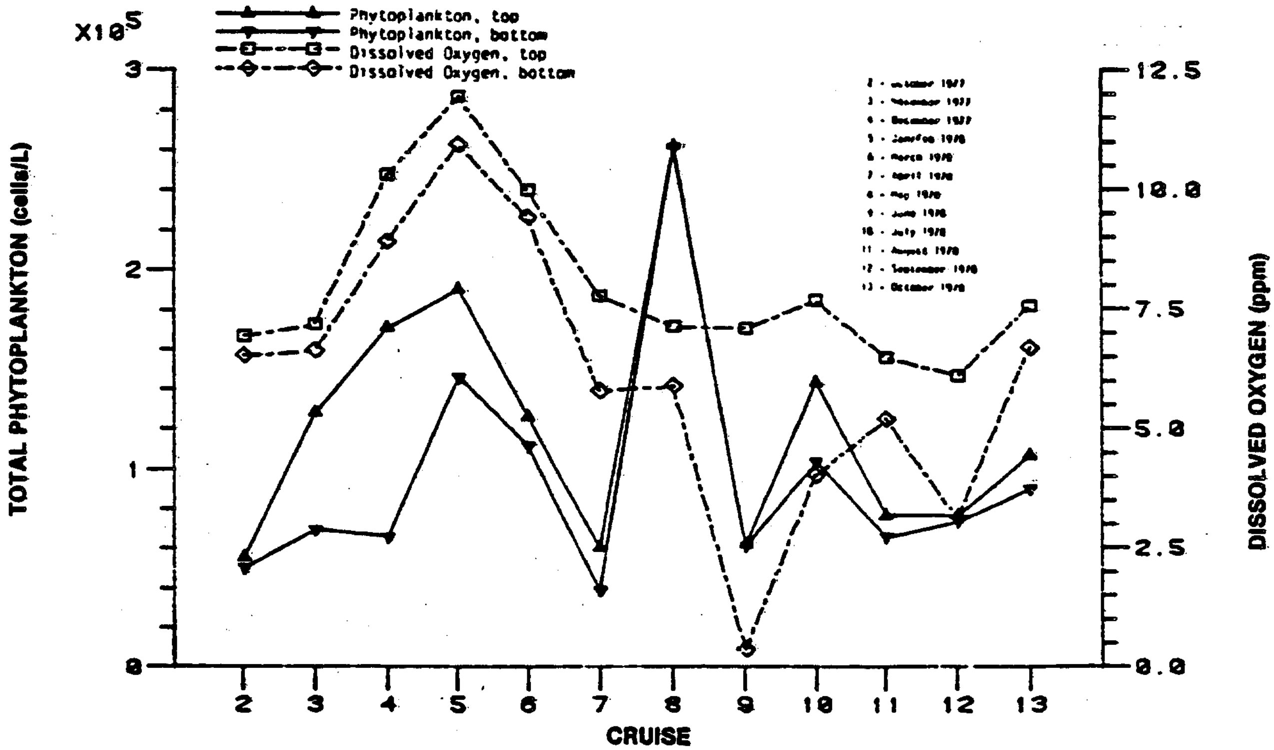


Figure F-25. **Plot of monthly mean values (over all sites) of total phytoplankton (number of cells/L) and dissolved oxygen (ppm) in the Texoma study region for the period October 1977 to October 1978.**

Table F-14. Seasonal distribution of phytoplankton at West Hackberry and Big Hill sites, October 1977 to October 1978 *

DIVISION/Family	Month: Oct	Nov	Dec	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
BACILLARIOPHYTA												
Asterionella japonica	WB	WB	WB	WB	WB							
Bacteriastrum varians	WB								B	B	B	
Biddulphia granulata	WB	WB							B	B	B	
Biddulphia mobiliensis	WB	WB	WB						B	B	B	B
Chaetoceros affinis	WB	WB		WB	WB			B	B	B	B	
Chaetoceros compressus				W	W				B	B	B	B
Chaetoceros curvisetus	W	WB	WB	W	W		WB					
Chaetoceros decipiens	W	WB	WB	WB	WB	WB	WB	B	B	B		B
Chaetoceros peruvianus									B			
Chaetoceros sp.				WB					B	B	B	B
Coscinodiscus centralis	WB	WB	WB	WB	WB	WB	WB	B	B	B	B	B
Coscinodiscus concinnus	W									B	B	B
Coscinodiscus excentricus				WB	WB			B	B	B	B	B
Coscinodiscus granii	W									B		
Coscinodiscus radiatus	W	WB	W	WB	WB		W					
Coscinodiscus sp.		WB	W	W	WB	W			B	B		
Ditylum brightwellii	WB	WB	W	WB	WB		WB					
Ditylum sp.	W	WB		W	W							
Eucampia sp.	B		WB									
Guinardia flaccida	WB	W										
Gyrosigma sp.									B	B	B	
Hemiaulus sp.	WB		WB							B	B	B
Lithodesmium undulatus	WB	W							B	B	B	
Navicula sp.	W	WB										
Nitzschia paradoxa				WB	WB				B	B	B	
Nitzschia seriata	WB	WB	WB	WB	WB							
Pleurosigma sp.							W	B	B	B		
Rhizosolenia acuminata									B	B	B	
Rhizosolenia alata	WB								B	B	B	
Rhizosolenia imbricata	WB	WB	WB	WB	WB		W	B	B	B	B	
Rhizosolenia robusta	W	WB	WB				WB	B	B	B	B	
Rhizosolenia sp.	W	W	WB	WB	WB							
Skeletonema costatum	WB	WB	WB	WB	WB		W	B	B	B	B	B
Skeletonema sp.			W		WB							
Stephanodiscus sp.							WB					
Stephanopyxis sp.				WB	WB							
Surirella sp.	W											
Thalassionema nitzschioides	WB	W	WB	WB	WB	WB	WB					
Thalassiosira decipiens	W	WB		W	W							
Thalassiothrix frauenfeldii	W	WB		W	W				B	B	B	B
Thalassiothrix longissima									B	B	B	B
Thalassiothrix mediterranea							WB					
PYRROPHYTA												
Ceratium tripos	WB	WB			WB	WB	WB	B	B	B		B
Ceratium sp.					WB	WB	WB	B	B	B	B	B
Gymnodinium sp.									B	B	B	B
Peridinium sp.									B	B	B	
Number of Species: Total	29	23	17	21	23	6	14	10	26	28	23	14
West Hackberry	29	23	17	21	23	6	14	--	--	--	--	--
Big Hill	17	19	13	15	18	5	10	10	26	28	23	14

*W--West Hackberry site.
B--Big Hill site.
WB--Both sites.

Table F-15. Seasonal and site patterns of phytoplankton community dominance in the Texoma study area (October 1977 to October 1978).[a]

	Big Hill Cluster				West Hackberry Cluster					
	Big Hill		Big Hill Control		Black Bayou		West Hackberry		West Hackberry Control	
OCT		(6)[b]		(4)		(4)		(20)		(12)
	23.67	Biddulphia granulata	57.65	Biddulphia mobiliensis	28.95	Coscinodiscus centralis	16.23	Biddulphia granulata	23.32	Biddulphia mobiliensis
	17.95	Rhizosolenia alata	10.17	Chaetoceros affinis	27.63	Ceratium tripos	9.65	Coscinodiscus centralis	22.54	Rhizosolenia imbricata
	14.04	Biddulphia mobiliensis	6.13	Coscinodiscus centralis	10.42	Skeletonema costatum	9.57	Rhizosolenia sp.	12.88	Biddulphia granulata
	10.18	Chaetoceros affinis	5.60	Rhizosolenia imbricata	8.11	Biddulphia mobiliensis	9.29	Nitzschia seriata	10.30	Coscinodiscus centralis
	6.37	Nitzschia seriata	4.60	Ditylum brightwellii	8.11	Rhizosolenia imbricata	8.67	Rhizosolenia alata	9.63	Chaetoceros affinis
	6.29	Coscinodiscus centralis	4.08	Thalassionema nitzschioides	4.71	Ditylum brightwellii	7.39	Chaetoceros affinis	4.82	Nitzschia seriata
	4.29	Rhizosolenia imbricata	3.56	Nitzschia seriata	4.71	Nitzschia seriata	6.31	Biddulphia mobiliensis	4.48	Rhizosolenia alata
	3.95	Ditylum brightwellii	3.56	Skeletonema costatum	2.63	Chaetoceros affinis	5.94	Rhizosolenia imbricata	3.38	Skeletonema costatum
	3.93	Skeletonema costatum	2.56	Ceratium tripos	2.08	Asterionella japonica	4.12	Ceratium tripos	2.78	Ceratium tripos
	3.86	Ceratium tripos	1.04	Bacteriastrum varians	1.32	Chaetoceros decipiens	3.52	Skeletonema costatum	2.65	Guinardia flaccida
	3.46	Thalassionema nitzschioides			1.32	Thalassionema nitzschioides	2.99	Navicula sp.	2.06	Ditylum brightwellii
	2.01	Hemiaulus sp.					2.76	Ditylum brightwellii		
							2.16	Surirella sp.		
							1.88	Asterionella japonica		
							1.51	Thalassiosira decipiens		
							1.26	Guinardia flaccida		
							1.20	Bacteriastrum varians		
							1.19	Coscinodiscus concinnus		
NOV		(8)		(4)		(4)		(16)		(8)
	21.88	Rhizosolenia robusta	30.05	Skeletonema costatum	25.67	Skeletonema costatum	16.45	Skeletonema costatum	28.20	Chaetoceros currisetum
	21.37	Skeletonema costatum	29.13	Rhizosolenia robusta	18.52	Rhizosolenia robusta	16.09	Chaetoceros currisetum	19.16	Skeletonema costatum
	11.21	Coscinodiscus centralis	13.25	Chaetoceros curvisetus	12.77	Ceratium tripos	13.02	Chaetoceros decipiens	18.52	Biddulphia mobiliensis
	10.08	Chaetoceros decipiens	11.39	Biddulphia mobiliensis	11.40	Chaetoceros curvisetus	12.50	Coscinodiscus centralis	8.08	Nitzschia seriata
	7.44	Biddulphia mobiliensis	4.31	Chaetoceros affinis.	10.52	Chaetoceros affinis	9.08	Rhizosolenia robusta	5.67	Chaetoceros decipiens
	4.88	Nitzschia seriata	2.69	Ceratium tripos	7.40	Coscinodiscus centralis	6.40	Biddulphia mobiliensis	5.49	Chaetoceros affinis
	3.32	Chaetoceros curvisetus	2.55	Coscinodiscus sp.	6.32	Chaetoceros decipiens	5.83	Chaetoceros affinis	3.89	Rhizosolenia robusta
	2.53	Ditylum brightwellii	2.04	Chaetoceros decipiens	4.28	Biddulphia mobiliensis	3.44	Nitzschia seriata	3.45	Coscinodiscus centralis
	2.03	Ceratium tripos	1.53	Ditylum brightwellii	3.12	Asterionella japonica	2.78	Ceratium tripos	2.86	Navicula sp.
	1.93	Coscinodiscus radiatus	1.02	Asterionella japonica			2.61	Rhizosolenia imbricata	1.68	Ceratium tripos
	1.39	Asterionella japonica	1.02	Coscinodiscus radiatus			2.02	Ditylum brightwellii	1.68	Coscinodiscus radiatus
	1.34	Navicula sp.					1.92	Coscinodiscus radiatus	1.04	Rhizosolenia imbricata
							1.73	Rhizosolenia sp.		
							1.55	Biddulphia granulata		
							1.09	Navicula sp.		
DEC		(8)		(4)		(4)		(16)		(8)
	53.50	Skeletonema costatum	56.14	Skeletonema costatum	56.65	Skeletonema costatum	31.31	Skeletonema costatum	57.58	Skeletonema costatum
	17.58	Rhizosolenia robusta	22.54	Rhizosolenia robusta	18.02	Rhizosolenia robusta	25.68	Rhizosolenia robusta	20.88	Rhizosolenia robusta
	10.30	Chaetoceros curvisetus	11.61	Chaetoceros curvisetus	11.53	Chaetoceros curvisetus	20.78	Chaetoceros curvisetus	9.41	Chaetoceros curvisetus
	7.29	Thalassionema nitzschioides	4.69	Thalassionema nitzschioides	3.99	Thalassiunema nitzschioides	8.11	Coscinodiscus centralis	4.50	Chaetoceros decipiens
	4.81	Coscinodiscus centralis	2.34	Coscinodiscus centralis	3.37	Coscinodiscus centralis	4.20	Chaetoceros decipiens	3.04	Coscinodiscus centralis
	2.00	Chaetoceros decipiens	1.79	Asterionella japonica	2.49	Chaetoceros decipiens	2.27	Eucampia sp.	2.07	Thalassionema nitzschioides
					1.32	Eucampia sp.	2.19	Thalassionema nitzschioides		
							2.16	Hemiaulus sp.		
							1.14	Asterionella japonica		

Table F-15 (continued)

	Big Hill Cluster		West Hackberry Cluster		
	Big Hill	Big Hill Control	Black Bayou	West Hackberry	West Hackberry Control
FEB	(8) 24.82 Coscinodiscus centralis 16.33 Asterionella japonica 15.41 Thalassionema nitzschioides 11.34 Chaetoceros decipiens 7.45 Coscinodiscus radiatus 7.02 Ditylum brightwellii 4.65 Chaetoceros affinis 4.44 Stephanopyxis sp. 3.27 Coscinodiscus excentricus 3.00 Skeletonema costatum 1.75 Rhizosolenia imbricata	NO DATA	(2) 28.40 Asterionella japonica 24.30 Coscinodiscus centralis 23.43 Ditylum brightwellii 13.49 Thalassionema nitzschioides 6.40 Coscinodiscus radiatus 4.97 Stephanopyxis sp.	(14) 29.08 Asterionella japonica 15.08 Nitzschia seriata 12.40 Coscinodiscus centralis 7.73 Skeletonema costatum 6.96 Chaetoceros decipiens 6.62 Thalassionema nitzschioides 5.01 Ditylum brightwellii 3.83 Chaetoceros affinis 2.44 Rhizosolenia imbricata 2.14 Coscinodiscus sp. 2.07 Ditylum sp. 1.74 Chaetoceros compressus 1.70 Coscinodiscus radiatus 1.29 Nitzschia paradoxa	(8) 21.29 Asterionella japonica 20.30 Coscinodiscus centralis 12.37 Thalassionema nitzschioides 9.26 Skeletonema costatum 8.14 Chaetoceros decipiens 7.09 Coscinodiscus radiatus 6.38 Chaetoceros affinis 5.40 Nitzschia seriata 3.88 Ditylum brightwellii 2.39 Rhizosolenia imbricata 1.23 Stephanopyxis sp. 1.19 Nitzschia paradoxa
MAR	(8) 25.20 Coscinodiscus centralis 12.81 Ceratium tripos 11.76 Asterionella japonica 9.55 Ditylum brightwellii 9.02 Thalassionema nitzschioides 7.04 Chaetoceros decipiens 6.18 Coscinodiscus radiatus 5.44 Chaetoceros affinis 3.54 Coscinodiscus excentricus 2.94 Skeletonema costatum 1.86 Rhizosolenia imbricata 1.79 Skeletonema sp. 1.61 Stephanopyxis sp. 1.27 Ceratium sp.	(4) 37.65 Coscinodiscus centralis 17.47 Asterionella japonica 10.96 Chaetoceros affinis 10.52 Ceratium tripos 8.33 Nitzschia seriata 7.04 Thalassionema nitzschioides 5.85 Coscinodiscus sp. 2.17 Ditylum brightwellii	(4) 33.49 Coscinodiscus centralis 16.34 Asterionella japonica 14.81 Ditylum brightwellii 12.33 Thalassionema nitzschioides 12.06 Ceratium tripos 3.82 Chaetoceros decipiens 3.82 Stephanopyxis sp. 3.33 Thalassiothrix frauenfeldii	(17) 29.04 Asterionella japonica 16.95 Coscinodiscus centralis 10.31 Skeletonema costatum 9.54 Nitzschia seriata 7.08 Ditylum brightwellii 6.34 Chaetoceros affinis 4.45 Ceratium tripos 4.45 Thalassionema nitzschioides 2.98 Chaetoceros decipiens 1.77 Rhizosolenia imbricata 1.28 Ceratium sp. 1.22 Chaetoceros compressus 1.15 Coscinodiscus radiatus	(8) 17.68 Coscinodiscus centralis 16.97 Asterionella japonica 13.84 Skeletonema costatum 9.06 Ceratium tripos 7.19 Chaetoceros affinis 6.32 Ditylum brightwellii 5.81 Thalassionema nitzschioides 5.26 Chaetoceros decipiens 3.97 Coscinodiscus radiatus 3.50 Nitzschia seriata 3.20 Rhizosolenia imbricata 3.13 Coscinodiscus sp. 1.30 Nitzschia paradoxa 1.26 Rhizosolenia sp.
APR	(7) 77.58 Coscinodiscus centralis 16.84 Ceratium tripos 4.85 Chaetoceros decipiens	(4) 90.53 Coscinodiscus centralis 4.41 Chaetoceros decipiens 3.22 Ceratium tripos 1.47 Ceratium sp.	(4) 72.36 Coscinodiscus centralis 22.89 Ceratium tripos 4.75 Chaetoceros decipiens	(12) 73.09 Coscinodiscus centralis 15.63 Ceratium tripos 5.70 Ceratium sp. 5.58 Coscinodiscus sp.	(8) 57.31 Coscinodiscus centralis 33.98 Ceratium tripos 8.29 Chaetoceros decipiens
MAY	(6) 51.46 Thalassiothrix mediterranea 37.08 Coscinodiscus centralis 5.51 Ceratium tripos 4.05 Ceratium sp. 1.35 Rhizosolenia robusta	(2) 27.26 Ceratium tripos 25.63 Coscinodiscus centralis 17.26 Thalassionema nitzschioides 10.37 Rhizosolenia robusta 7.04 Chaetoceros decipiens 6.67 Ceratium sp. 4.00 Ditylum brightwellii 1.11 Stephanodiscus sp.	(2) 54.78 Thalassiothrix mediterranea 12.84 Chaetoceros decipiens 9.28 Coscinodiscus centralis 9.26 Rhizosolenia robusta 8.75 Ceratium tripos 4.61 Thalassionema nitzschioides	(14) 64.32 Thalassiothrix mediterranea 13.63 Chaetoceros decipiens 6.42 Coscinodiscus centralis 3.90 Ditylum brightwellii 3.69 Skeletonema costatum 2.14 Rhizosolenia robusta 1.67 Ceratium tripos 1.52 Ceratium sp. 1.16 Rhizosolenia imbricata	(10) 57.34 Coscinodiscus centralis 30.91 Thalassiothrix mediterranea 4.63 Ditylum brightwellii 4.62 Ceratium tripos 2.50 Ceratium sp.

Table F-15 (continued)

	Big Hill Cluster				West Hackberry Cluster		
	Big Hill		Big Hill Control		Black Bayou	West Hackberry	West Hackberry Control
JUN		(16)		(4)	NO SAMPLES	NO SAMPLES	NO SAMPLES
	12.33	Ceratium tripos	16.49	Ceratium tripos			
	11.37	Coscinodiscus excentricus	14.62	Rhizosolenia imbricata			
	11.15	Coscinodiscus centralis	12.94	Ceratium sp.			
	10.07	Chaetoceros affinis	12.12	Pleurosigma sp.			
	9.99	Pleurosigma sp.	11.47	Biddulphia mobiliensis			
	9.98	Biddulphia mobiliensis	8.81	Coscinodiscus excentricus			
	9.26	Rhizosolenia imbricata	8.75	Coscinodiscus centralis			
	8.96	Chaetoceros decipiens	7.96	Chaetoceros affinis			
	6.57	Rhizosolenia robusta	2.72	Rhizosolenia robusta			
	6.38	Ceratium sp.	2.72	Skeletonema costatum			
	3.93	Skeletonema costatum	1.39	Chaetoceros decipiens			
JUL		(16)		(4)	NO SAMPLES	NO SAMPLES	NO SAMPLES
	9.21	Rhizosolenia alata	12.24	Rhizosolenia acuminata			
	8.86	Ceratium sp.	9.13	Chaetoceros decipiens			
	8.25	Bacteriastrum varians	8.80	Coscinodiscus centralis			
	7.90	Rhizosolenia acuminata	8.12	Ceratium sp.			
	7.60	Biddulphia mobiliensis	7.59	Biddulphia mobiliensis			
	6.88	Biddulphia granulata	7.26	Bacteriastrum varians			
	6.84	Chaetoceros affinis	6.78	Gymnodinium sp.			
	6.65	Coscinodiscus centralis	6.76	Biddulphia granulata			
	6.49	Skeletonema costatum	5.62	Chaetoceros affinis			
	6.17	Chaetoceros decipiens	5.43	Skeletonema costatum			
	6.10	Gymnodinium sp.	4.25	Chaetoceros compressus			
	4.59	Chaetoceros compressus	3.88	Coscinodiscus sp.			
	4.45	Coscinodiscus sp.	3.82	Chaetoceros peruvianus			
	2.10	Thalassiothrix frauenfeldii	3.63	Rhizosolenia alata			
	1.86	Pleurosigma sp.	1.99	Peridinium sp.			
	1.47	Gyrosigma sp.	1.97	Thalassiothrix frauenfeldii			
	1.16	Rhizosolenia imbricata	1.69	Chaetoceros sp.			
			1.04	Rhizosolenia robusta			
AUG		(16)		(4)	NO SAMPLES	NO SAMPLES	NO SAMPLES
	8.84	Biddulphia granulata	16.73	Chaetoceros compressus			
	7.79	Rhizosolenia acuminata	15.79	Biddulphia mobiliensis			
	6.79	Chaetoceros decipiens	15.53	Rhizosolenia robusta			
	6.60	Chaetoceros sp.	13.90	Rhizosolenia acuminata			
	5.81	Biddulphia mobiliensis	10.49	Chaetoceros affinis			
	5.66	Gyrosigma sp.	10.02	Coscinodiscus centralis			
	5.61	Coscinodiscus concinnus	8.85	Biddulphia granulata			
	4.96	Thalassiothrix longissima	5.74	Thalassiothrix longissima			
	4.79	Bacteriastrum varians	1.47	Thalassiothrix frauenfeldii			
	4.56	Coscinodiscus centralis	1.47	Chaetoceros sp.			
	4.01	Ceratium sp.					
	4.01	Gymnodinium sp.					
	3.68	Skeletonema costatum					
	3.65	Thalassiothrix frauenfeldii					
	3.25	Chaetoceros affinis					
	2.85	Rhizosolenia alata					
	2.61	Chaetoceros compressus					
	2.53	Coscinodiscus excentricus					
	2.37	Nitzschia paradoxa					
	2.14	Ceratium tripos					
	1.76	Rhizosolenia robusta					
	1.44	Hemiaulus sp.					
	1.25	Coscinodiscus sp.					
	1.09	Rhizosolenia imbricata					

Table F-15 (continued)

	Big Hill Cluster				West Hackberry Cluster		
	Big Hill		Big Hill Control		Black Bayou	West Hackberry	West Hackberry Control
SEP		(16)		(4)	NO SAMPLES	NO SAMPLES	NO SAMPLES
	9.10	Rhizosolenia acuminata	20.53	Coscinodiscus centralis			
	8.35	Coscinodiscus centralis	15.67	Nitzschia paradoxa			
	8.12	Skeletonema costatum	13.40	Chaetoceros sp.			
	7.60	Biddulphia mobiliensis	8.54	Coscinodiscus concinnus			
	6.29	Biddulphia granulata	8.15	Rhizosolenia acuminata			
	6.21	Chaetoceros affinis	7.73	Skeletonema costatum			
	5.47	Chaetoceros compressus	6.78	Thalassiothrix frauenfeldii			
	5.20	Rhizosolenia imbricata	6.36	Biddulphia granulata			
	4.79	Chaetoceros sp.	4.67	Ceratium sp.			
	4.54	Bacteriastrum varians	4.44	Biddulphia mobiliensis			
	4.52	Ceratium sp.	2.64	Bacteriastrum varians			
	4.52	Coscinodiscus concinnus	1.09	Peridinium sp.			
	4.14	Gyrosigma sp.					
	3.95	Gymnodinium sp.					
	2.91	Nitzschia paradoxa					
	2.85	Hemiaulus sp.					
	2.83	Thalassiothrix longissima					
	2.69	Coscinodiscus excentricus					
	2.16	Rhizosolenia alata					
	1.63	Rhizosolenia robusta					
	1.40	Lithodesmium undulatum					
OCT		(16)		(4)	NO SAMPLES	NO SAMPLES	NO SAMPLES
	12.85	Chaetoceros compressus	11.85	Biddulphia granulata			
	9.71	Chaetoceros sp.	9.03	Coscinodiscus centralis			
	9.69	Skeletonema costatum	8.93	Chaetoceros decipiens			
	8.39	Chaetoceros decipiens	8.07	Thalassiothrix frauenfeldii			
	8.36	Coscinodiscus centralis	7.97	Skeletonema costatum			
	8.28	Biddulphia granulata	7.50	Coscinodiscus excentricus			
	6.67	Coscinodiscus concinnus	7.26	Ceratium sp.			
	6.61	Hemiaulus sp.	7.02	Chaetoceros compressus			
	6.59	Coscinodiscus excentricus	6.93	Gymnodinium sp.			
	6.26	Thalassiothrix frauenfeldii	6.69	Thalassiothrix longissima			
	5.02	Thalassiothrix longissima	6.59	Ceratium tripos			
	5.00	Ceratium sp.	5.49	Hemiaulus sp.			
	4.27	Gymnodinium sp.	4.14	Coscinodiscus concinnus			
	1.84	Ceratium tripos	2.18	Chaetoceros sp.			

[a]Only species comprising 1% or more of the community are shown.

[b]Number in parantheses is the number of samples on which composition is based.

Results of reciprocal averaging ordination for Big Hill and BHC sites showed essentially temporal trends, with no site-to-site differences particularly evident (Figs. F-26 and F-27). Samples group out according to cruise (month of collection). Three groupings of samples from the Big Hill cluster of sites are apparent on the first two axes of the ordination analysis: (1) late fall through early winter (October through December); (2) midwinter through spring (February through May); and (3) late spring through summer (June through October). Again, the ordination display labeled by site shows no pattern. Figure F-28 shows the species that are most characteristic of each area of the display. In general, these species correspond to those identified from the community composition presented above.

Tables F-16 and F-17 summarize the results of the factor analysis of phytoplankton species densities, showing the seasonality of occurrence characterized by the species loading on each factor. Results generally confirm those seen in the ordination analysis. The overwhelming trend was for the community to show distinct seasonal transitions.

Zooplankton

Zooplankton standing crops at the Big Hill site showed highest means during the March through July period (Table F-18, Fig. F-29), while relatively high means were also found at the West Hackberry sites in September 1977. Lowest means were found during the October to February period. Over the entire 13-month study, means for the Big Hill sites were 2,500 to 3,600 individuals/m^3, with BHC showing the greatest vertical range. Zooplankton numbers did not respond to the increased densities of phytoplankton in the late fall of 1977, possibly due to temperature limitations. However, the near-bottom samples did show a very sharp increase in concentration of zooplankton, possibly because of the increased detrital pool resulting from the apparent phytoplankton die-off in the winter of 1978. During May, and apparently in response to the phytoplankton bloom occurring at the time, near-surface zooplankton density increased sharply, to be followed, during July and August sampling, by the highest near-bottom densities of the study for zooplankton. Again, these increased near-bottom densities may have been in response to an increase in the labile particulate organic pool in the near-bottom waters resulting from a previous phytoplankton die-off. The near-surface densities remained at about the level of May. Sharp decreases for densities in both layers of the water column were seen in August.

Because of their peak in the midspring to midsummer period, total zooplankton were negatively correlated with dissolved oxygen (-0.43) and positively correlated with temperature (0.58), while correlations with salinities were not significant. Zooplankton numbers remained relatively high over a wide range of salinities during this midspring to midsummer period.

During the course of the study, 119 zooplankton taxonomic groups were differentiated in samples from the Texoma study area (Table F-19). It is noted that, during the period when samples were taken at West Hackberry and Big Hill sites, the majority of taxa were present in both

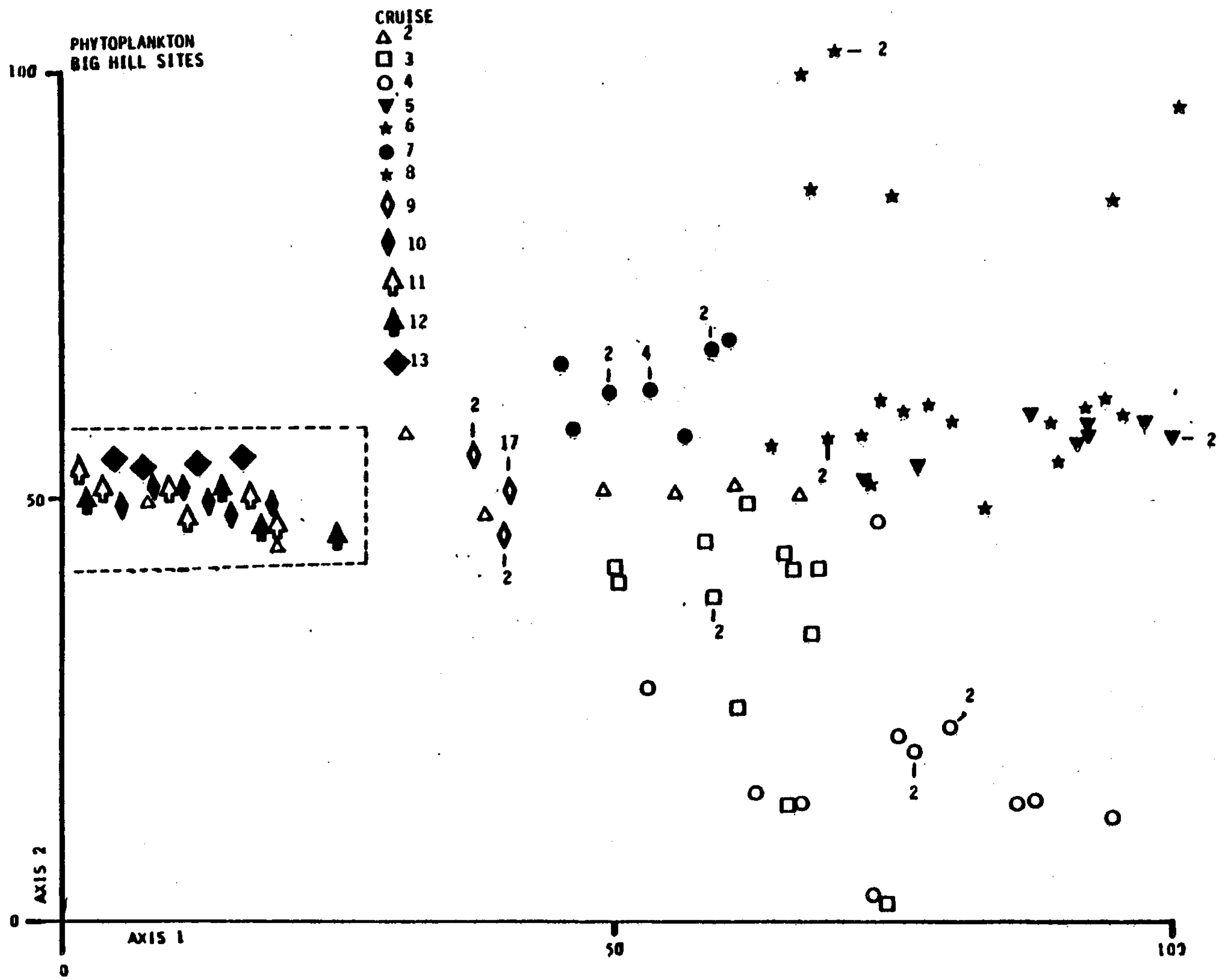


Figure F-26. Sample ordinations of phytoplankton data from the Big Hill sites labeled by cruise. The area delineated by the box has hidden samples including 2 from cruise 2, 16 from cruise 10, 16 from cruise 11, 21 from cruise 12, and 17 from cruise 13.

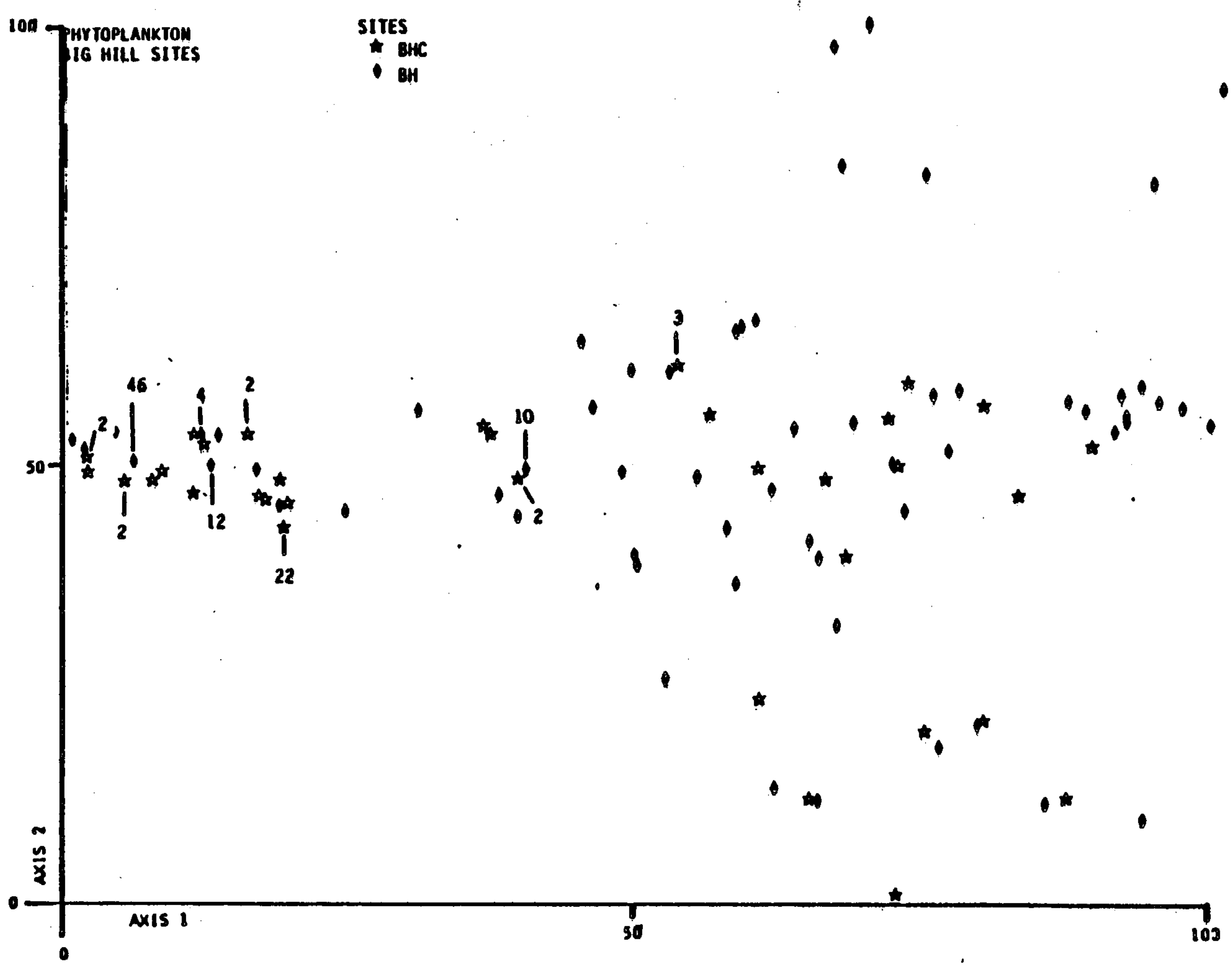


Figure F-27. Sample ordination of phytoplankton data labeled by site.

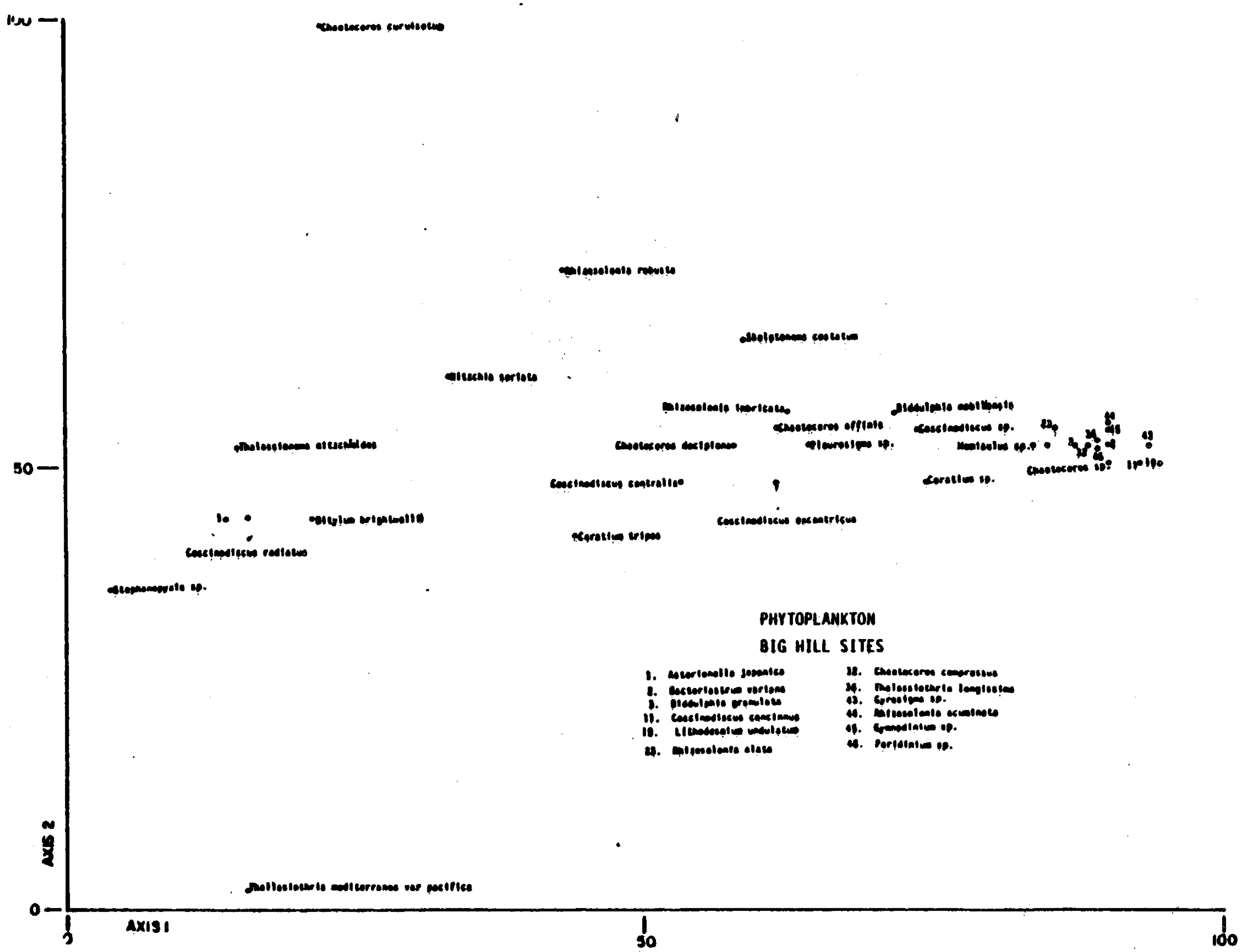


Figure F-28. Species ordination using phytoplankton at the Big Hill cluster of sites.

Table F-16. Monthly mean factor scores for the phytoplankton data set for the Big Hill sites (October 1977 - October 1978)

Month	Factor 2	Factor 6	Factor 5	Factor 4	Factor 8	Factor 3	Factor 7	Factor 1
October 77	-1.9472	0.4960	0.0399	0.3188	-0.9975	0.2091	0.4451	0.2336
November	-0.9487	-1.8351	-0.2968	0.2232	-0.0649	0.3932	0.3335	0.6055
December	0.4075	-1.0867	0.4357	0.4484	-0.7862	0.7523	0.2610	0.6298
Jan/Feb	0.3977	0.0552	-2.7580	0.1380	0.2891	0.5742	0.4328	0.5086
March	0.0428	0.2126	-1.2704	0.0097	0.1088	0.4816	0.3958	0.5980
April	0.5457	0.2881	0.1472	-0.4914	-0.4690	0.6415	0.3076	0.6022
May	0.5424	-0.1370	-0.0716	-3.6865	-0.6104	0.6721	0.4018	0.6962
June	-0.0054	0.2123	0.2950	0.2537	1.1954	0.5052	0.3394	0.6478
July	-0.3207	0.2973	0.4129	0.0937	0.0978	-2.0546	-0.3033	0.0208
August	0.2242	0.2622	0.3654	0.3149	-0.1287	-0.2973	-0.5874	-0.4123
September	0.1736	0.4232	0.4436	0.3273	-0.3181	-0.2302	-0.9743	-0.4136
October 78	0.5527	0.0472	0.2063	0.1739	0.5642	0.0585	0.2115	-2.1141

Table F-17. Summary of major factor loadings and seasonality of the phytoplankton data set for the Big Hill sites (October 1977 - October 1978)

Phytoplankton species	Seasonal occurrence	Promax-rotated factor loadings[1]
Factor 2		
Nitzchia seriata (21)	Oct-Nov	-0.813
Biddulphia mobiliensis (4)	Oct-Nov	-0.718
Chaetoceros affinis (6)	Oct-Nov	-0.672
Rhizosolenia imbricata (24)	Oct, Jun-Sep	-0.524
*Rhizosolenia alata (23)	Oct, Jul	-0.445
*Biddulphia granulata (3)	Oct, Jul-Oct	-0.427
*Ditylum brightwellii (15)	Oct-Nov, Feb-Mar	-0.414
Factor 6		
Skeletonema costatum (26)	Nov-Dec	-0.594
Rhizosolenia robusta (25)	Nov-Dec	-0.810
Chaetoceros curvisetus (7)	Nov-Dec	-0.891
Chaetoceros decipiens (8)	Nov, Feb	-0.610
*Coscinodiscus radiatus (13)	Nov, Feb-Mar	-0.374
*Thalassiothrix frauenfeldii (31)	Nov, Jul-Oct	-0.398
Factor 5		
Stephanopyxis sp. (35)	Feb-Mar	-0.850
Asterionella japonica (1)	Feb-Mar	-0.754
Thalassionema nitzchioides	Feb-Mar	-0.595
*Ditylum brightwellii (15)	Feb-Mar, Oct-Nov	-0.583
*Coscinodiscus radiatus (13)	Feb-Mar, Nov	-0.487
Factor 4		
Ceratium sp. (38)	May, Jul, Aug-Oct	-0.720
Thalassiothrix mediterranea (40)	May	-0.801
Coscinodiscus centralis (10)	April-May (present all year)	-0.942
Ceratium tripos (5)	Mar, May	-0.482
Factor 8		
*Coscinodiscus excentricus (33)	Jun, Oct	0.661
Pleurosigma sp. (41)	Jun	0.592
Factor 3		
*Rhizosolenia alata (23)	Oct, Jul	-0.478
Bacteriastrum varians (2)	Jul-Sep	-0.836
Gymnodinium sp. (45)	Jul-Oct	-0.729
Rhizosolenia acuminata (44)	Jul-Sep	-0.697
Coscinodiscus sp. (9)	Jul	-0.565
Factor 7		
Nitzchia paradoxa (34	Sep	-0.763
Gyrosigma sp. (43)	Aug-Sep	-0.500
Lithodesmium undulatum (19)	Sep	-0.600
Factor 1		
Hemiaulus sp. (18)	Sep-Oct	-0.736
Chaetoceros sp. (37)	Aug-Oct	-0.811
Chaetoceros compressus (37)	Aug-Oct	-0.702
Coscinodiscus concinnus (11)	Aug-Oct	-0.675
Thalassiothrix longissima (36)	Aug-Oct	-0.608
*Thalassiothrix frauenfeldii (31)	Jul-Oct, Nov	-0.517
*Biddulphia granulata (3)	Oct, Jul-Oct	-0.505
*Coscinodiscus excentricus (33)	Jun, Oct	-0.369

[1]Minimum residuals factoring with Promax (oblique) rotation was used in the analysis.

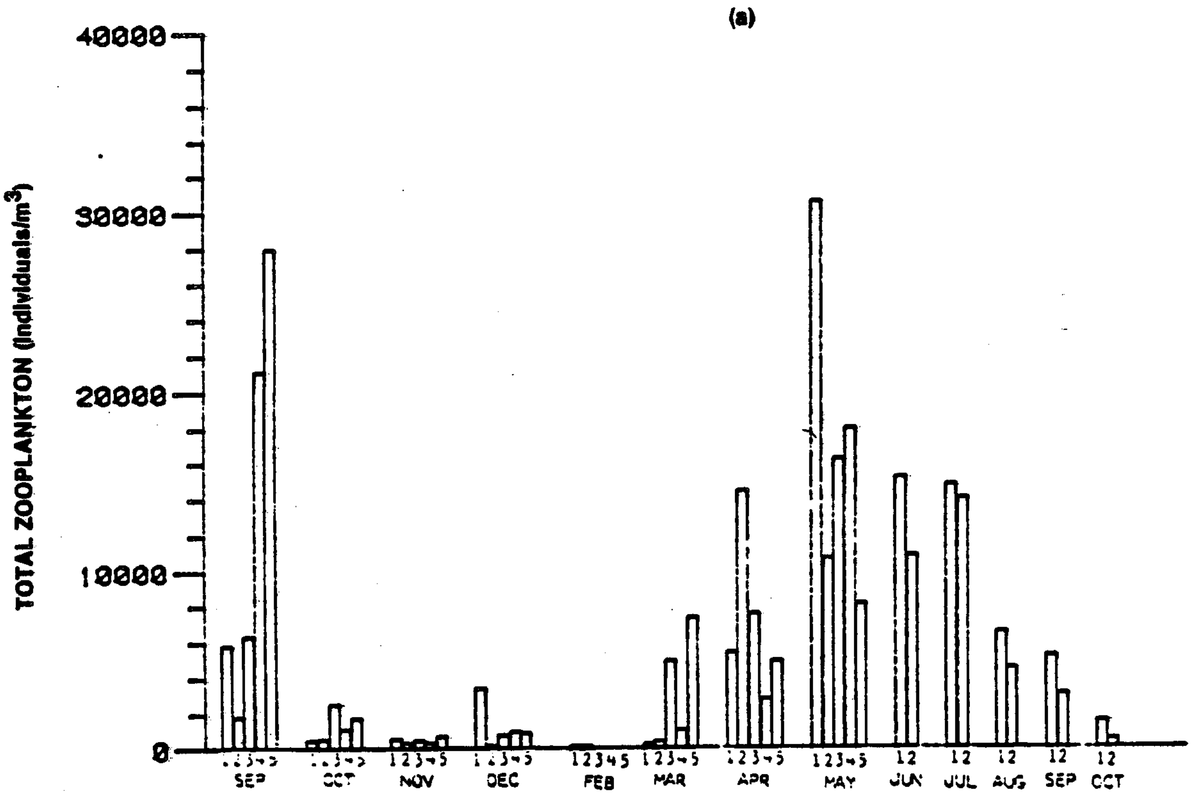
*Denotes species loading on 2 factors.

Table F-18. Mean number of zooplankton individuals for five sites in the Texoma region by depth, site, and cruise (September 1977 to October 1978)

Month	Big Hill Top	Big Hill Bottom	Big Hill Control Top	Big Hill Control Bottom	Big Hill Cluster Top	Big Hill Cluster Bottom	Black Bayou Top	Black Bayou Bottom	West Hackberry Top	West Hackberry Bottom	West Hackberry Control Top	West Hackberry Control Bottom	West Hackberry Cluster Top	West Hackberry Cluster Bottom	Overall Top	Overall Bottom
SEPT	5016	2035	1810	-----	3941	2035	6318	21-65	22126	19321	27945	17248	20488	18711	14735	14413
CL*					(396-39108)	(1-8)							(14524-28864)	(15772-22156)	(9152-23720)	(9380-22104)
N**	2	2	1	0	3	2	1	1	8	9	3	5	12	15	15	17
OCT	475	11367	569	12293	497	2368	2538	370	1139	958	1715	1174	1729	922	1032	1233
CL					(360-686)	(769-7285)							(701-2606)	(551-1546)	(658-1617)	(759-1998)
N	6	6	2	2	8	8	2	2	10	10	6	6	10	10	26	26
NOV	538	650	320	1952	453	938	455	462	341	764	703	343	437	565	442	658
CL					(177-1160)	(282-3111)							(255-748)	(320-997)	(287-697)	(402-1075)
N	4	4	2	2	6	6	2	2	8	8	4	4	14	14	20	20
DEC	1420	840	234	10859	1400	1972	790	2708	943	3381	920	974	910	2296	1050	2235
CL					(419-4678)	(162-23876)							(462-1789)	(1104-4769)	(605-1820)	(1194-4180)
N	4	2	2	1	6	3	2	2	7	8	3	4	12	14	18	17
JAN/FEB	77	83	173	71	101	79	107	202	101	55	30	32	62	50	75	60
CL					(50-201)	(45-138)							(35-110)	(28-90)	(49-113)	(40-88)
N	4	4	2	2	6	6	1	1	5	5	4	4	10	10	16	16
MAR	277	501	400	2801	304	771	4922	6349	1062	516	7380	1069	2403	870	1272	838
CL					(163-565)	(331-1797)							(1317-4377)	(524-1441)	(736-2198)	(556-1263)
N	6	6	2	2	8	8	2	2	10	10	6	6	18	18	26	26
APR	5423	17797	14490	26019	7525	20199	7557	1915	2762	29152	4945	27296	3767	17414	4636	18206
CL					(4537-12478)	(14020-29076)							(2258-6282)	(10626-28532)	(3148-6833)	(12861-25744)
N	4	4	2	2	6	6	2	2	8	8	4	4	14	14	20	20
MAY	30675	3953	10707	8553	21598	5113	16310	5226	17993	8852	8114	33656	13871	12311	15953	9328
CL					(13257-35158)	(1334-19554)							(10724-17919)	(6314-23987)	(12577-19816)	(5202-16696)
N	4	4	2	2	6	6	2	2	7	7	4	4	13	13	19	19
OVERALL	1127	1440	938	3520	1065	1578	2399	1798	1722	2277	2050	1959	1894	2110	1588	1945
CL	(633-2000)	(647-2007)	(424-2075)	(1264-9788)	(668-1694)	(946-2629)	(1040-5532)	(823-3926)	(1148-2579)	(1479-3504)	(1114-3772)	(1028-3726)	(1392-2572)	(1523-2918)	(1231-2044)	(1487-2542)
N	34	32	15	13	49	45	14	14	63	65	34	37	111	116	160	161
JUN	15229	23063	10872	17797	14236	21897	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES	
CL					(11178-18122)	(16814-28507)										
N	8	8	2	2	10	10										
JUL	14847	21761	14047	10775	14684	21128	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES	
CL					(11229-19179)	(17744-25137)										
N	8	8	2	2	10	10										
AUG	6563	3620	4531	4059	6094	3704	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES	
CL					(4544-8169)	(2311-5931)										
N	8	8	2	2	10	10										
SEP	5186	7914	3075	4285	4671	7000	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES	
CL					(3266-6676)	(4464-10960)										
N	8	8	2	2	10	10										
OCT	1533	2138	475	1839	1213	2075	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES	
CL					(786-1869)	(1430-3010)										
N	8	8	2	2	10	10										
OVERALL	1533	2138	475	1839	1213	2076	NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES		NO SAMPLES	
CL	(2074-4081)	(2350-4747)	(929-3013)	(2480-8378)	(1891-3390)	(2662-4869)										
N	74	72	25	23	99	96										

*95% Confidence Limits.

**N = Number of Samples.



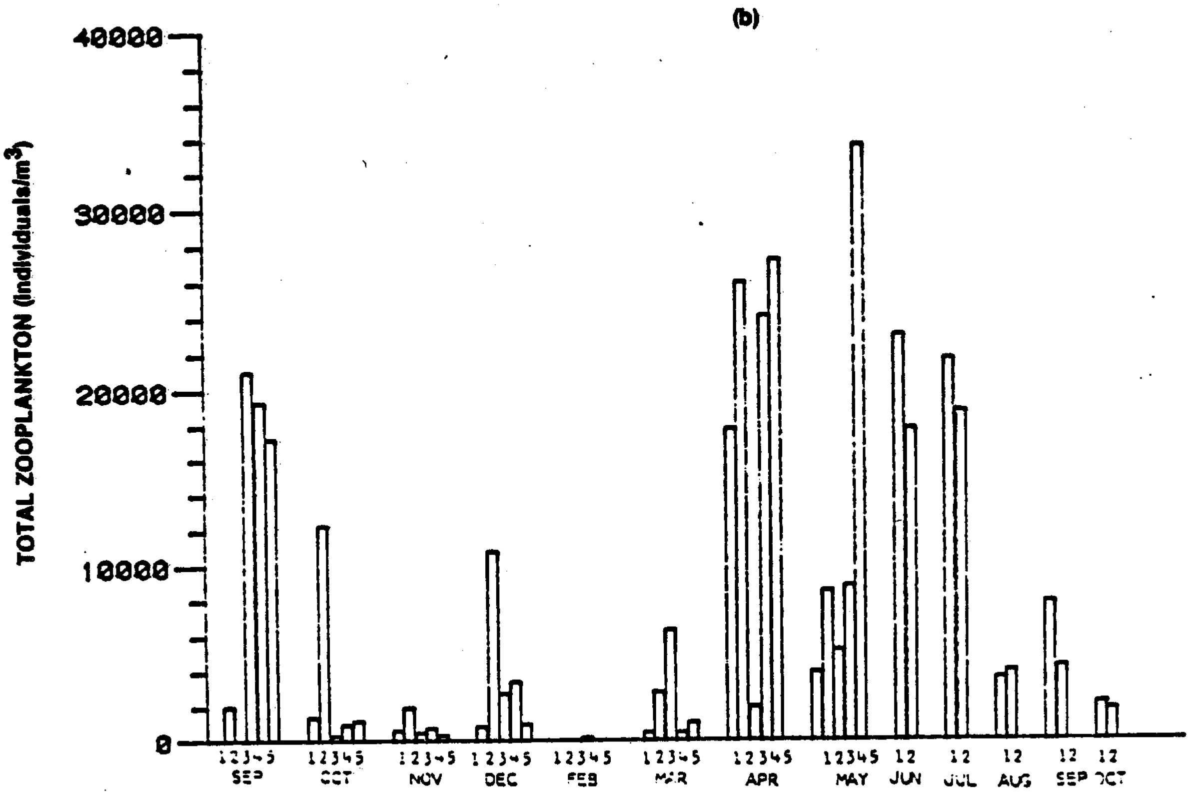


Figure F-29. **Total abundance of zooplankton (individuals/m^3): (a) top samples, (b) bottom samples.**

Table F-19. Seasonal distribution of zooplankton at West Hackberry and Big Hill sites, September 1977 to October 1978.

PHYLUM/Species	Month: Sep	Oct	Nov	Dec	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
PROTOZOA													
Globigerina inflata			WB										
Globigerina sp.				W									
Noctiluca sp.		WB	WB	W	WB	WB	WB	WB					
Unidentified tintinnid	W		W		W	W							
COELENTERATA													
Hyroid medusae								WB					
Muggiaea sp.		W											
Obelia sp.			W	W									
Turritopsis nutricula		B											
Unidentified anthomedusid	WB	WB	W		W	WB	WB	WB	B	B	B	B	B
Unidentified leptomedusid	WB	WB	WB	WB				W	B	B	B	B	B
Unidentified siphonophorid		WB	WB										
CTENOPHORA													
Beroe sp.						W	W						
Bolinopsis infundibulum			W										
Mnemiopsis sp.		B											
Pleurobrachia sp.		B											
Unidentified ctenophore	WB	WB	WB	WB			W	W					
ROTIFERA													
Synchaeta sp.	W		WB	WB	WB	WB	B	W					
MOLLUSCA													
Ensis minor				B									
Gastropod larvae					W	WB	WB	WB					
Janthina exiqua		W											
Lamellibranch larvae					WB	B	WB	WB					
Litiopa melanostoma		W											
Prosobranch larvae	W	W	WB	WB									
Unidentified gastropod						W	W	W					
Unidentified opisthobranch	W	WB	WB	WB									
Unidentified pteropod						WB	WB	WB					
Venerid larvae	W	WB	WB	WB									
ANNELIDA													
Magelona sp. larvae			B				B						
Nectochaete larvae			B				B						
Polychaete larvae	WB	WB	WB	WB	B	WB	WB	WB	B	B	B	B	B
Tomopteris septentrionalis			W										
Unidentified spionid								WB					
ARTHROPODA													
Acartia spp.	WB	WB	WB	WB	WB	WB	WB	WB	B	B	B	B	B
Acetes americanus	W	B				W							
Anomuran larvae	WB	W					W						
Barnacle nauplii	WB	WB	WB	WB	WB	WB	WB	WB					
Brachyuran larvae		W						WB	B	B	B	B	B
Brachyuran megalops	W					WB		B	B	B	B	B	
Caridean								WB					
Centropages furcatus	WB	WB	WB										
Candacia sp.												B	
Conchoecia elegans		WB											
Conchoecia sp.				W		W	W						
Copepod nauplii	WB	WB	WB	WB	WB	WB	WB	WB	B	B	B	B	B
Copilia sp.									B	B			

Table F-19 (continued)

PHYLUM/Species	Sep	Oct	Nov	Dec	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
	Month												
Coryaceus amazonicus	W	WB	WB	WB		W	WB	WB					
Crustacean nauplii	W												
Cyprid larvae	WB	WB	W	WB	WB	WB	W	W					
Decapod zoea	W	WB											
Eucalanus pileatus	WB	WB	WB	B		WB	WB	WB	B	B	B	B	B
Euterpina acutifrons	WB	WB	WB	WB	W		WB	WB		B	B	B	B
Euphausid larvae		W	WB				WB	WB					
Ertemocaris sp. larvae		W											
Galathea sp. larvae	W	WB	W										
Halocypris brevirostris		B											
Hyperia sp.		B	B			W		W					
Labidocera spp.	WB	WB	W	WB		W		W	B	B	B	B	B
Labidocera spp. nauplii	W	WB	WB	WB	WB	W	WB	WB					
Lucifer faxoni	WB	W	W				WB	B	B	B	B	B	B
Lysiosquilla sp.								W					
Macrosetella gracilis				W		W							
Macruran larvae		W											
Meganyctiphanes norvegica	W	WB	WB										
Miracia efferata				W									
Oithona nana	WB	WB	WB	WB	WB	WB	WB	WB	B	B	B	B	B
Oncaea mediterranea				W	WB	WB							
Pagurid zoea		W						WB		B	B	B	B
Panopeus herbstii	B												
Paracalanus crassirostris	WB	WB	WB	WB	WB	WB	WB	WB		B	B	B	B
Paracalanus parvus					B								
Penaeus sp. post larvae			W					B			B	B	B
Penilia avirostris		W	W	W		WB	W	WB					
Podon sp.		W											
Portunus sp.	WB	WB					W	WB					
Portunus sp. zoea		W		W			WB	WB					
Sapphirina tropinal					B								
Squilla sp.											B		
Temora turbinata	WB	WB	WB	WB	WB	WB	WB	WB	B	B	B	B	B
Tortanus setacaudatus	W	W	WB	WB		WB	WB	W	B	B	B		
Unidentified calanoid #1	WB	WB											
Unidentified calanoid #2	WB	WB	WB	WB	W						B		
Unidentified calanoid #3		W											
Unidentified calanoid #4		W											
Unidentified calanoid #5		W											
Unidentified calanoid copepods		W											
Unidentified cladoceran #1									B	B	B		B
Unidentified cladoceran #2		W						W					
Unidentified cyclopoid #1	W	WB											
Unidentified cyclopoid #2		W											
Unidentified harpacticoid	W	W	W	WB	WB	WB	WB	W					
Unidentified mysid	WB	W							B	B	B	B	B
Unidentified ostracod		W											
PHORONIDA													
Phoronis sp.	W		WB			B	WB	WB			B		
BRYOZOA													
Cyphonautes larva								WB					
Membranipora sp.	W	WB	WB	WB				WB					
ECHINODERMATA													
Amphiura filiformis	W												
Echinoderm larvae						B	WB	WB					
Leptosynapta inhaerens				B									

Table F-19 (continued)

PHYLUM/Species	Sep	Oct	Nov	Dec	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
	Month												
Ophiopluteus larvae								WB					
Ophiuroid larvae	W	W	WB	W									
CHAETOGNATHA													
Sagitta sp.	WB	WB	WB	WB	W	WB	WB	WB	B	B	B	B	B
HEMICHORIDATA													
Tornaria larvae	W												
CHORDATA													
Brevoortia sp.	WB			WB	WB	W	W	W					
Doliolum sp.			WB	B									
Fish eggs	WB	WB	WB	WB			WB	WB	B	B	B	B	B
Fish larvae	W						WB	B	B	B	B	B	
Fritillaria sp.		W											
Oikopleura sp.	WB	WB	WB	WB	W	WB	WB	WB	B	B	B	B	
Unidentified salpidae		W								B	B	B	
UNASSIGNED													
Veliger larvae								B					
Trochophor larvae			B		WB	WB	WB	WB					
Indeterminata													

*W--West Hackberry site.
B--Big Hill site.
WB--Both sites.

areas. Those that were site-specific were usually of modest numerical significance to the community and would, therefore, be easily missed in a sampling program. Their absence at one site or the other is, therefore, not considered conclusive.

Table F-20 shows the observed changes in community composition from site to site and month to month. The zooplankton community is very dynamic, with the precise composition varying markedly with time and place. However, relatively few species ever became numerically dominant. Generally speaking, the most characteristic organism in the community was Acartia sp., followed by Paracalanus crassirostris, Oithona nana, and Oikopleura sp. Other taxa became periodically important, but their contribution was sharply delimited in time. These included Eucalanus pileatus (June to August 1978), Temora turbinata (summer and fall 1977 and 1978 and August to October 1978), Synchaeta sp. (February), and Noctiluca sp. (February to April). Larval forms frequently constituted an important percentage of the zooplankton numbers on given cruises. Copepod nauplii, nauplii of Labidocera sp., and barnacle larvae were the more numerically prominant larval forms.

Some numerically dominant zooplankton groups showed spatial differences. Acartia sp., E. pileatus, and O. nana were more common in the western (Big Hill) sites, whereas P. crassirostris, Labidocera sp. nauplii, and barnacle larvae were more numerous at the eastern (West Hackberry) sites. There were few depth differences for most of the numerically important forms. O. nana, however, was notably more abundant in top samples, while Sagitta sp., a large predator that was relatively abundant in the Texoma study area, had a distribution pattern similar to that of O. nana. That is, it was most numerous in near-surface samples and at the western sites.

Results of ordination analysis for important zooplankton species confirmed that the dominant trend was temporal, with most samples from a given cruise grouping together on the ordination axes (Figs. F-30 and F-31). Samples from each cruise are more or less distinct. It is interesting that the midwinter samples (cruise 5) are the most distinct, along with those from October 1977, the latter being clearly differentiated on axis 2 from the sample collected in the late summer and early fall of 1978. The pattern of the April and May samples merging back into the space of the November and December samples may indicate a similar community-level response to a phytoplankton bloom resulting from response to high nutrient concentrations during these two periods. Virtually all of the samples from the July to October 1978 period are grouped in the lower left corner, indicating that they form a distinct yet homogeneous grouping based on species composition. A very similar situation was seen earlier for the phytoplankton samples from this late-spring to midfall period (Fig. F-26). Comparison of Fig. F-30 with Fig. F-31 shows the species responsible for the cruise differences in relative composition. The distinct summer group of samples was characterized by fish eggs (Fig. F-32); fish larvae (Fig. F-33); Penaeus sp. (Fig. F-34); and brachyuran larvae and megalops. Synchaeta sp. and Noctiluca sp. most distinguished the winter samples, while Centropages furcatus, Meganyctiphanes norvegica, and an unidentified calanoid copepod (#1) distinguished the October 1977 samples. Acartia sp., which

Table F-20. Seasonal and site patterns of zooplankton community dominance in the Texoma study area (September 1977 to October 1978).

	Big Hill Cluster		West Hackberry Cluster		
	Big Hill	Big Hill Control	Black Bayou	West Hackberry	West Hackberry Control
SEP	(1)[b]	(4)	(2)	(17)	(8)
	37.51 Cyprid larvae	22.59 Acartia spp.	26.93 Paracalanus crassirostris	31.16 Paracalanus crassirostris	31.93 Oikopleura sp.
	31.27 Lucifer faxoni	16.60 Temora tubinata	25.59 Oithona nana	21.35 Oithona nana	21.45 Acartia spp.
	6.24 Unidentified calanoid copepod #2	13.27 Oikopleura sp.	17.88 Oikopleura sp.	18.09 Acartia sp.	17.30 Paracalanus crassirostris
	6.24 Centropages furcatus	10.87 Labidocera spp.	12.00 Acartia spp.	15.58 Oikopleura sp.	15.83 Oithona nana
	6.24 Oikopleura sp.	9.31 Paracalanus crassirostris	8.48 Copepod nauplii	3.13 Copepod nauplii	3.02 Labidocera spp.
	6.24 Stellifer sp. larvae	8.85 Oithona nana	2.94 Euterpina acutifrons	2.67 Labidocera spp. nauplii	2.12 Labidocera spp. nauplii
		4.12 Sagitta sp.	1.58 Fish eggs	1.27 Tortanus setacaudatus	1.77 Copepod nauplii
		3.18 Mysid	1.36 Venerid larvae	1.21 Labidocera spp.	1.04 Venerid larvae
		3.15 Copepod nauplii			
		1.53 Lucifer faxoni			
		1.32 Ctenophore			
		1.26 Anthomedusid			
OCT	(4)	(12)	(4)	(20)	(12)
	34.78 Copepod nauplii	24.44 Temora turbinata	12.92 Copepod nauplii	20.02 Oithona nana	11.72 Oikopleura sp.
	12.53 Oithona nana	12.52 Copepod nauplii	12.54 Oithona nana	15.61 Oikopleura sp.	10.87 Temora turbinata
	11.03 Oikopleura sp.	10.22 Acartia spp.	12.34 Temora turbinata	12.47 Unidentified calanoid #1	10.17 Euterpina acutifrons
	7.57 Unidentified calanoid #1	9.04 Paracalanus crassirostris	9.67 Noctiluca sp.	9.03 Copepod nauplii	9.71 Oithona nana
	4.81 Corycaeus amazonicus	7.63 Euterpina acutifrons	8.58 Euterpina acutifrons	8.20 Paracalanus crassirostris	9.09 Paracalanus crassirostris
	4.70 Temora turbinata	7.28 Oithona nana	7.51 Oikopleura sp.	5.39 Acartia spp.	8.33 Copepod nauplii
	4.55 Euterpina acutifrons	5.50 Corycaeus amazonicus	6.33 Sagitta sp.	5.00 Unidentified calanoid copepods	6.25 Noctiluca sp.
	4.32 Eucalanus pileatus	4.22 Centropages furcatus	6.25 Paracalanus crassirostris	3.93 Temora turbinata	5.15 Unidentified calanoid #1
	3.58 Centropages furcatus	3.27 Oikopleura sp.	3.75 Corycaeus amazonicus	2.53 Euterpina acutifrons	4.89 Eucalanus pileatus
	2.41 Polychaete larvae	1.98 Noctiluca sp.	2.97 Unidentified calanoid #1	2.48 Eucalanus pileatus	3.71 Corycaeus amazonicus
	1.86 Sagitta sp.	1.78 Unidentified calanoid #1	2.86 Acartia spp.	2.04 Sagitta sp.	3.71 Sagitta sp.
	1.76 Paracalanus crassirostris	1.78 Eucalanus pileatus	2.57 Polychaete larvae	2.01 Polychaete larvae	2.61 Harpacticoid copepod
	1.56 Venerid larvae	1.68 Sagitta sp.	2.44 Centropages furcatus	1.85 Noctiluca sp.	2.41 Polychaete larvae
	1.13 Siphonophore	1.41 Labidocera spp. nauplii	2.23 Venerid larvae	1.29 Fish eggs	1.79 Venerid larvae
		1.27 Polychaete larvae	2.05 Eucalanus pileatus	1.10 Centropages furcatus	1.75 Centropages furcatus
			1.01 Siphonophore	1.02 Corycaeus amazonicus	1.72 Acartia spp.
NOV	(4)	(8)	(4)	(16)	(8)
	19.72 Temora turbinata	16.54 Oikopleura sp.	19.77 Oikopleura sp.	28.01 Oithona nana	27.90 Paracalanus crassirostris
	18.05 Oithona nana	14.52 Acartia spp.	17.82 Copepod nauplii	24.23 Paracalanus crassirostris	22.95 Oithona nana
	17.50 Copepod nauplii	14.01 Oithona nana	12.82 Oithona nana	15.57 Acartia spp.	9.61 Acartia spp.
	6.69 Polychaete larvae	13.76 Synchaeta sp.	8.04 Corycaeus amazonicus	4.94 Oikopleura sp.	9.54 Oikopleura sp.
	6.28 Oikopleura sp.	11.60 Copepod nauplii	7.34 Temora turbinata	4.71 Copepod nauplii	5.38 Labidocera spp. nauplii
	5.06 Acartia spp.	10.32 Paracalanus crassirostris	5.13 Paracalanus crassirostris	3.28 Euterpina acutifrons	5.25 Copepod nauplii
	3.79 Sagitta sp.	4.45 Polychaete larvae	4.97 Acartia spp.	2.48 Sagitta sp.	3.51 Sagitta sp.
	3.50 Venerid larvae	3.85 Temora turbinata	4.95 Euterpina acutifrons	2.30 Barnacle nauplii	2.32 Corycaeus amazonicus
	2.90 Leptomedusid	1.93 Labidocera spp. nauplii	4.10 Polychaete larvae	2.01 Prosobranch larvae	2.05 Membranipora sp.
	2.83 Paracalanus crassirostris	1.26 Sagitta sp.	3.34 Noctiluca sp.	1.94 Noctiluca sp.	1.91 Euterpina acutifrons
	2.16 Ophiuroid larvae		2.48 Sagitta sp.	1.40 Labidocera spp. nauplii	1.39 Noctiluca sp.
	1.87 Noctiluca sp.		2.04 Synchaeta sp.	1.33 Membranipora sp.	1.39 Noctiluca sp.
	1.65 Eucalanus pileatus		1.39 Leptomedusid	1.14 Polychaete larvae	1.34 Polychaete larvae
	1.60 Corycaeus amazonicus		1.09 Labidocera spp. nauplii	1.12 Venerid larvae	
	1.33 Euterpina actifrons			1.11 Temora turbinata	

Table F-20 (continued)

	Big Hill Cluster		West Hackberry Cluster		
	Big Hill	Big Hill Control	Black Bayou	West Hackberry	West Hackberry Control
DEC	(3)	(6)	(4)	(15)	(7)
	38.52 Paracalanus crassirostris	25.98 Paracalanus crassirostris	34.68 Acartia spp.	26.32 Acartia spp.	34.42 Labidocera spp. nauplii
	22.09 Acartia spp.	19.70 Labidocera spp. nauplii	18.26 Paracalanus crassirostris	20.54 Labidocera spp. nauplii	28.77 Acartia spp.
	14.10 Oithona nana	17.82 Oithona nana	17.22 Labidocera spp. nauplii	18.76 Oikopleura sp.	20.08 Paracalanus crassirostris
	12.55 Labidocera spp. nauplii	16.75 Acartia spp.	8.75 Oikopleura sp.	14.46 Paracalanus crassirostris	5.10 Oikopleura sp.
	5.37 Barnacle nauplii	7.35 Oikopleura sp.	6.60 Synchaeta sp.	5.15 Synchaeta sp.	2.61 Oithona nana
	1.30 Oikopleura sp.	3.27 Copepod nauplii	5.25 Oithona nana	4.69 Barnacle nauplii	1.94 Barnacle nauplii
	1.28 Copepod nauplii	1.79 Synchaeta sp.	2.34 Barnacle nauplii	4.08 Oithona nana	1.30 Fish eggs
	1.02 Sagitta sp.	1.66 Labidocera spp.	2.21 Copepod nauplii	1.77 Copepod nauplii	1.15 Synchaeta sp.
			1.31 Tortanus setacaudatus		
FEB	(4)	(8)	(2)	(10)	(8)
	66.88 Synchaeta sp.	59.78 Synchaeta sp.	37.66 Acartia spp.	35.82 Synchaeta sp.	38.78 Synchaeta sp.
	10.42 Acartia spp.	18.52 Noctiluca sp.	26.61 Barnacle nauplii	19.96 Noctiluca sp.	23.84 Noctiluca sp.
	6.25 Barnacle nauplii	7.97 Acartia spp.	19.14 Synchaeta sp.	14.32 Acartia spp.	12.24 Copepod nauplii
	5.17 Noctiluca sp.	4.81 Trochophore larvae	7.67 Oikopleura sp.	8.92 Barnacle nauplii	10.98 Acartia spp.
	2.94 Onchaea mediterranea	2.49 Barnacle nauplii	4.46 Tintinnid	3.46 Copepod nauplii	3.66 Paracalanus crassirostris
	2.56 Polychaete larvae	1.63 Labidocera spp. nauplii	2.97 Sagitta sp.	3.36 Oithona nana	2.88 Barnacle nauplii
	1.77 Labidocera spp. nauplii	1.25 Tintinnid	1.49 Oithona nana	3.34 Paracalanus crassirostris	1.79 Sagitta sp.
	1.35 Oithona nana			1.96 Sagitta sp.	1.49 Labidocera spp. nauplii
				1.92 Labidocera spp. nauplii	1.39 Brevoortia sp. larvae
				1.58 Euterpina acutifrons	1.15 Lamellibranch larvae
				1.19 Tintinnid	
				1.04 Trochophore larvae	
MAR	(4)	(8)	(4)	(20)	(12)
	31.22 Acartia spp.	38.15 Barnacle nauplii	80.54 Noctiluca sp.	54.84 Noctiluca sp.	86.41 Noctiluca sp.
	30.13 Barnacle nauplii	22.06 Acartia spp.	12.55 Acartia spp.	30.62 Acartia spp.	5.72 Acartia spp.
	18.06 Noctiluca sp.	12.37 Noctiluca sp.	2.47 Penilia avirostris	7.04 Barnacle nauplii	2.29 Penilia avirostris
	10.08 Copepod nauplii	11.22 Copepod nauplii		2.19 Copepod nauplii	1.62 Paracalanus crassirostris
	2.09 Trochophore larvae	3.74 Synchaeta sp.		1.06 Penilia avirostris	
	1.93 Synchaeta sp.	3.22 Cyprid larvae			
	1.38 Tintinnid	2.83 Tintinnid			
	1.24 Polychaete larvae	1.57 Oithona nana			
	1.02 Oithona nana	1.18 Gastropod larvae			
		1.10 Polychaete larvae			

Table F-20 (continued)

	Big Hill Cluster				West Hackberry Cluster					
	Big Hill		Big Hill Control		Black Bayou		West Hackberry		West Hackberry Control	
	(4)		(8)		(4)		(16)		(8)	
APR	30.22	Barnacle nauplii	57.93	Acartia spp.	31.11	Paracalanus crassirostris	64.05	Acartia spp.	60.10	Acartia spp.
	19.30	Acartia spp.	13.62	Noctiluca sp.	15.53	Acartia spp.	11.75	Labidocera spp. nauplii	9.58	Copepod nauplii
	18.54	Noctiluca sp.	8.79	Paracalanus crassirostris	10.60	Oikopleura sp.	6.64	Copepod nauplii	7.21	Paracalanus crassirostris
	8.00	Labidocera spp. nauplii	4.19	Labidocera spp. nauplii	9.90	Noctiluca sp.	5.82	Barnacle nauplii	6.12	Noctiluca sp
	6.91	Paracalanus crassirostris	3.96	Copepod nauplii	9.18	Copepod nauplii	4.16	Paracalanus crassirostris	5.18	Labidocera spp. nauplii
	3.42	Oithona nana			5.81	Labidocera spp. nauplii	2.07	Oikopleura sp.	3.53	Oikopleura sp.
	3.23	Copepod nauplii			5.75	Anthomedusid	1.72	Noctiluca sp.	1.45	Lamellibranch larvae
	3.19	Oikopleura sp.			4.22	Tortanus setacaudatus			1.22	Portunus sp. zoea
	1.63	Corycaeus amazonicus			2.13	Sagitta sp.			1.14	Oithona nana
	1.14	Polychaete larvae			1.75	Oithona nana			1.11	Corycaeus amazonicus
					1.12	Barnacle nauplii				
	(4)		(8)		(4)		(14)		(8)	
MAY	38.64	Acartia spp.	43.97	Labidocera spp. nauplii	59.08	Labidocera spp. nauplii	28.73	Labidocera spp. nauplii	30.90	Acartia spp.
	15.66	Oikopleura sp.	40.65	Acartia spp.	28.61	Acartia spp.	23.76	Acartia spp.	29.15	Labidocera spp. nauplii
	12.83	Copepod nauplii	4.42	Copepod nauplii	3.36	Echinoderm larvae	15.84	Copepod nauplii	10.74	Pteropod
	7.59	Hydroid medusa	2.64	Anthomedusid	2.11	Leptomedusid	9.26	Paracalanus crassirostris	6.50	Barnacle nauplii
	5.66	Labidocera spp. nauplii	1.98	Echinoderm larvae	1.67	Oithona nana	4.98	Barnacle nauplii	3.83	Lamellibranch larvae
	5.23	Paracalanus crassirostris	1.57	Paracalanus crassirostris	1.52	Pteropod	3.58	Pteropod	3.66	Hydroid medusa
	4.49	Ophiopluteus larvae	1.14	Pteropod	1.05	Copepod nauplii	2.79	Lamellibranch larvae	3.59	Copepod nauplii
	2.70	Barnacle nauplii					1.96	Echinoderm larvae	3.13	Paracalanus crassirostris
	1.80	Trochophore larvae					1.87	Trochophore larvae	1.42	Anthomedusid
	1.68	Pteropod					1.74	Anthomedusid	1.39	Trochophore larvae
	1.05	Oithona nana					1.54	Hydroid medusa	1.36	Echinoderm larvae
							1.49	Ophiopluteus larvae	1.18	Ophiopluteus larvae
							1.76	Oithona nana		

Table F-20 (continued)

Month	Big Hill Cluster: Big Hill (%)	Big Hill (species)	Big Hill Control (%)	Big Hill Control (species)	West Hackberry Cluster: Black Bayou	West Hackberry	West Hackberry Control
JUN		(4)		(16)	NO SAMPLES	NO SAMPLES	NO SAMPLES
	72.63	Acartia spp.	74.60	Acartia spp.			
	10.49	Oikopleura sp.	9.48	Labidocera spp.			
	9.21	Eucalanus pileatus	7.57	Eucalanus pileatus			
	3.85	Copepod nauplii	4.42	Copepod nauplii			
	1.50	Oithona nana	1.64	Oithona nana			
JUL		(4)		(16)	NO SAMPLES	NO SAMPLES	NO SAMPLES
	47.80	Oikopleura sp.	54.11	Acartia spp.			
	22.58	Acartia sp.	22.67	Oikopleura sp.			
	9.68	Eucalanus pileatus	10.50	Eucalanus pileatus			
	7.53	Copepod nauplii	6.36	Oithona nana			
	5.48	Oithona nana	2.41	Copepod nauplii			
	5.31	Paracalanus crassirostris					
AUG		(4)		(16)	NO SAMPLES	NO SAMPLES	NO SAMPLES
	27.00	Acartia spp.	33.22	Acartia spp.			
	20.26	Oikopleura sp.	20.62	Paracalanus crassirostris			
	16.56	Paracalanus crassirostris	12.94	Oithona nana			
	10.94	Oithona nana	9.89	Eucalanus pileatus			
	7.05	Eucalanus pileatus	6.22	Oikopleura sp.			
	5.15	Temora turbinata	6.10	Euterpina acutifrons			
	3.03	Copepod nauplii	2.79	Temora turbinata			
	1.02	Sagitta sp.	1.35	Copepod nauplii			
			1.17	Fish eggs			
			1.16	Unidentified calanoid copepod #2			
			1.14	Sagitta sp.			
SEP		(4)		(16)	NO SAMPLES	NO SAMPLES	NO SAMPLES
	27.85	Acartia spp.	59.92	Acartia spp.			
	19.47	Oikopleura sp.	34.65	Eucalanus pileatus			
	15.86	Paracalanus crassirostris	2.08	Oithona nana			
	10.18	Eucalanus pileatus					
	6.73	Oithona nana					
	5.26	Copepod nauplii					
	3.42	Sagitta sp.					
	2.91	Candacia sp.					
	2.75	Polychaete larvae					
	1.93	Temora turbinata					
	1.44	Labidocera spp.					
OCT		(4)		(16)	NO SAMPLES	NO SAMPLES	NO SAMPLES
	60.71	Acartia spp.	38.20	Acartia spp.			
	10.24	Oithona nana	19.29	Oithona nana			
	9.99	Copepod nauplii	10.17	Paracalanus crassirostris			
	5.97	Labidocera spp.	9.46	Temora turbinata			
	5.68	Sagitta sp.	5.97	Copepod nauplii			
	2.96	Brachyuran larvae	4.88	Sagitta sp.			
	1.42	Polychaete larvae					
	1.12	Eucalanus pileatus					

[a]Only species comprising 1% or more of the community are shown.

[b]Number in parantheses is the number of samples on which composition is based.

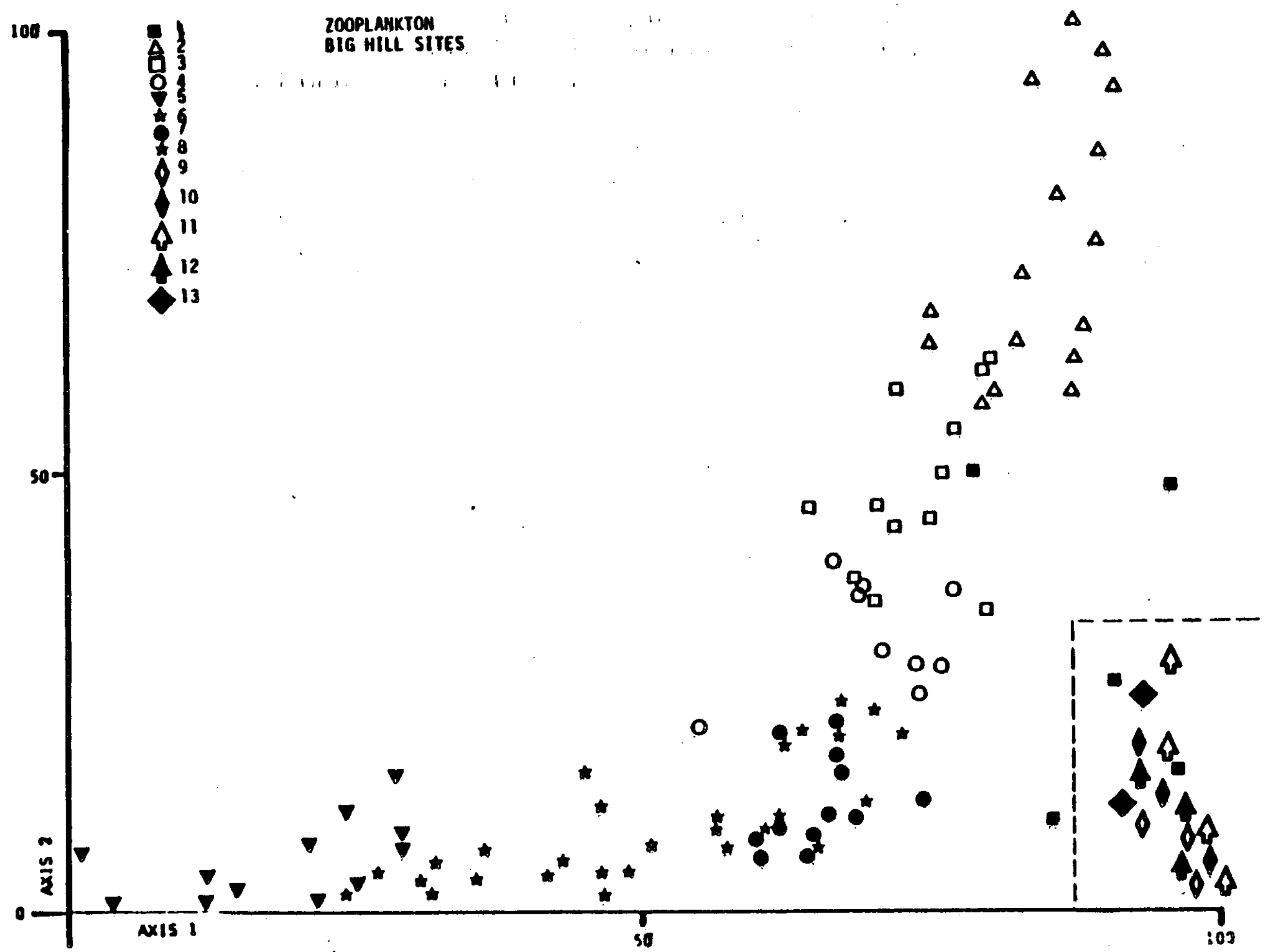


Figure F-30. Sample ordination of zooplankton data from the Big Hill sites labeled by cruise. The area delineated by the box has hidden samples including 17 from cruise 9, 18 from cruise 10, 16 from cruise 11, 17 from cruise 12, and 18 from cruise 13.

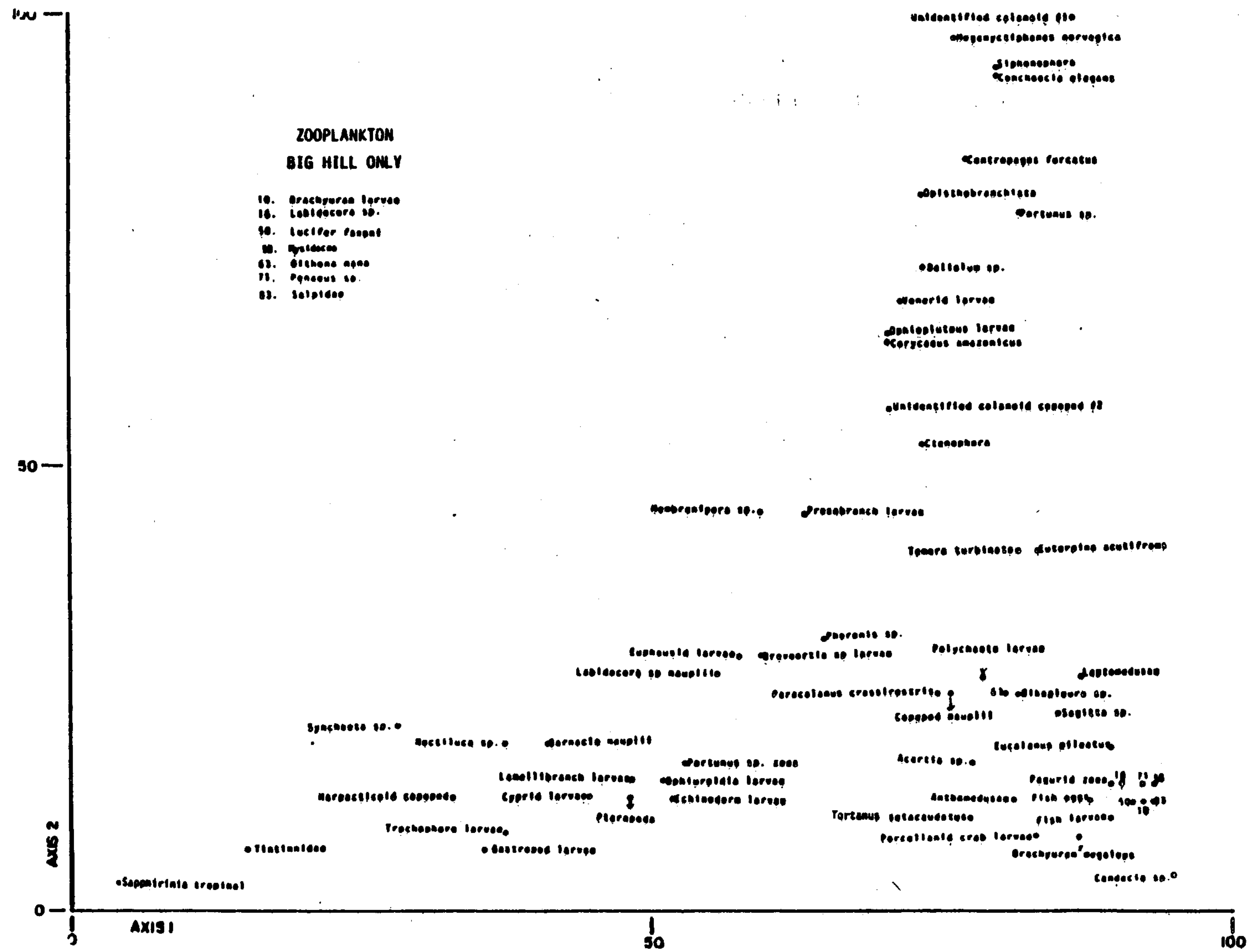
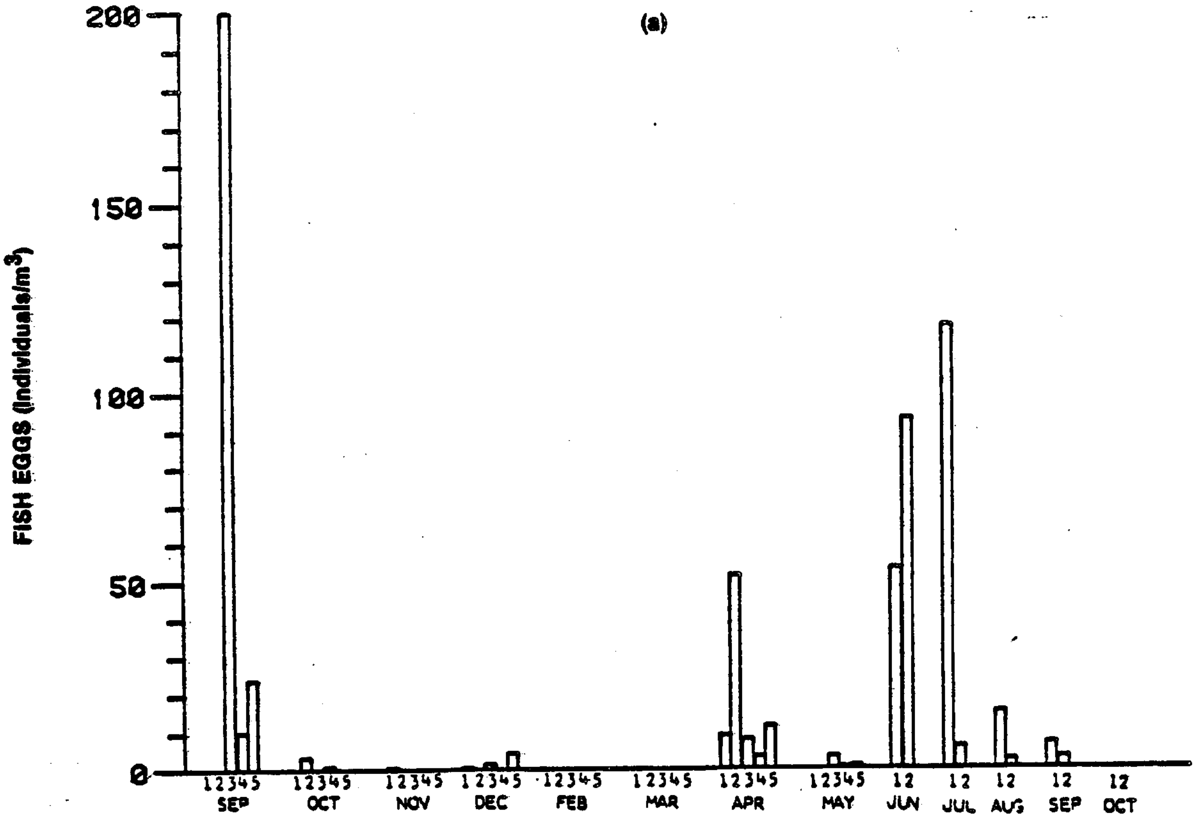


Figure F-31. Species ordination of zooplankton at the Big Hill cluster of sites.



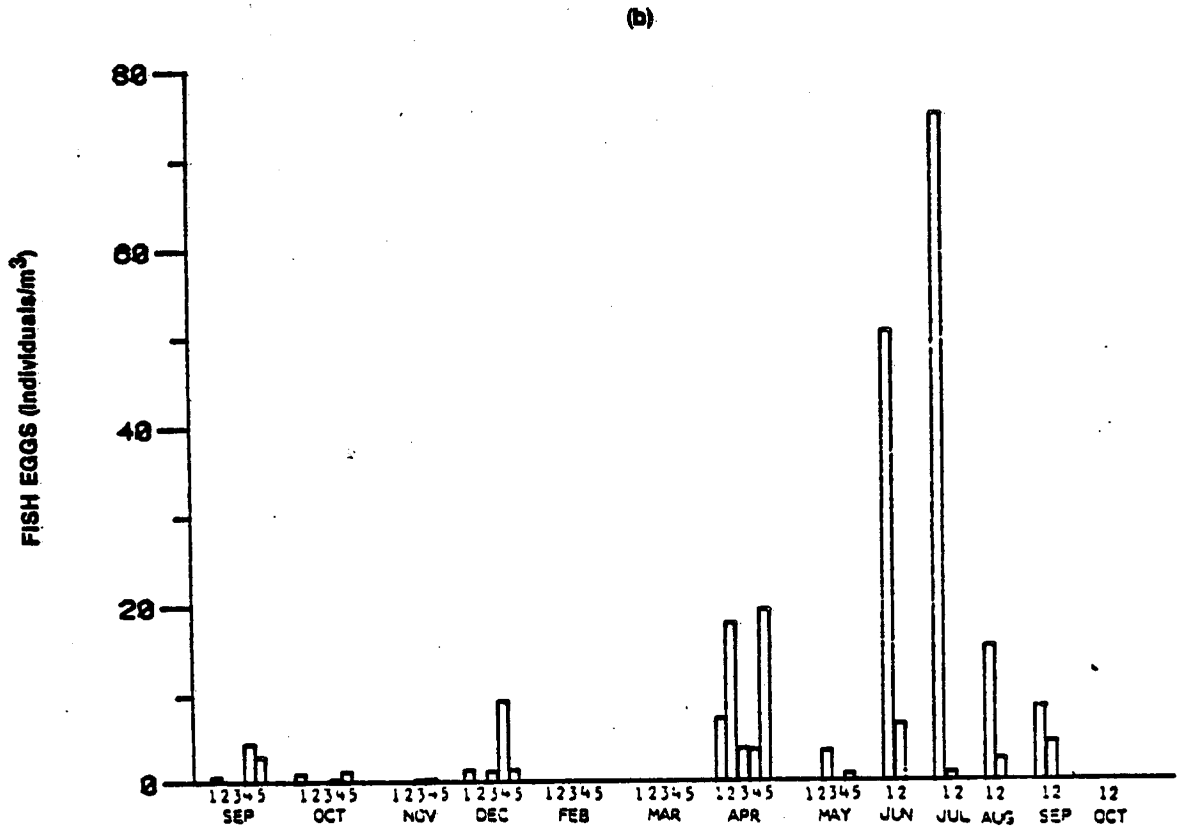
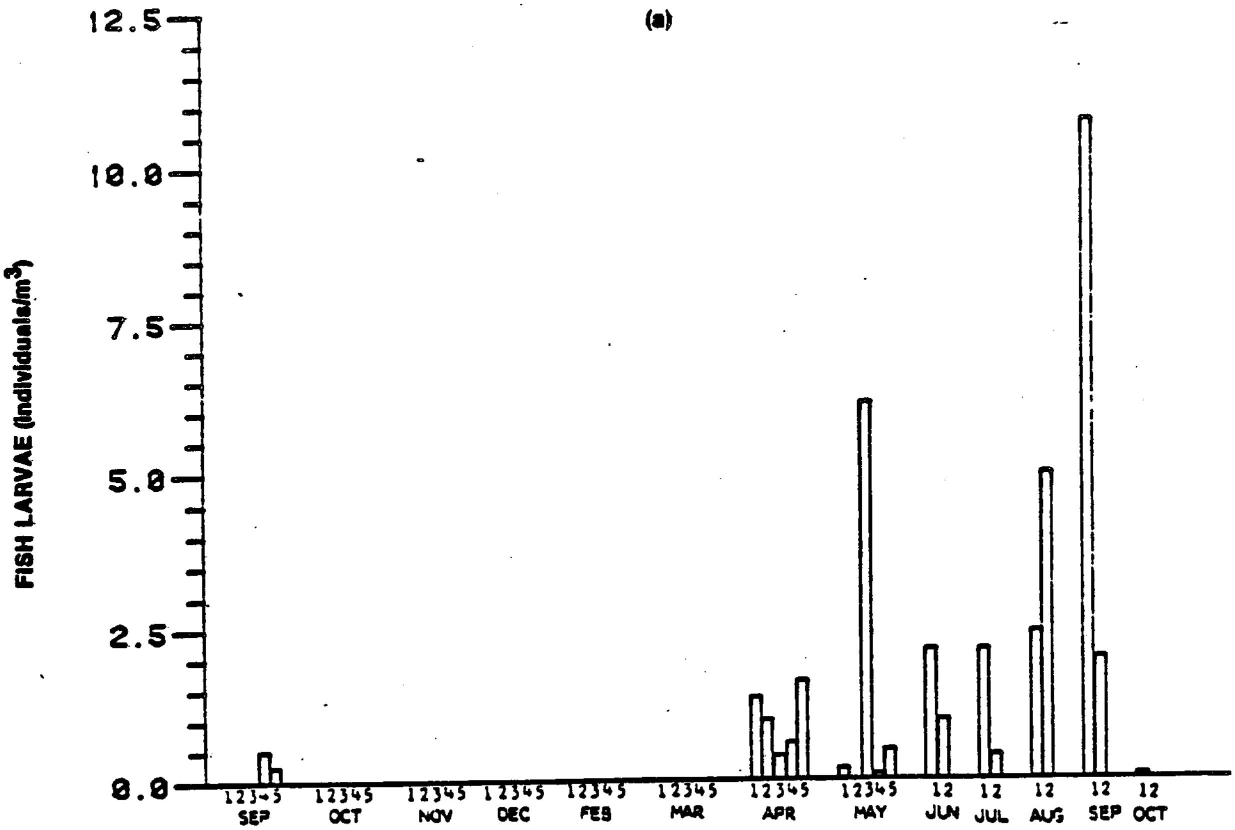


Figure F-32. **Abundance of fish eggs (individuals/m^3): (a) top samples, (b) bottom samples.**



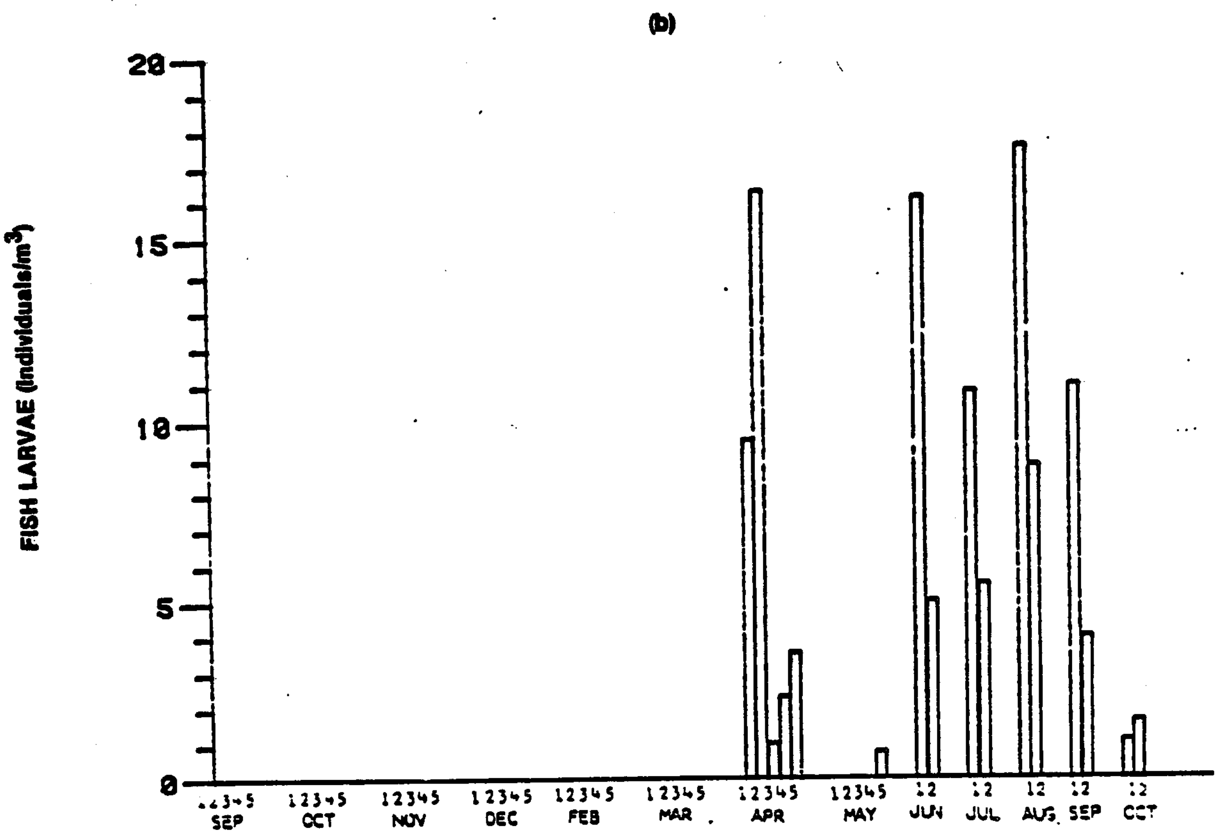
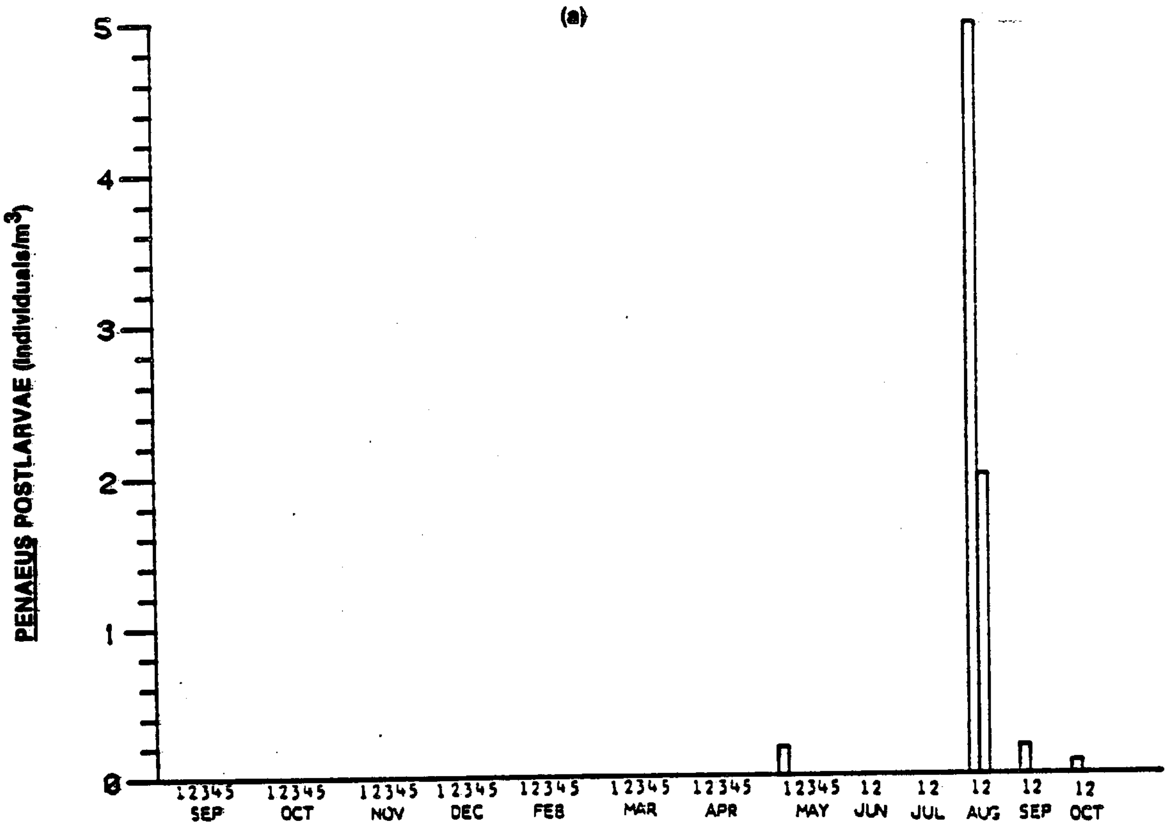


Figure F-33. **Abundance of fish larvae (individuals/m^3): (a) top samples, (b) bottom samples.**



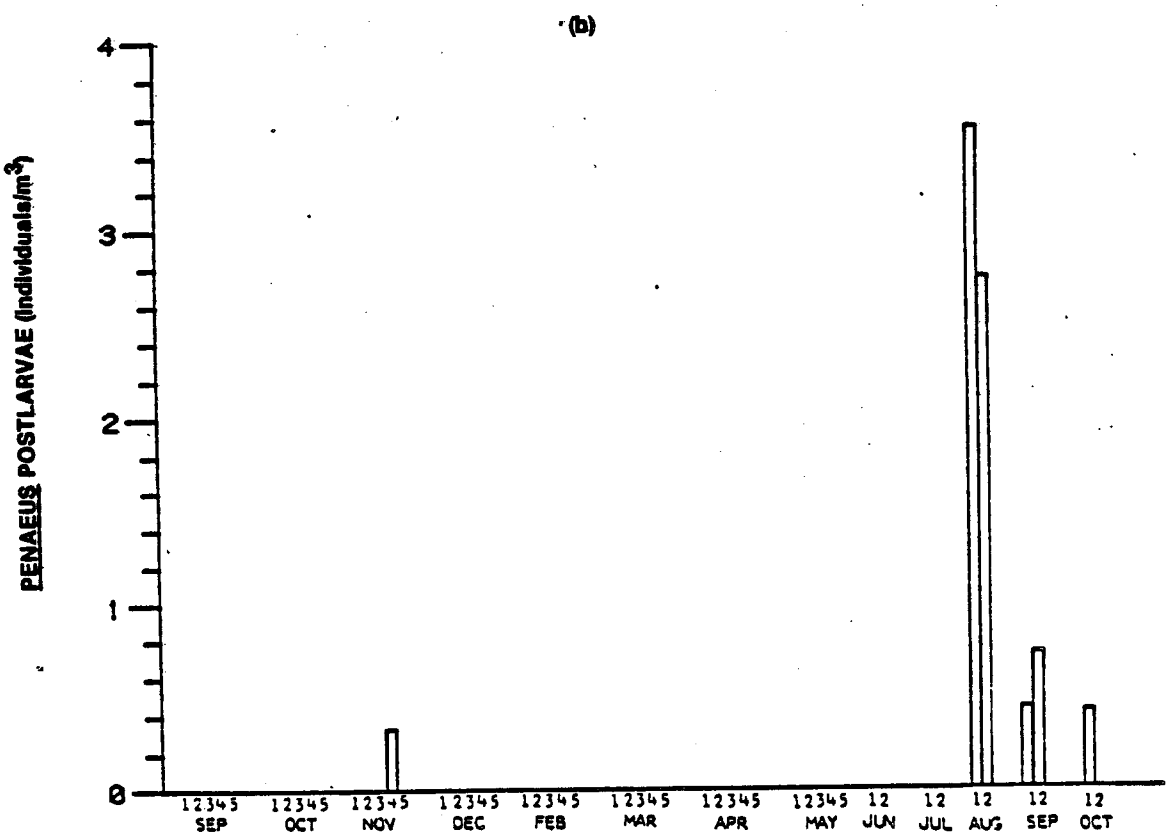


Figure F-34. **Abundance of Penaeus sp. postlarvae (individuals/m^3): (a) top samples, (b) bottom samples.**

numerically dominated the species composition during much of the late spring and early summer (Fig. F-35) is centrally located on the ordination display, along with other taxa with similar temporal distributions (e.g., P. crassirostris).

Sediments

Typical results of textural analysis of surficial sediments collected from November 1977 through October 1978 are presented in Figs. F-36 to F-46. The grain size distribution at the five sites remained fairly constant through time. Figures F-47 to F-52 are triangular facies diagrams for these same collections. The sediments graded from silty clays in the west to clayey sands in the east. However, there was considerable heterogeneity within certain sites (especially West Hackberry). At Big Hill and BHC stations, difficulty was often experienced in collecting an uncompacted surficial sample, suggesting the presence of an outcrop of Beaumont clay.

A representative cumulative frequency plot and histogram for the central (diffuser) station at the Big Hill site (Figs. F-53 and F-54) show that the sediments had a strong negative skew (toward the clay fraction). Sands were generally absent from samples at the Big Hill site, with the highest percentage of clay being found during the February to May period, probably because of the erosion of the coarser layer of sediments that seasonally overlies the Beaumont clay.

Tables F-21 to F-28 and Figs. F-55 to F-62 show the cruise and site means for important sediment parameters at the Texoma sites. One important result from a comparison of the standard errors accompanying the means in these tables is the much greater variability exhibited by samples from the West Hackberry site as compared with those from Big Hill. Analyses of variance and multiple means tests for these data (Tables F-29 and F-30) show that, for all parameters whose values increase with decreasing grain size (percent silt, clays and fines, M_{ϕ}, M_D), Big Hill and BHC had significantly higher means as compared with the other Texoma sites, with only percent silt not significantly greater at Big Hill compared with West Hackberry. Big Hill and BHC sites usually did not differ significantly, except for the significantly higher percentage of silt at BHC and clay at Big Hill.

Figure F-63 is a plot of the mean (over all cruises) percentage of sand for the Big Hill stations. The Big Hill site, with the finest textured sediments, showed a relatively narrow range of station means for percent sand (1.4 to 8.9 percent), with both longshore (increasing to the west) and onshore-offshore (increasing offshore) trends evident.

Results of reciprocal averaging ordination for sediment texture parameters for the five Texoma sites (Fig. F-64) confirmed the variable spatial aspect of the samples from the West Hackberry site. Axis 1, which explains more variance than any other axis for these data, shows essentially spatial trends, with temporal differences definitely subordinate. The Big Hill and BHC samples (which are the most finely textured) are located to the left of the display; West Hackberry control and Black Bayou samples (which include the most coarse textured samples) are located to the left. West Hackberry samples span all of axis 1.

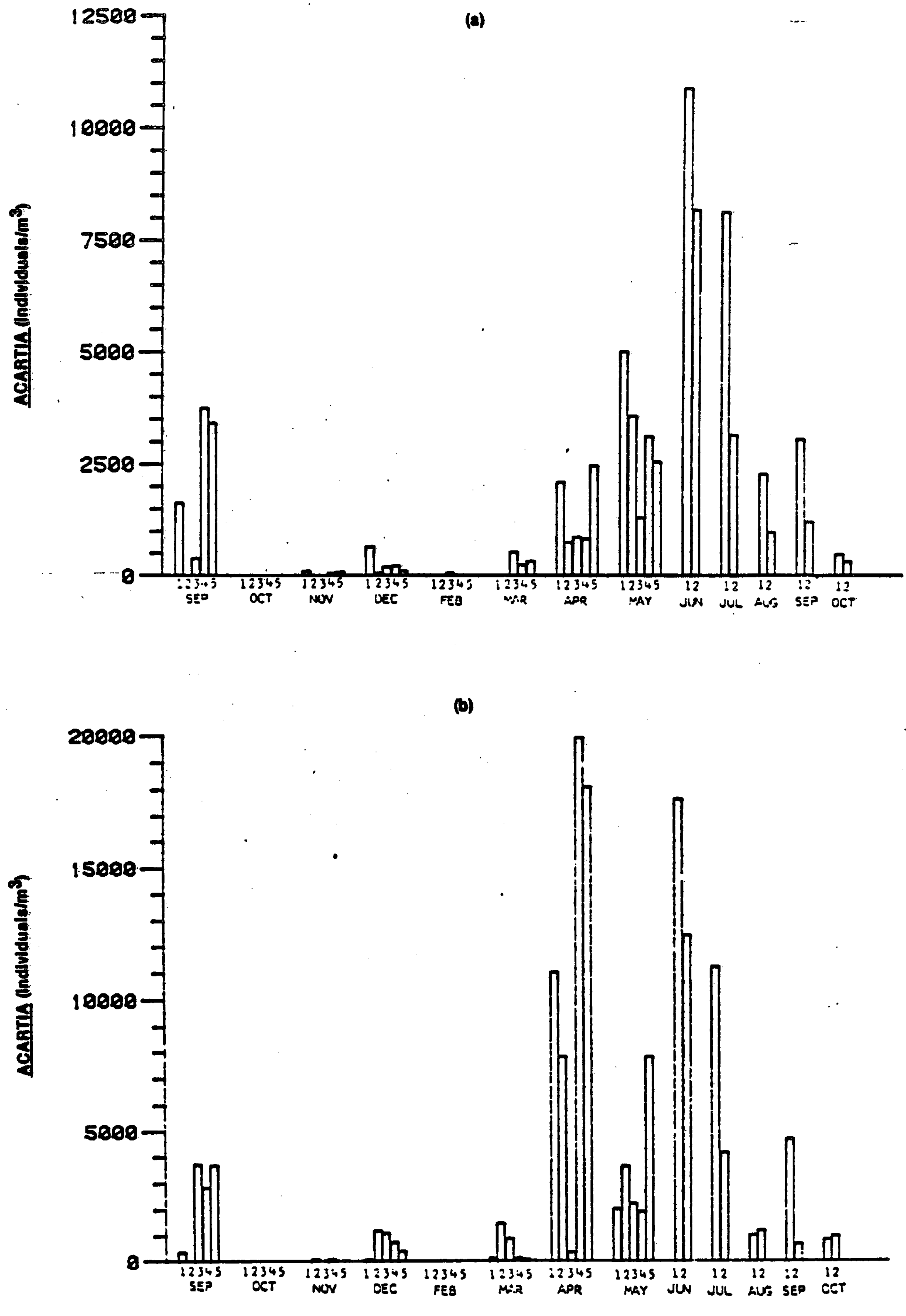


Figure F-35. Abundance of Acartia sp. (individuals/m^3): (a) top samples, (b) bottom samples.

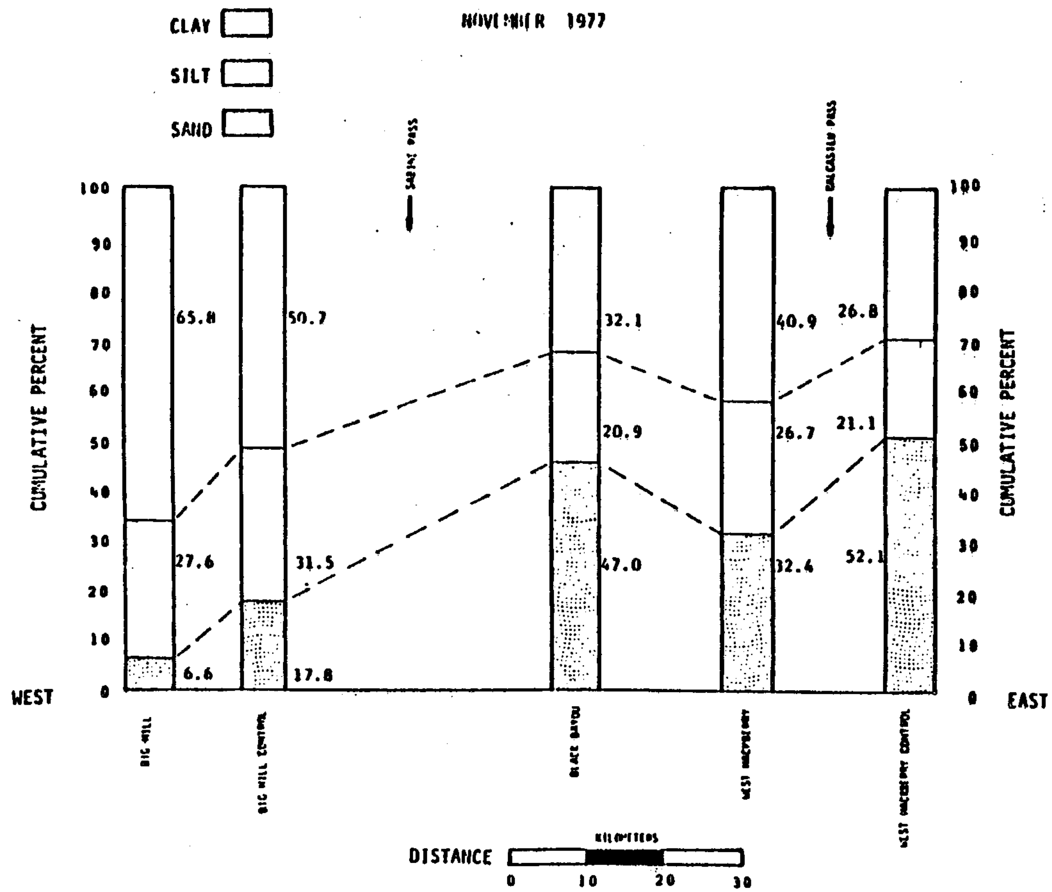


Figure F-36. Mean percentages of sand, silt, and clay at the Texoma study sites for November 1977 (Cruise 3).

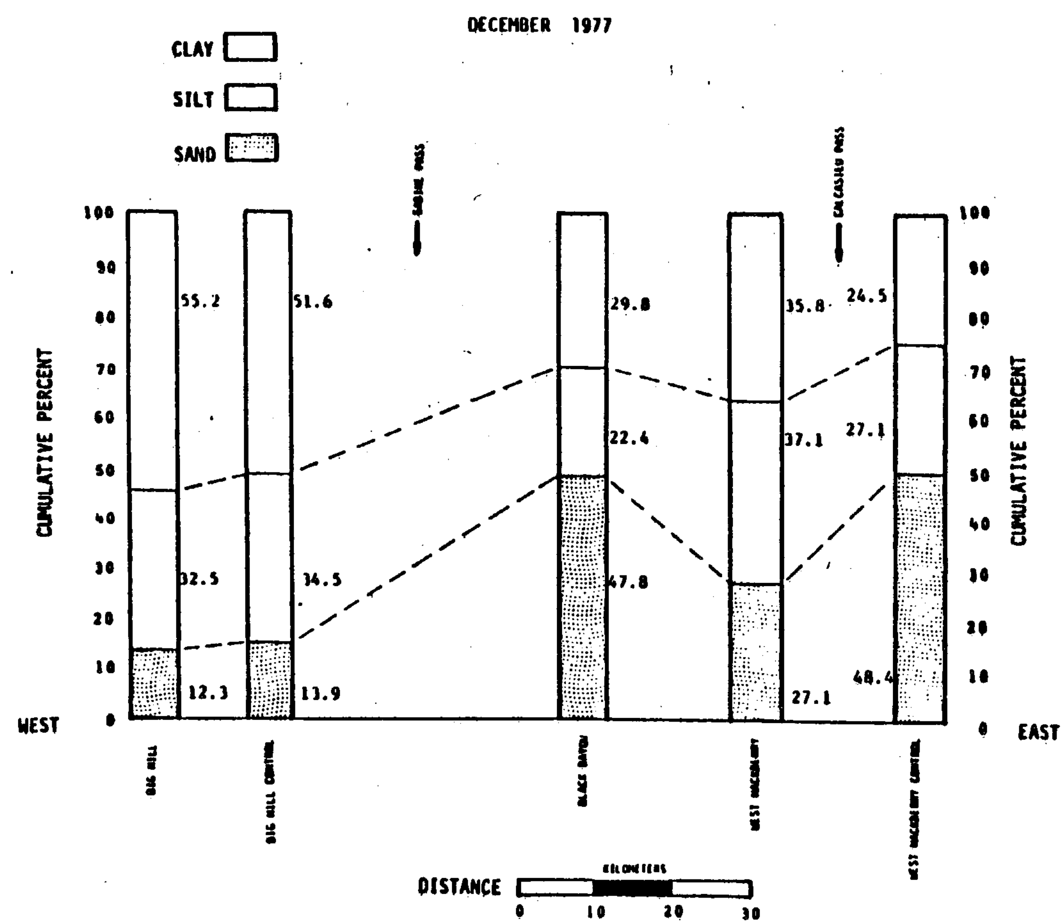


Figure F-37. Mean percentages of sand, silt, and clay at the Texoma study sites for December 1977 (Cruise 4).

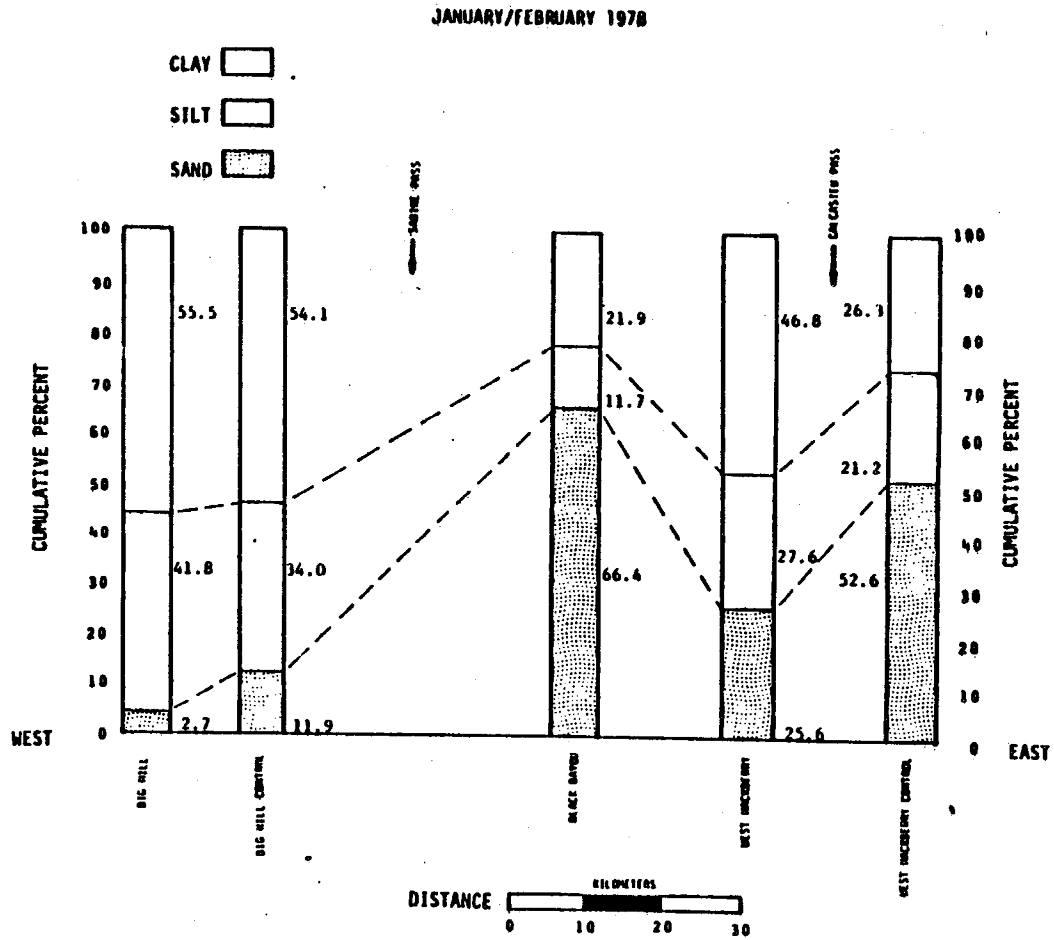


Figure F-38. Mean percentages of sand, silt, and clay at the Texoma study sites for January/February 1978 (Cruise 5).

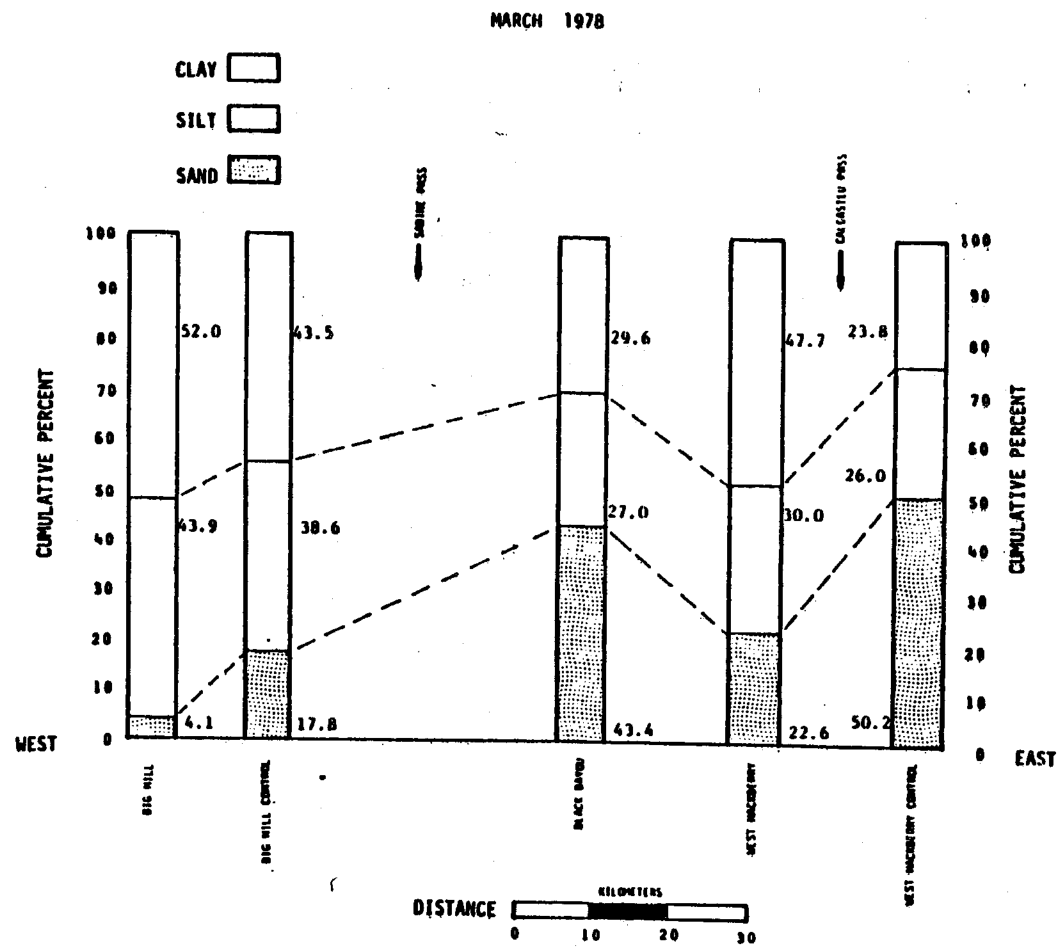


Figure F-39. Mean percentages of sand, silt, and clay at the Texoma study sites for March 1978 (Cruise 6).

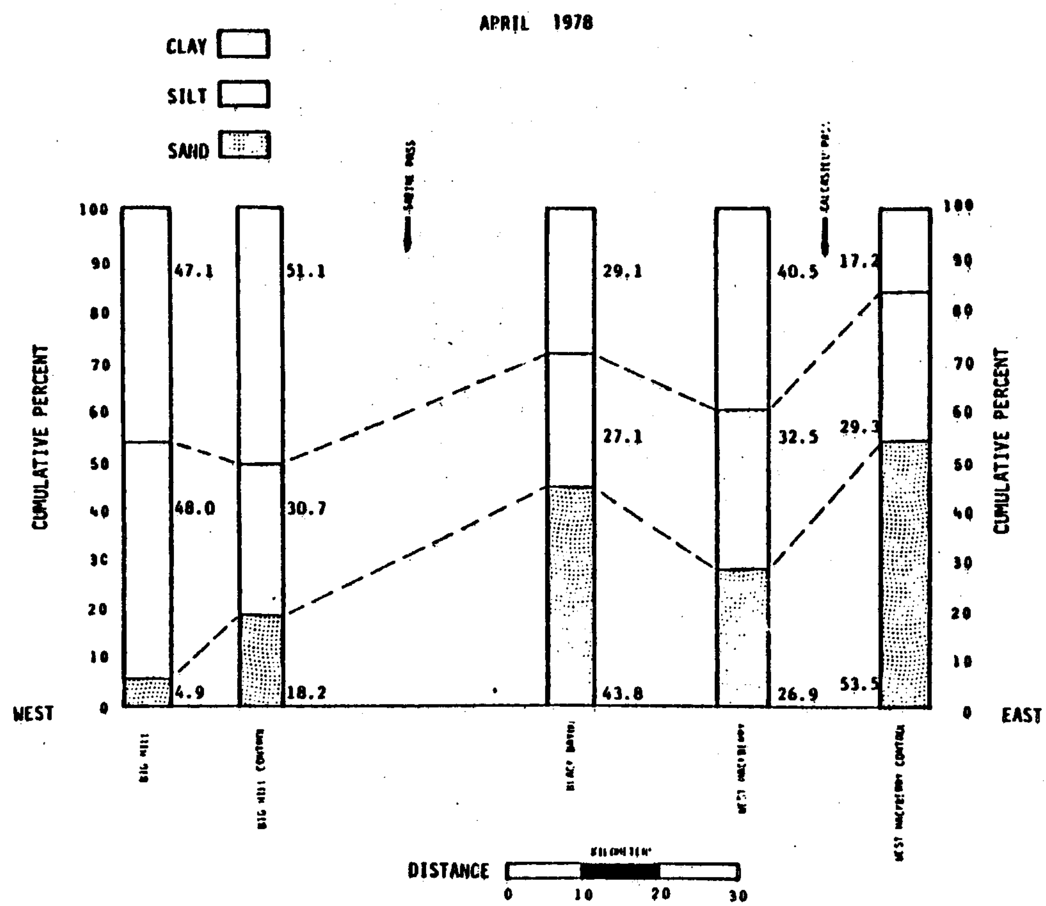


Figure F-40. **Mean percentages of sand, silt, and clay at the Texoma study sites for April 1978 (Cruise 7).**

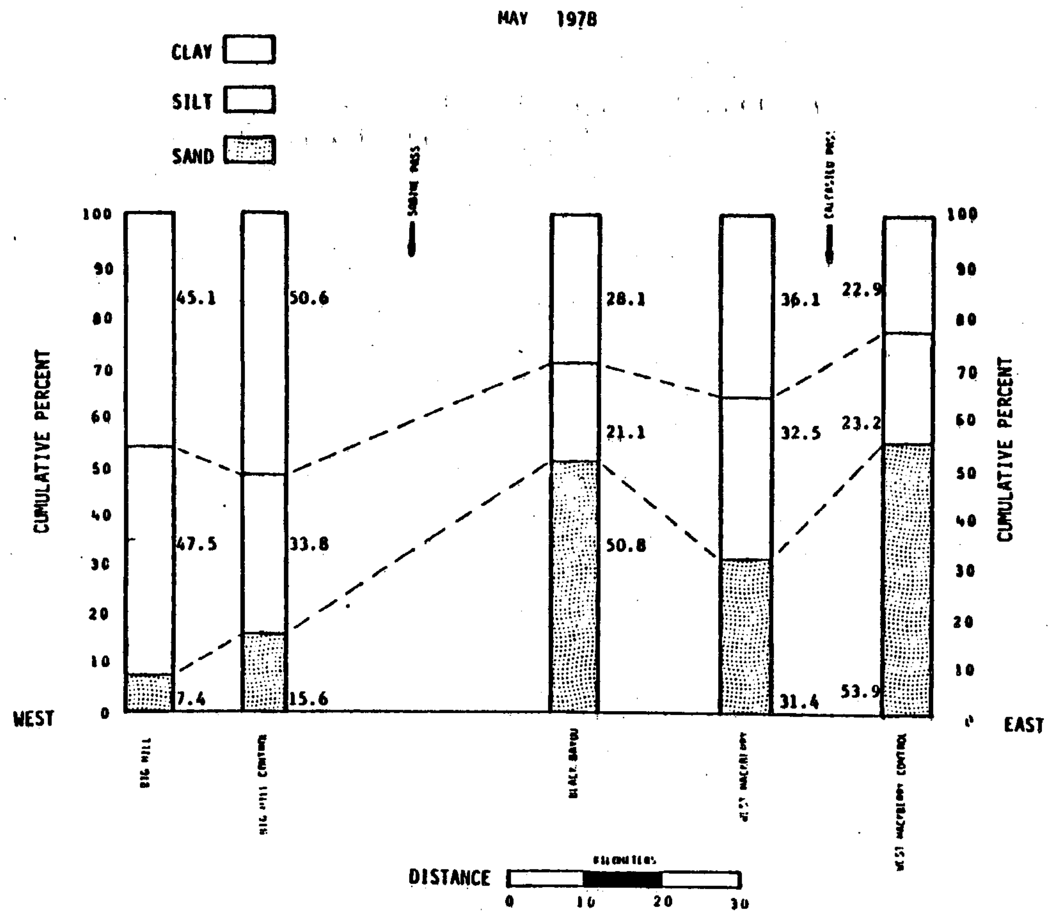


Figure F-41. Mean percentages of sand, silt, and clay at the Texoma study sites for May 1978 (Cruise 8).

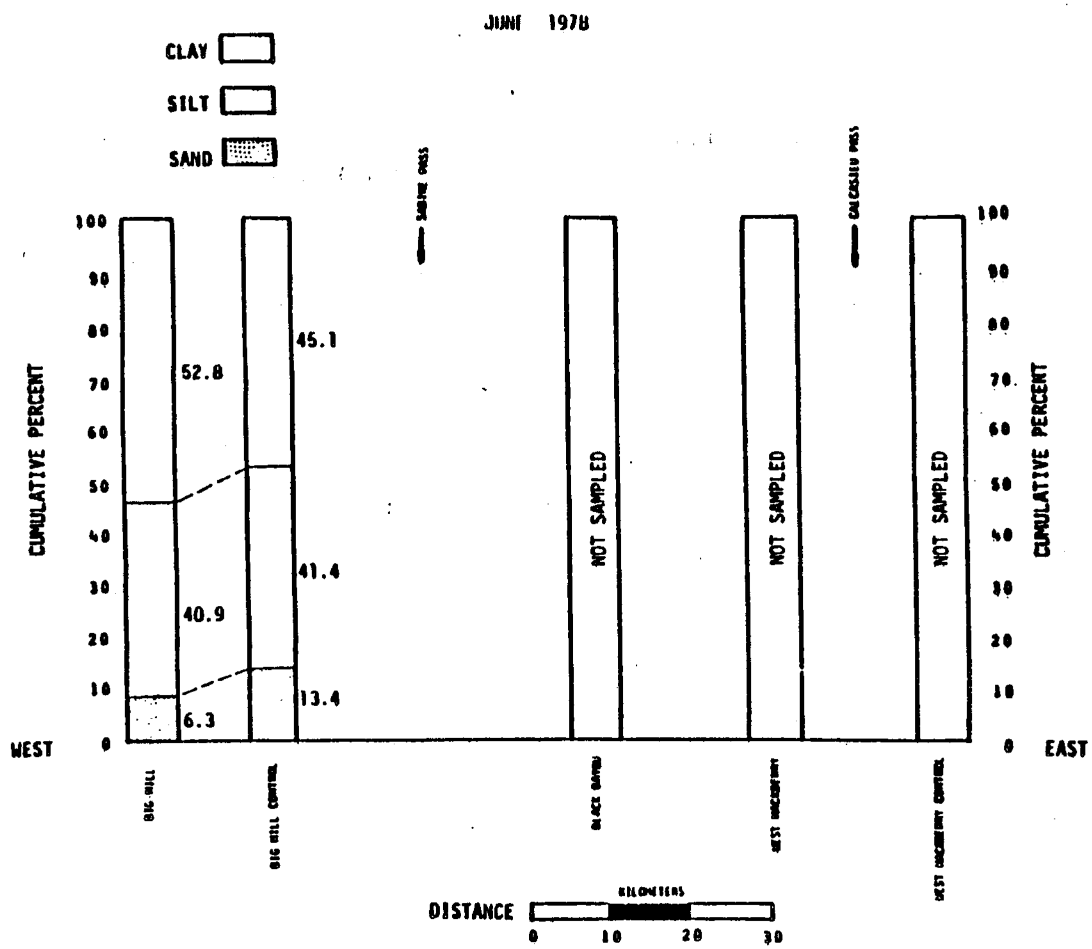


Figure F-42. Mean percentages of sand, silt, and clay at the Texoma study sites for June 1978 (Cruise 9).

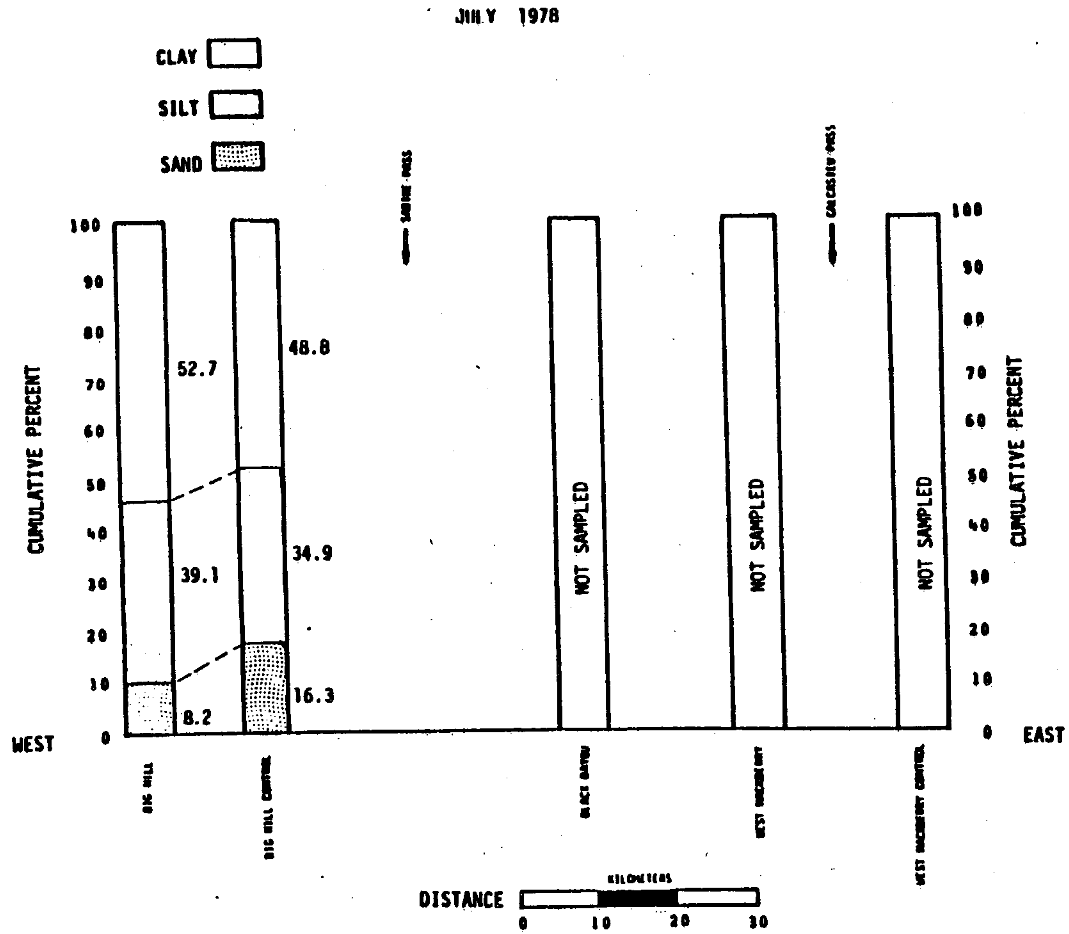


Figure F-43. **Mean percentages of sand, silt, and clay at the Texoma study sites for July 1978 (Cruise 10).**

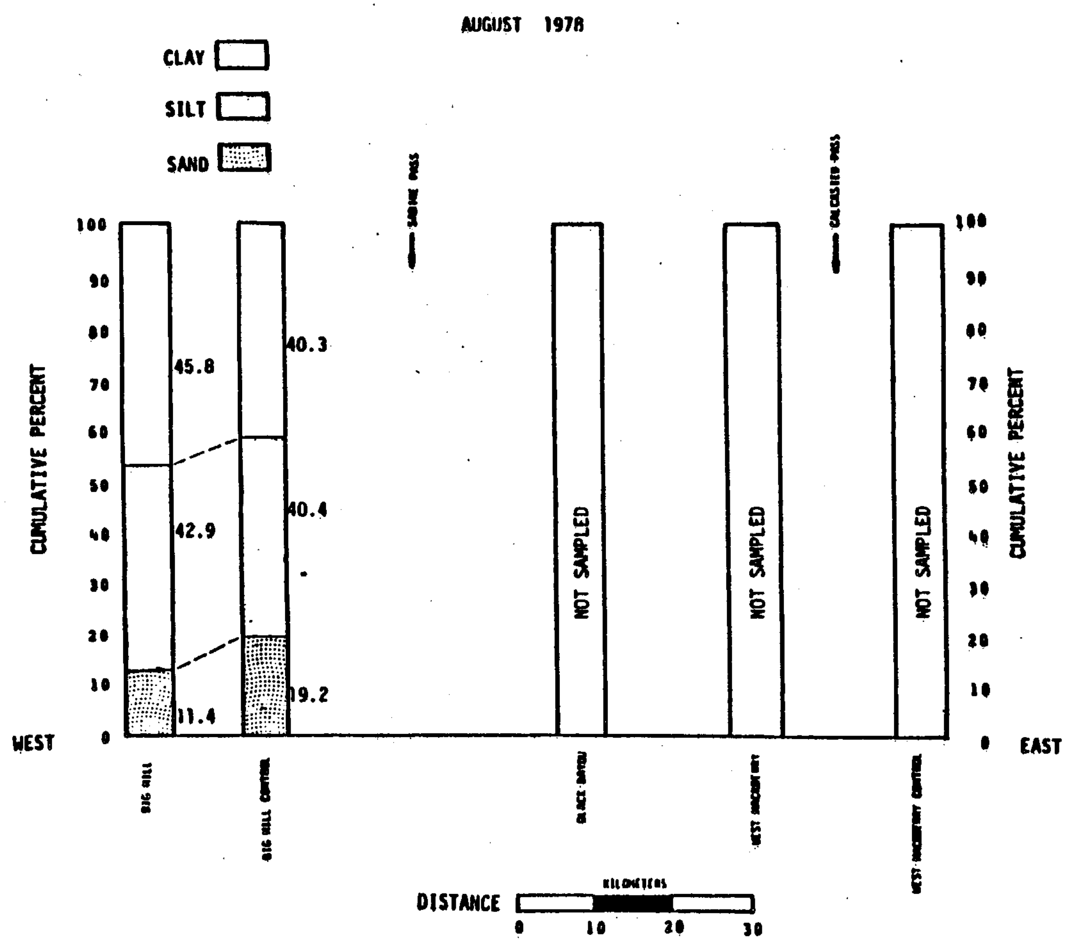


Figure F-44. Mean percentages of sand, silt, and clay at the Texoma study sites for August 1978 (Cruise 11).

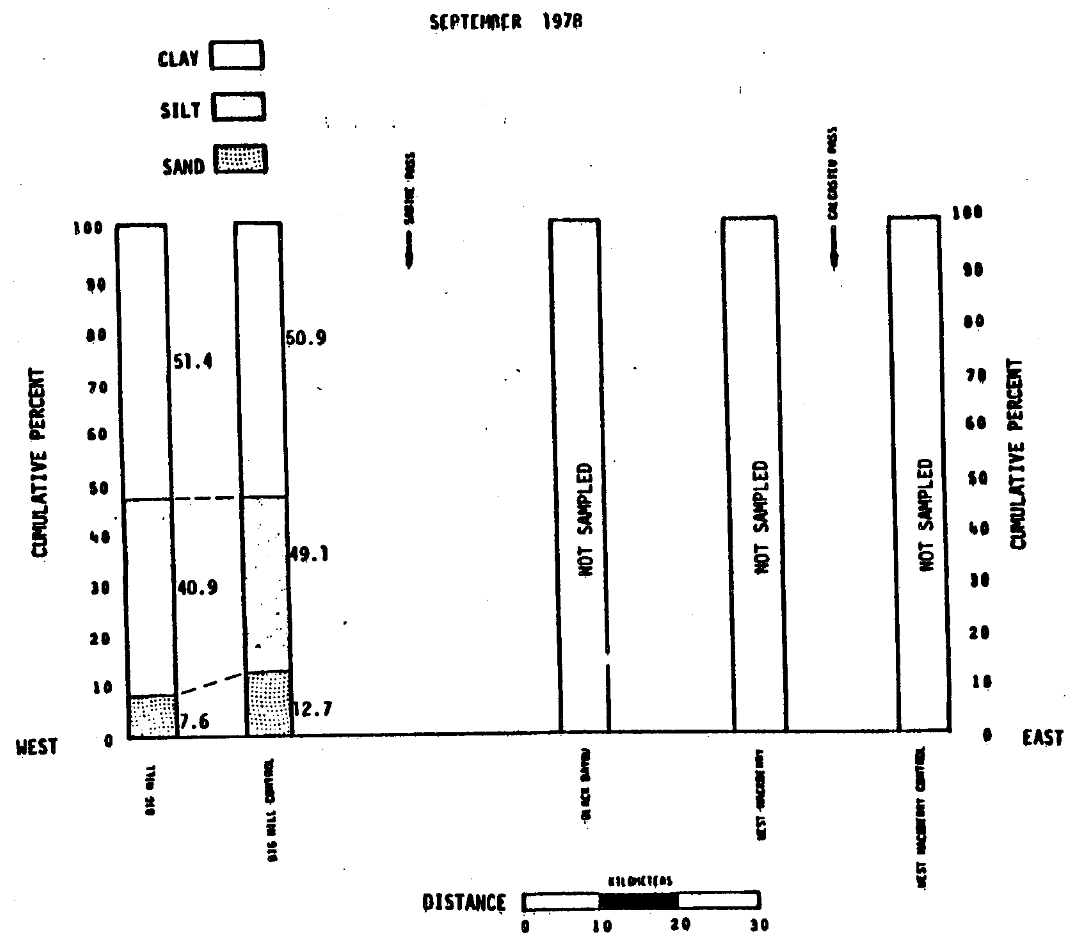


Figure F-45. Mean percentages of sand, silt, and clay at the Texoma study sites for September 1978 (Cruise 12).

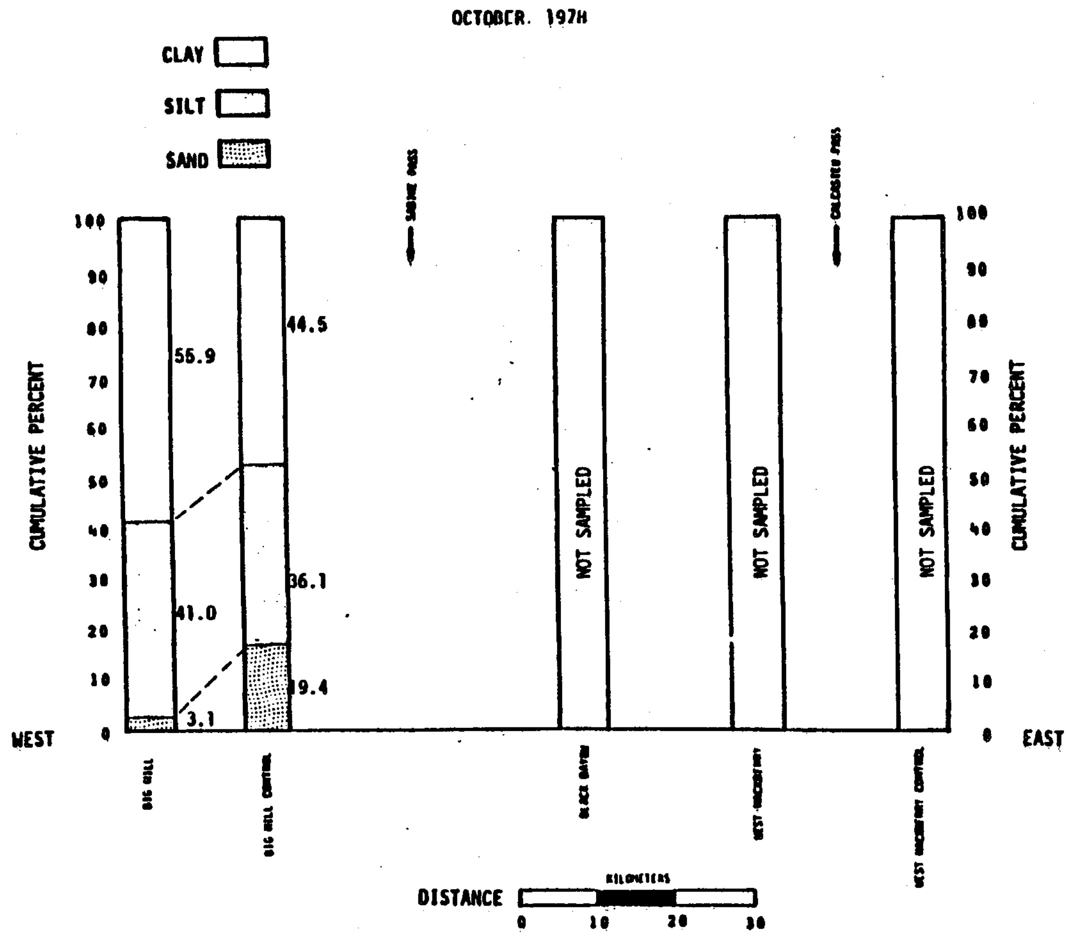


Figure F-46. Mean percentages of sand, silt, and clay at the Texoma study sites for October 1978 (Cruise 13).

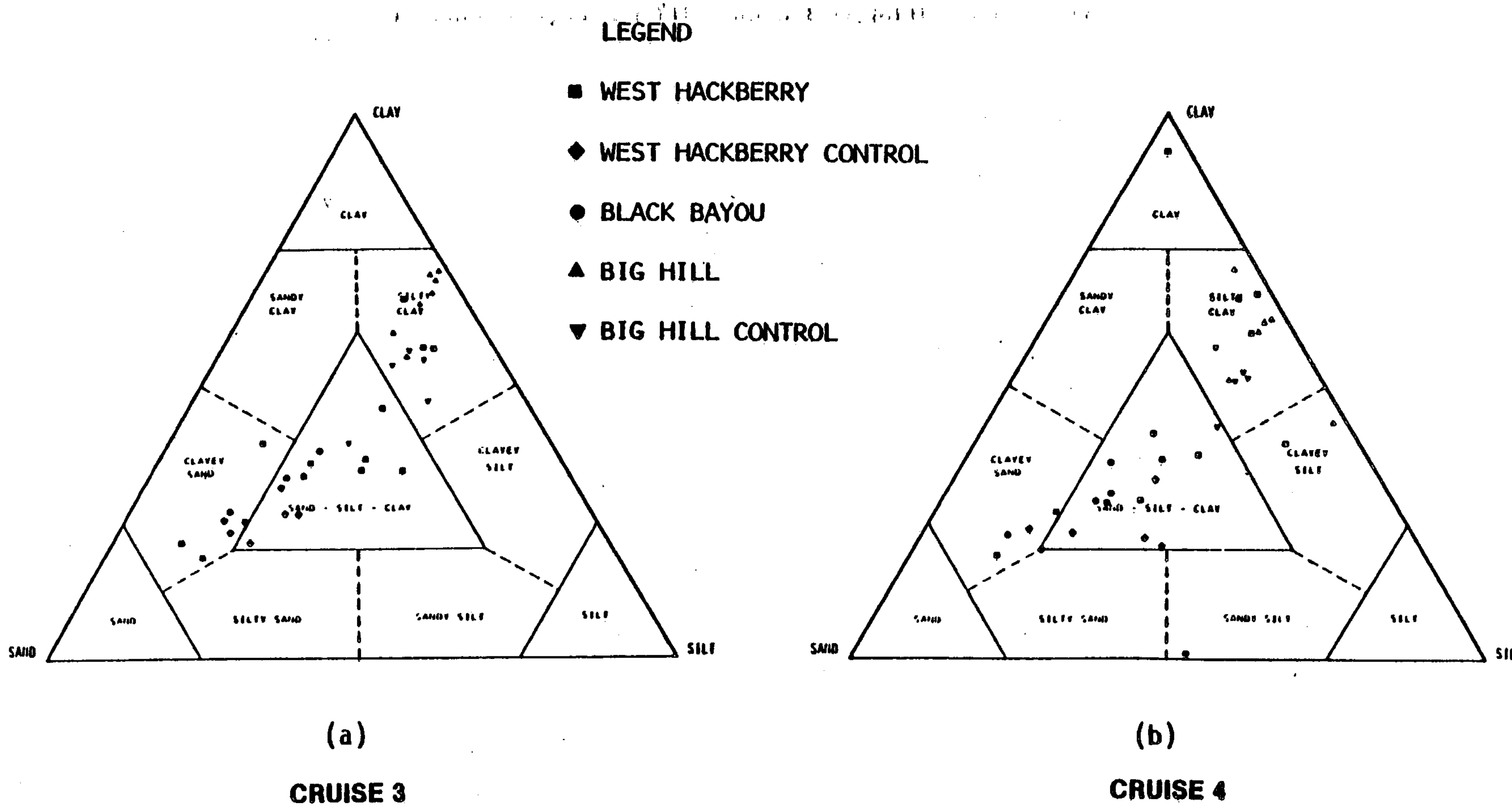
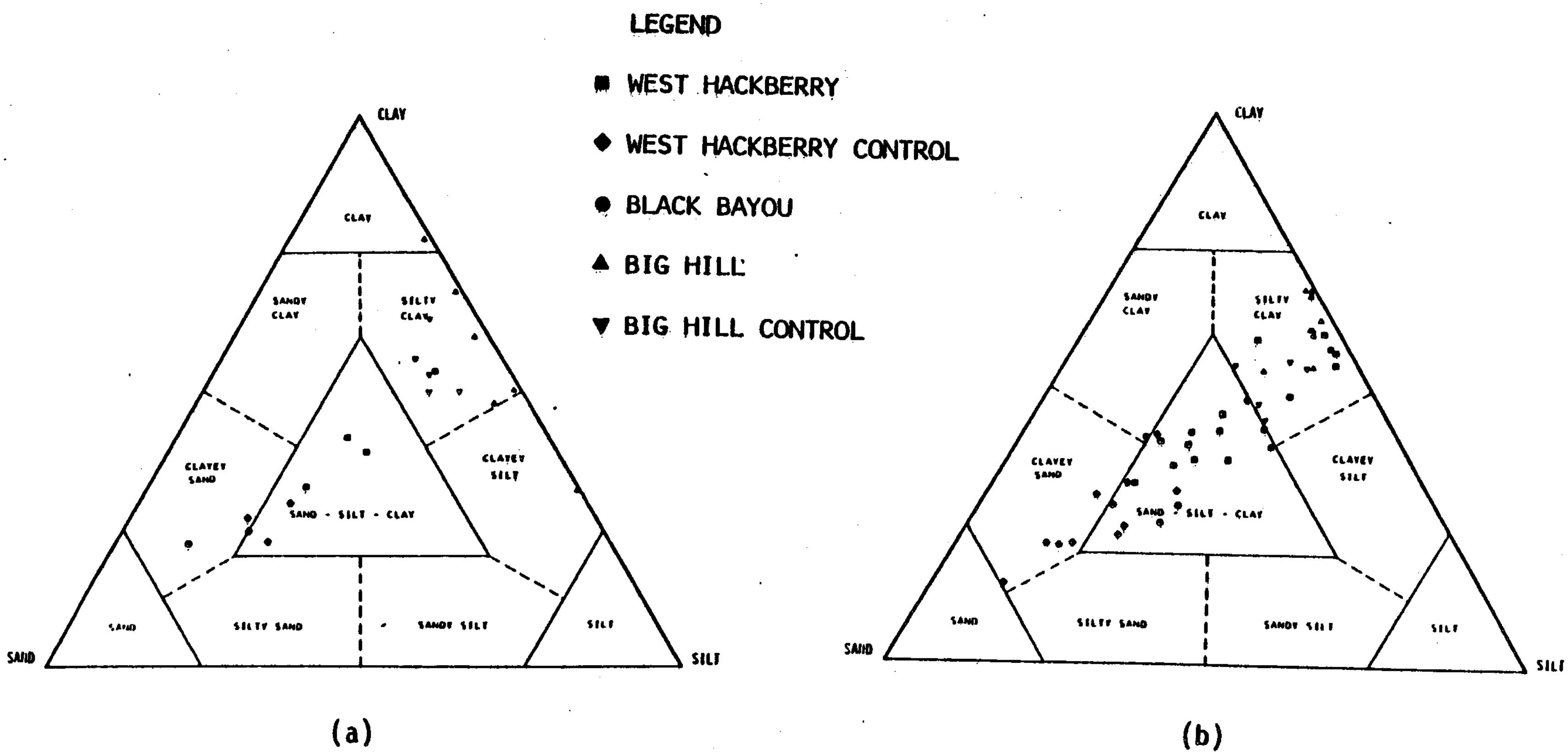


Figure F-47. Triangular facies diagrams for surficial sediment samples taken in the Texoma study area: (a) November 1977, (b) December 1977.



CRUISE 5

CRUISE 6

Figure F-48. Triangular facies diagrams for surficial sediment samples taken in the Texoma study area: (a) January/February 1978, (b) March 1978.

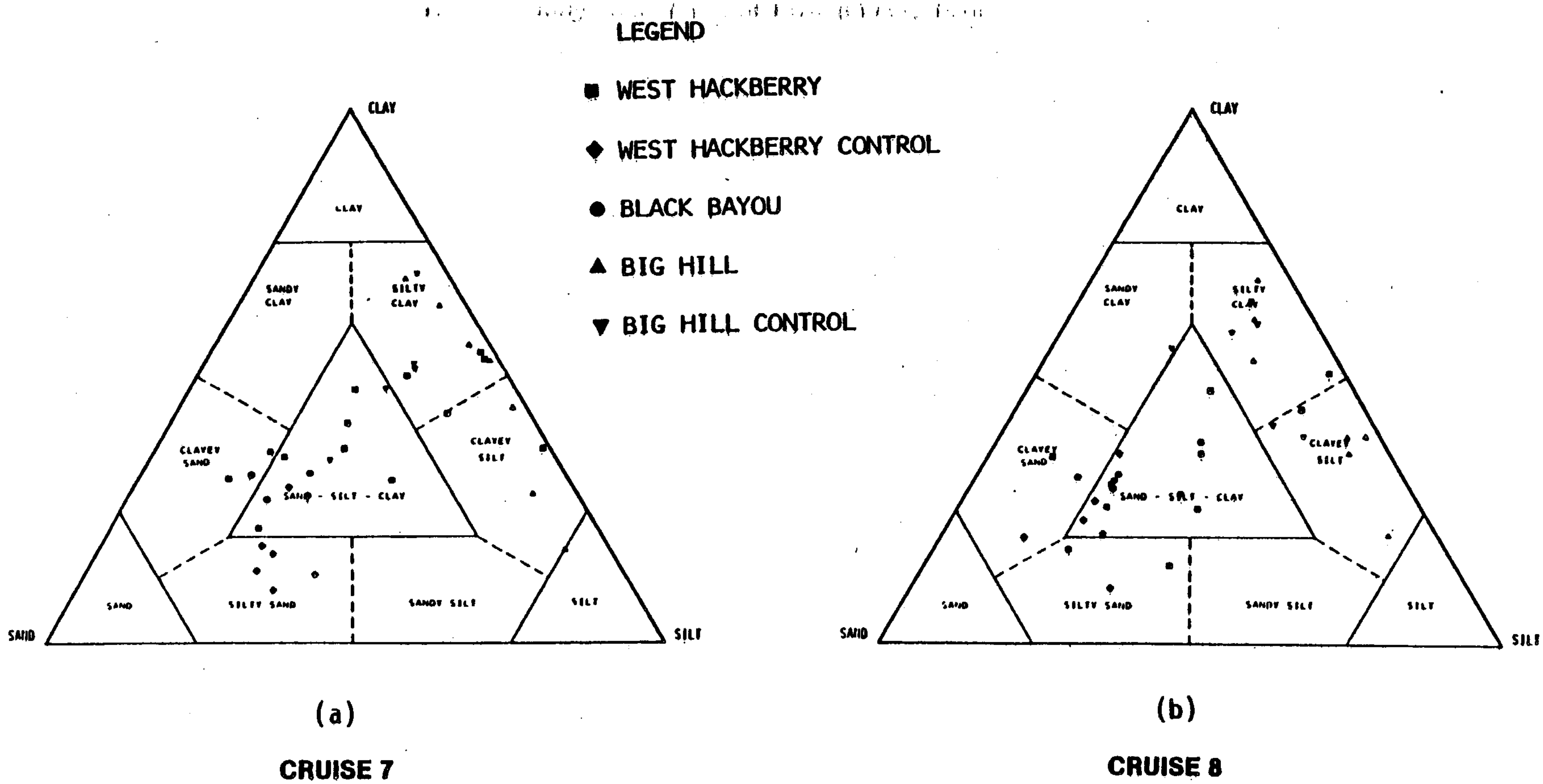


Figure F-49. Triangular facies diagrams for surficial sediment samples taken in the Texoma study area: (a) April 1978, (b) May 1978.

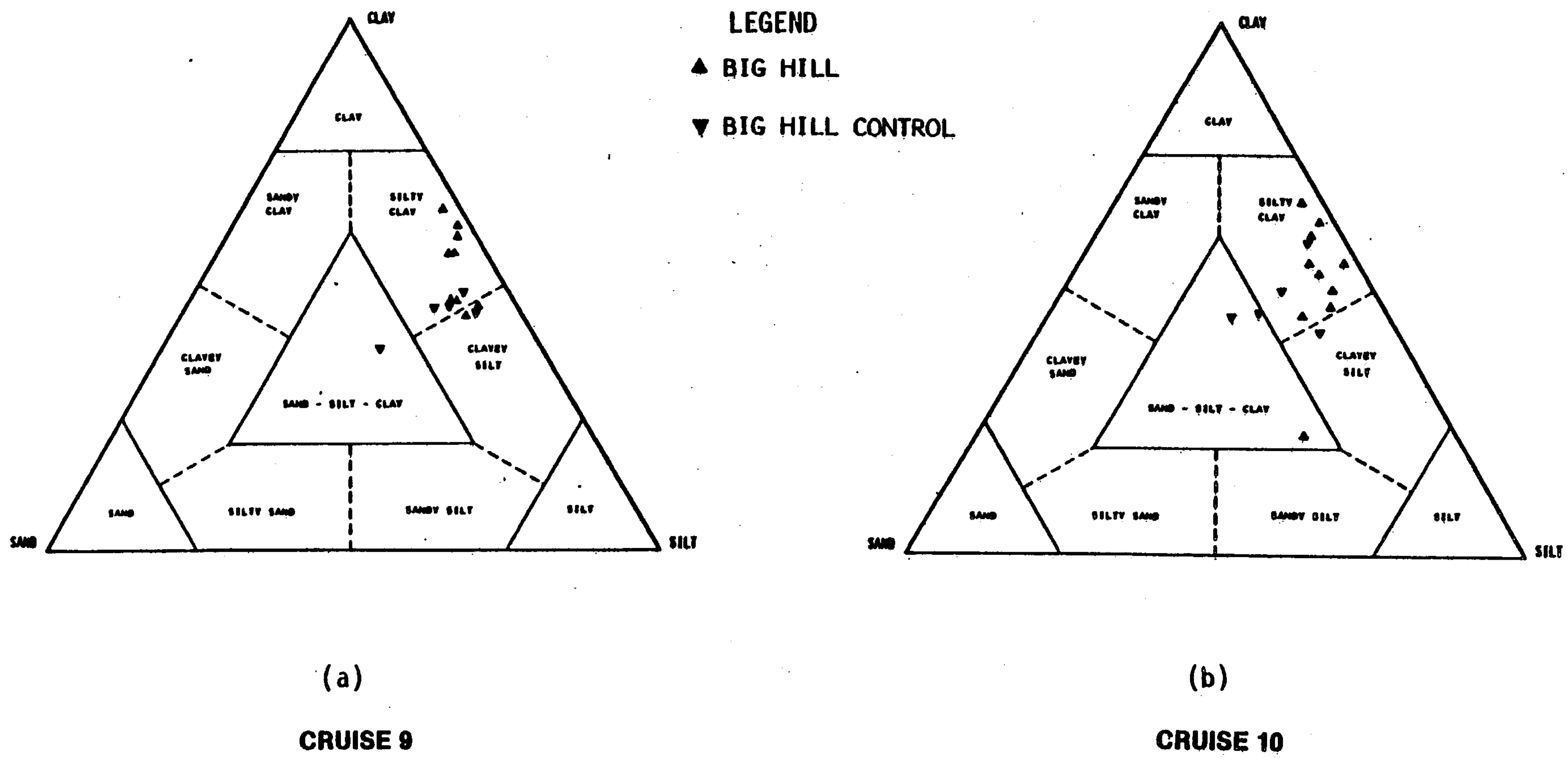
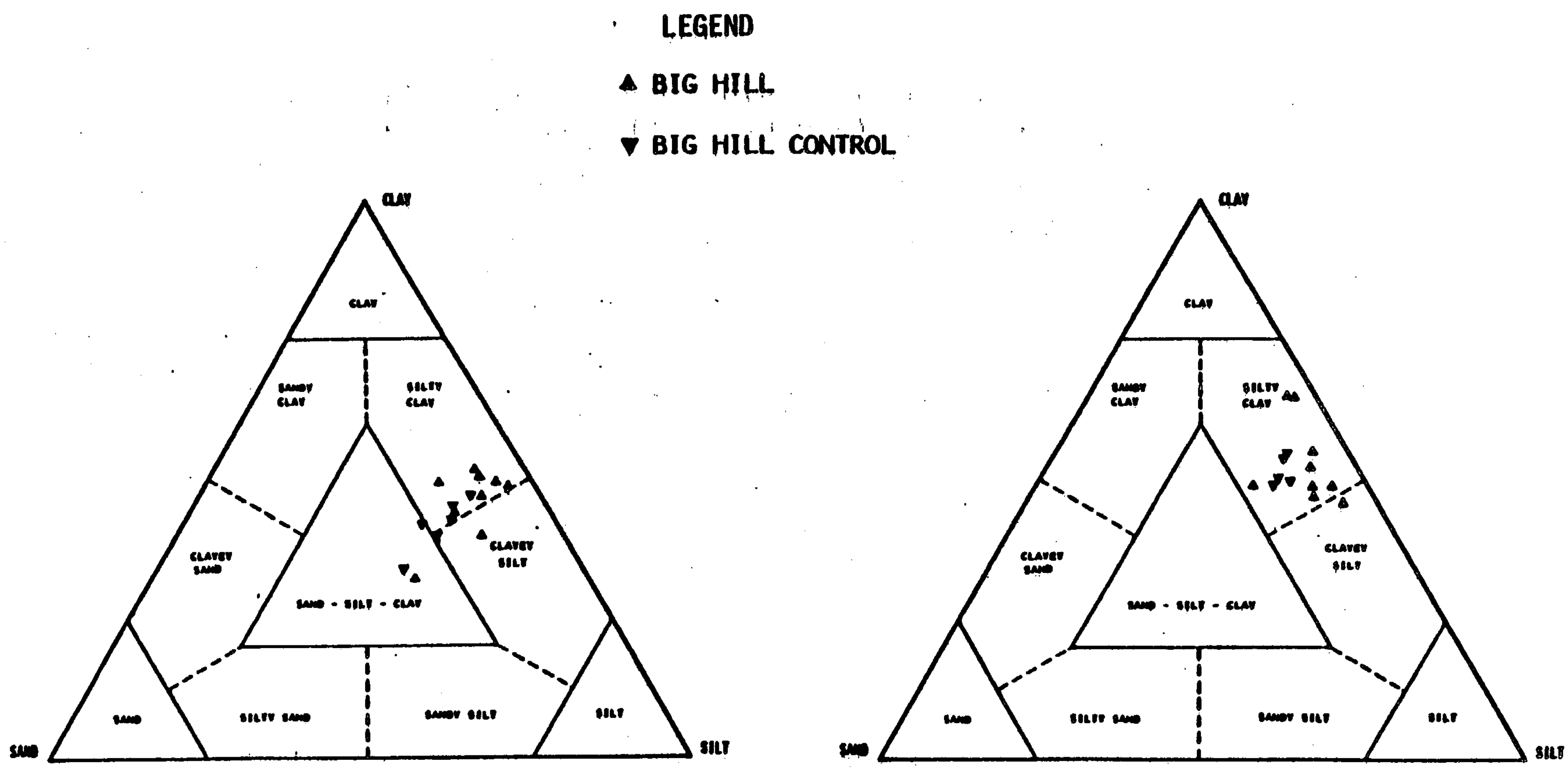


Figure F-50. Triangular facies diagrams for surficial sediment samples taken in the Texoma study area: (a) June 1978, (b) July 1978.



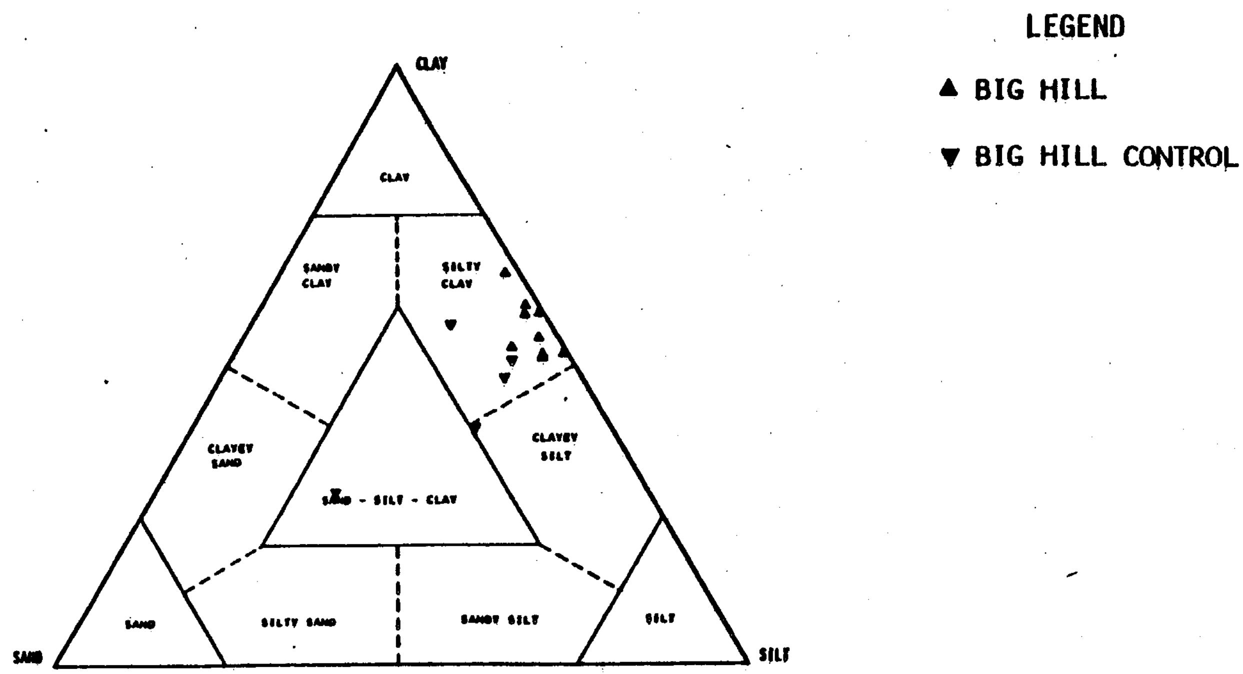
(a)

CRUISE 11

(b)

CRUISE 12

Figure F-51. Triangular facies diagrams for surficial sediment samples taken in the Texoma study area: (a) August 1978, (b) September 1978.



CRUISE 13

Figure F-52. **Triangular facies diagrams for surficial sediment samples taken in the Texoma study area in October 1978.**

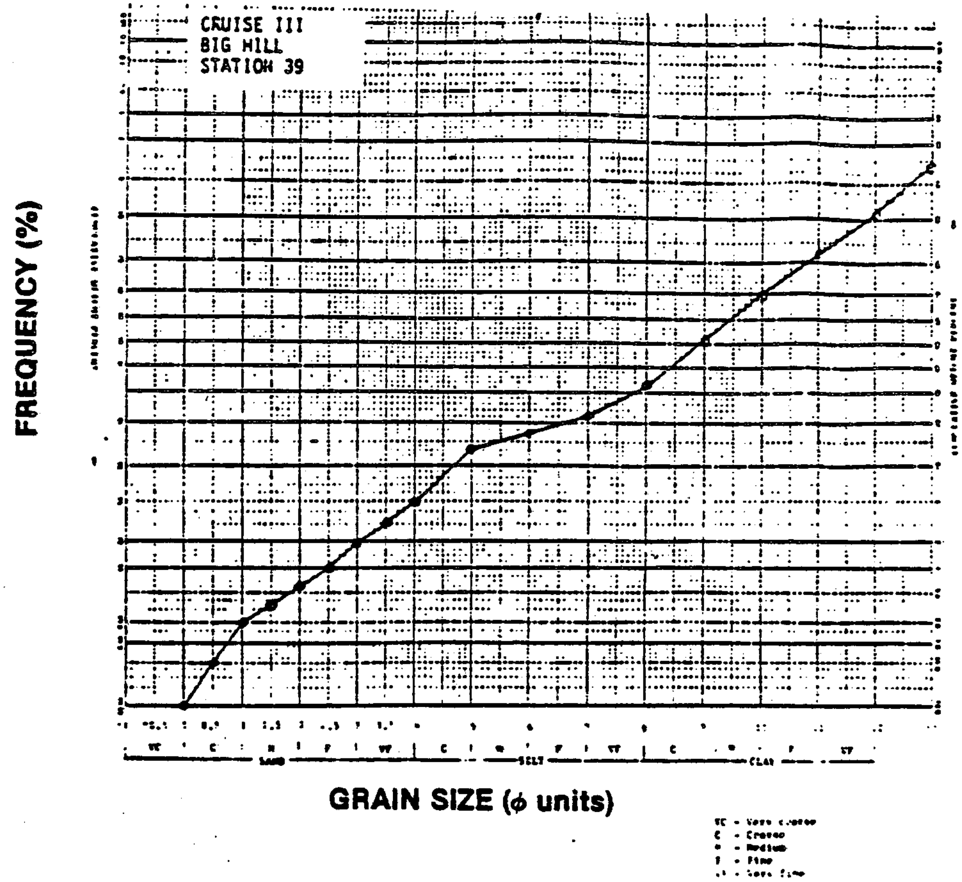


Figure F-53. **Cumulative frequency plot of particle size distribution of the surficial sediments at the center station (Station 39) of the Big Hill study site during November 1977.**

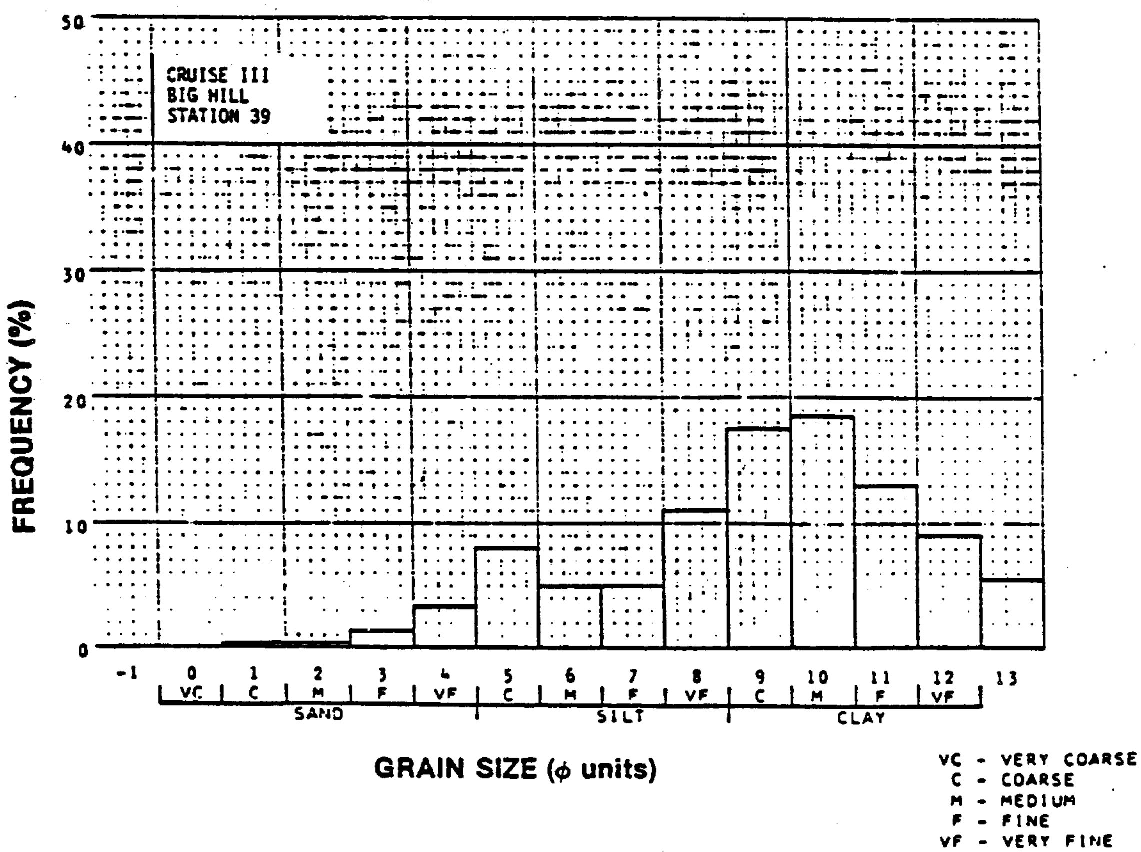


Figure F-54. **Histogram plot of particle size distribution of the surficial sediments at the center station (Station 39) of the Big Hill study site during November 1977.**

Table F-21. Cruise by site means for percent fines for five sites in the Texoma region (November 1977 to October 1978)

Site	Month: NOV	DEC	JAN/FEB	MAR	APR	MAY	Overall	Month: JUN	JUL	AUG	SEP	OCT	Overall
Big Hill	94.42	91.01	97.62	96.16	95.39	92.94	95.02	94.01	92.67	89.35	92.67	97.10	94.27
CL*							(93.70-96.21)						(93.39-95.09)
N**	7	7	6	17	7	7	51	9	10	9	9	9	97
Big Hill Control	82.73	86.28	88.17	84.09	86.02	84.74	84.77	87.17	84.21	81.07	87.48	81.86	84.64
CL							(82.79-86.66)						(83.05-86.16)
N	5	5	5	10	5	5	35	5	5	5	5	5	60
Black Bayou	53.04	52.17	33.60	54.34	56.32	49.20	52.60	NO SAMPLES					
CL							(49.84-55.27)						
N	5	5	1	10	5	5	31						
West Hackberry	69.19	76.22	77.27	80.40	76.45	70.56	76.40	NO SAMPLES					
CL							(72.75-79.78)						
N	11	12	5	34	12	12	86						
West Hackberry Control	47.89	51.66	47.45	50.81	46.49	46.05	49.10	NO SAMPLES					
CL							(46.54-51.59)						
N	6	6	4	19	6	6	47						
Over Five Sites	72.15	74.39	81.39	76.79	75.18	71.56	75.30	NO SAMPLES					
CL	(65.46-78.40)	(67.50-80.69)	(72.38-88.99)	(72.90-80.45)	(68.50-81.26)	(65.12-77.54)	(73.03-77.56)						
N	31	35	21	90	35	35	247						
Over Three East Sites	59.90	65.07	61.62	68.14	64.78	59.78	64.60	NO SAMPLES					
CL	(52.80-66.70)	(56.60-72.90)	(47.30-74.80)	(63.50-72.50)	(56.50-72.50)	(52.70-66.40)	(61.80-67.20)						
N	22	23	10	63	23	23	164						
Over Two West Sites	90.24	89.14	94.16	92.56	91.08	89.86	91.46	91.84	90.16	86.17	90.96	93.03	91.08
CL	(85.52-94.11)	(82.11-94.58)	(90.96-96.72)	(90.00-94.81)	(86.25-94.91)	(86.70-92.67)	(90.01-92.79)	(89.14-94.17)	(86.56-93.28)	(82.19-89.90)	(80.80-92.87)	(88.47-96.57)	(90.09-91.97)
N	12	12	11	27	12	12	86	14	15	14	14	14	157

*95% Confidence Limits.

**N = Number of Samples.

Table F-22. Cruise by site means for M_D for five sites in the Texoma region (November 1977 to October 1978)

Site	NOV	DEC	JAN/FEB	MAR	APR	MAY	Overall	JUN	JUL	AUG	SEP	OCT	Overall
	Month							Month					
Big Hill	9.07	7.81	8.10	8.16	8.29	7.79	8.20	7.93	8.00	7.59	8.08	8.91	8.16
SE*							±0.13						±0.09
N**	7	7	6	17	7	7	51	9	10	9	9	9	97
Big Hill Control	8.05	7.78	8.32	7.50	7.82	8.20	7.87	7.07	7.45	6.52	7.98	6.99	7.58
SE							±0.18						±0.14
N	2	5	5	10	5	5	32	5	5	5	5	5	57
Black Bayou	4.57	4.29	2.95	4.71	4.60	4.10	4.45	NO SAMPLES					
SE							±0.14						
N	5	5	1	10	5	5	31						
West Hackberry	6.03	6.15	6.45	6.93	6.49	6.02	6.49	NO SAMPLES					
SE							±0.19						
N	11	12	5	34	12	12	86						
West Hackberry Control	4.10	4.17	4.11	4.53	3.96	4.07	4.26	NO SAMPLES					
SE							±0.13						
N	6	6	4	19	6	6	47						
Over Five Sites	6.24	6.11	6.75	6.47	6.33	6.08	6.34	NO SAMPLES					
SE	±0.42	±0.35	±0.43	±0.19	±0.34	±0.32	±0.13						
N	31	35	21	90	35	35	247						
Over Three East Sites	5.17	5.23	5.17	5.85	5.42	5.09	5.46	NO SAMPLES					
SE	±0.39	±0.36	±0.57	±0.21	±0.35	±0.33	±0.13						
N	22	23	10	63	23	23	164						
Over Two West Sites	8.84	7.80	8.20	7.92	8.09	7.96	8.07	7.62	7.81	7.21	8.05	8.26	7.94
SE	±0.22	±0.47	±0.12	±0.15	±0.38	±0.14	±0.11	±0.23	±0.26	±0.24	±0.15	±0.40	±0.08
N	9	12	11	27	12	12	83	14	15	14	14	14	154

*Standard Error.

**N = Number of Samples.

Table F-23. Cruise by site means for M_{ϕ} for five sites in the Texoma region (November 1977 to October 1978)

Site	NOV	DEC	JAN/FEB	MAR	APR	MAY	Overall	JUN	JUL	AUG	SEP	OCT	Overall
	Month							Month					
Big Hill	8.76	8.21	8.10	7.76	7.57	6.75	7.83	7.91	8.08	7.27	8.01	12.14	8.23
SE*							±0.16						±0.19
N**	7	7	6	17	7	7	51	9	10	9	9	9	97
Big Hill Control	8.67	7.98	8.21	7.31	7.14	7.36	7.62	7.64	8.17	7.27	8.46	7.92	7.74
SE							±0.21						±0.14
N	2	5	5	10	5	5	32	5	5	5	5	5	57
Black Bayou	7.46	6.99	5.06	5.38	5.40	6.10	6.08						
SE							±0.21	NO SAMPLES					
N	5	5	1	10	5	5	31						
West Hackberry	8.02	7.16	7.12	7.28	6.88	5.95	7.11						
SE							±0.13	NO SAMPLES					
N	11	12	5	34	12	12	86						
West Hackberry Control	6.61	6.82	6.14	5.65	4.93	6.49	5.98						
SE							±0.23	NO SAMPLES					
N	6	6	4	19	6	6	47						
Over Five Sites	7.87	7.40	7.38	6.82	6.51	6.42	6.98						
SE	±0.24	±0.20	±0.28	±0.14	±0.24	±0.27	±0.09	NO SAMPLES					
N	31	35	21	90	35	35	247						
Over Three East Sites	7.51	7.03	6.53	6.49	6.05	6.12	6.59						
SE	±0.28	±0.24	±0.38	±0.16	±0.22	±0.38	±0.22	NO SAMPLES					
N	22	23	10	63	23	23	164						
Over Two West Sites	8.74	8.11	8.15	7.60	7.39	7.00	7.75	7.82	8.11	7.27	8.17	10.63	8.05
SE	±0.31	±0.27	±0.23	±0.20	±0.46	±0.23	±0.12	±0.19	±0.39	±0.30	±0.21	±0.80	±0.13
N	9	12	11	27	12	12	83	14	15	14	14	14	154

*Standard Error.

**N = Number of Samples.

Table F-24. Cruise by site means for percent carbonate carbon for five sites in the Texoma region (September 1977 to October 1978)

Site	Month: SEP	OCT	NOV	DEC	JAN/FEB	MAR	APR	MAY	Overall	Month: JUN	JUL	AUG	SEP	OCT	Overall
Big Hill	0.51	0.26	0.41	0.11	0.75	0.43	0.48	0.35	0.39	0.36	0.66	0.56	0.46	0.28	0.42
CL*									(0.32-0.45)						(0.38-0.47)
N**	9	9	6	7	7	9	4	7	58	9	10	9	9	9	104
Big Hill Control	0.42	0.26	0.17	0.08	0.53	0.51	0.39	0.42	0.32	0.66	0.56	0.66	0.73	0.19	0.40
CL									(0.27-0.39)						(0.34-0.46)
N	5	4	5	5	5	5	5	5	39	5	5	5	5	5	64
Black Bayou	0.32	0.36	0.15	0.07	0.28	0.33	0.33	0.19	0.24	NO SAMPLES					
CL									(0.19-0.29)						
N	5	5	5	4	1	5	5	5	35						
West Hackberry	0.36	0.29	0.21	0.07	0.48	0.52	0.45	0.29	0.32	NO SAMPLES					
CL									(0.28-0.35)						
N	16	17	13	11	5	17	12	12	103						
West Hackberry Control	0.35	0.18	0.45	0.36	0.51	0.56	0.57	0.39	0.39	NO SAMPLES					
CL									(0.32-0.45)						
N	10	10	5	5	4	9	6	6	55						
Over Five Sites	0.38	0.27	0.26	0.11	0.57	0.47	0.44	0.32	0.33	NO SAMPLES					
CL	(0.33-0.45)	(0.23-0.30)	(0.17-0.34)	(0.08-0.15)	(0.49-0.64)	(0.43-0.52)	(0.38-0.52)	(0.29-0.36)	(0.32-0.36)						
N	45	45	34	32	22	45	32	35	290						
Over Three East Sites	0.35	0.27	0.24	0.12	0.47	0.50	0.45	0.29	0.32	NO SAMPLES					
CL	(0.27-0.40)	(0.22-0.31)	(0.15-0.33)	(0.07-0.17)	(0.38-0.55)	(0.44-0.55)	(0.35-0.55)	(0.24-0.34)	(0.29-0.35)						
N	31	32	23	20	10	31	23	23	193						
Over Two West Sites	0.47	0.26	0.29	0.10	0.65	0.42	0.43	0.40	0.36	0.45	0.63	0.59	0.55	0.25	0.41
CL	(0.34-0.63)	(0.19-0.34)	(0.14-0.49)	(0.07-0.14)	(0.55-0.77)	(0.36-0.49)	(0.33-0.52)	(0.33-0.47)	(0.32-0.40)	(0.32-0.60)	(0.54-0.71)	(0.49-0.71)	(0.38-0.74)	(0.16-0.37)	(0.31-0.54)
N	14	13	11	12	12	14	9	12	97	14	15	14	14	14	168

*95% Confidence Limits.

**N = Number of Samples.

Table F-25. Cruise by site means for percent organic carbon for five sites in the Texoma region (September 1977 to October 1978)

Site	Month: SEP	OCT	NOV	DEC	JAN/FEB	MAR	APR	MAY	Overall	Month: JUN	JUL	AUG	SEP	OCT	Overall
Big Hill	0.22	0.52	0.38	0.49	0.23	0.45	0.65	0.22	0.37	0.35	0.46	0.18	0.28	0.21	0.33
CL*									(0.33-0.41)						(0.31-0.34)
N**	9	9	6	7	7	9	4	7	58	9	10	9	9	9	104
Big Hill Control	0.49	0.43	0.28	0.34	0.15	0.42	0.33	0.15	0.31	0.15	0.32	0.11	0.23	0.22	0.26
CL									(0.26-0.37)						(0.21-0.31)
N	5	4	5	5	5	5	5	5	39	5	5	5	5	5	64
Black Bayou	0.25	0.22	0.22	0.22	0.55	0.22	0.19	0.10	0.21	NO SAMPLES					
CL									(0.16-0.25)						
N	5	5	5	4	1	5	5	5	35						
West Hackberry	0.26	0.34	0.32	0.30	0.24	0.18	0.33	0.26	0.32	NO SAMPLES					
CL									(0.24-0.38)						
N	16	17	13	12	5	17	12	12	104						
West Hackberry Control	0.20	0.18	0.19	0.17	0.16	0.12	0.23	0.07	0.17	NO SAMPLES					
CL									(0.14-0.20)						
N	10	10	5	5	4	9	6	6	55						
Over Five Sites	0.26	0.32	0.29	0.31	0.21	0.24	0.34	0.13	0.26	NO SAMPLES					
CL	(0.21-0.31)	(0.29-0.36)	(0.26-0.33)	(0.27-0.34)	(0.18-0.24)	(0.21-0.28)	(0.28-0.40)	(0.11-0.16)	(0.24-0.28)						
N	45	45	34	33	22	45	32	35	291						
Over Three East Sites	0.24	0.26	0.26	0.24	0.23	0.16	0.30	0.11	0.22	NO SAMPLES					
CL	(0.17-0.29)	(0.23-0.29)	(0.22-0.31)	(0.20-0.29)	(0.17-0.30)	(0.14-0.18)	(0.23-0.36)	(0.08-0.12)	(0.20-0.23)						
N	31	32	23	21	10	31	23	23	194						
Over Two West Sites	0.30	0.49	0.33	0.42	0.20	0.44	0.45	0.20	0.34	0.27	0.41	0.15	0.26	0.21	0.30
CL	(0.20-0.43)	(0.44-0.54)	(0.24-0.45)	(0.36-0.49)	(0.15-0.24)	(0.37-0.51)	(0.33-0.58)	(0.13-0.25)	(0.31-0.39)	(0.20-0.35)	(0.34-0.48)	(0.13-0.18)	(0.23-0.30)	(0.14-0.30)	(0.21-0.34)
N	14	13	11	12	12	14	9	12	97	14	15	14	14	14	168

*95% Confidence Limits.

**N = Number of Samples.

Table F-26. Cruise by site means for percent clay for five sites in the Texoma region (November 1977 to October 1978)

Site	NOV	DEC	JAN/FEB	MAR	APR	MAY	Overall	JUN	JUL	AUG	SEP	OCT	Overall
	Month							Month					
Big Hill	65.97	55.62	55.78	57.03	46.69	44.80	54.86	52.78	52.63	45.74	51.45	55.94	53.38
CL*							(51.29-58.39)						(51.37-55.34)
N**	7	7	6	17	7	7	51	9	10	9	9	9	97
Big Hill Control	50.69	51.64	54.08	47.24	51.15	50.61	50.38	45.10	48.76	40.30	50.94	44.36	48.51
CL							(48.00-52.72)						(46.80-50.12)
N	5	5	5	10	5	5	35	5	5	5	5	5	60
Black Bayou	32.05	29.72	21.90	29.36	28.97	27.93	29.30	NO SAMPLES					
CL							(27.61-31.02)						
N	5	5	1	10	5	5	31						
West Hackberry	40.49	33.33	46.95	46.41	40.35	35.60	41.45	NO SAMPLES					
CL							(38.64-44.19)						
N	11	12	5	34	12	12	86						
West Hackberry Control	26.74	24.43	26.26	25.98	16.79	21.95	24.13	NO SAMPLES					
CL							(21.96-26.28)						
N	6	6	4	19	6	6	47						
Over Five Sites	43.40	38.07	45.77	42.05	37.00	35.86	40.39	NO SAMPLES					
CL	(38.58-48.24)	(32.61-43.70)	(39.25-52.35)	(39.23-44.79)	(32.36-41.78)	(31.40-40.44)	(38.65-42.20)						
N	34	35	21	90	35	35	250						
Over Three East Sites	34.69	30.15	35.79	37.27	31.21	30.20	33.96	NO SAMPLES					
CL	(30.20-39.10)	(24.00-36.50)	(26.40-45.60)	(34.30-40.10)	(26.60-35.80)	(25.60-34.70)	(32.00-35.80)						
N	22	23	10	63	23	23	164						
Over Two West Sites	59.71	53.97	55.01	53.42	48.54	47.22	53.04	50.04	51.34	43.79	51.27	51.81	51.52
CL	(54.62-64.67)	(48.83-59.04)	(48.44-61.38)	(49.62-57.08)	(40.13-57.03)	(39.97-54.41)	(50.74-55.37)	(46.35-53.77)	(46.23-56.48)	(40.98-46.60)	(48.78-53.74)	(47.34-56.17)	(49.98-52.94)
N	12	12	11	27	12	12	86	14	15	14	14	14	157

*95% Confidence Limits.

**N = Number of Samples.

Table F-27. Cruise by site means for percent silt for five sites in the Texoma region (November 1977 to October 1978)

Site	Month: NOV	DEC	JAN/FEB	MAR	APR	MAY	Overall	Month: JUN	JUL	AUG	SEP	OCT	Overall
Big Hill	27.55	30.95	41.44	38.37	47.95	47.38	38.66	40.89	38.97	42.84	40.87	40.96	39.70
CL*							(35.21-42.17)						(37.80-41.69)
N**	7	7	6	17	7	7	51	9	10	9	9	9	97
Big Hill Control	31.50	34.44	33.97	36.07	30.66	33.37	33.71	41.41	34.86	40.43	36.36	35.95	35.40
CL							(32.08-35.27)						(34.11-36.65)
N	5	5	5	10	5	5	35**	5	5	5	5	5	60
Black Bayou	20.74	27.17	11.70	24.58	26.83	21.02	22.86						
CL							(20.99-24.70)	NO SAMPLES					
N	5	5	1	10	5	5	31						
West Hackberry	26.10	37.07	27.48	30.80	31.90	32.14	31.18						
CL							(29.01-33.31)	NO SAMPLES					
N	11	12	5	34	12	12	86						
West Hackberry Control	20.97	26.66	21.10	23.58	29.24	22.84	24.02						
CL							(22.30-25.75)	NO SAMPLES					
N	6	6	4	19	6	6	47						
Over Five Sites	25.41	31.42	30.66	30.47	33.60	31.88	30.54						
CL	(23.36-27.46)	(26.98-36.03)	(26.14-35.41)	(28.83-32.18)	(29.81-37.44)	(28.03-35.87)	(29.29-31.71)	NO SAMPLES					
N	34	35	21	90	35	35	250						
Over Three East Sites	23.43	30.92	23.13	27.57	30.08	27.14	27.47						
CL	(20.70-26.20)	(24.70-37.30)	(18.40-26.80)	(25.80-29.10)	(26.30-33.80)	(24.00-30.40)	(26.00-28.70)	NO SAMPLES					
N	22	23	10	63	23	23	164						
Over Two West Sites	29.18	32.40	38.01	37.52	40.58	41.45	36.63	41.08	37.59	41.98	39.25	39.16	38.04
CL	(27.62-30.83)	(26.70-38.27)	(31.26-44.94)	(34.56-40.48)	(32.45-49.06)	(33.03-50.03)	(34.56-38.71)	(38.68-43.56)	(34.87-40.35)	(40.43-43.57)	(36.84-41.68)	(36.40-41.93)	(36.80-39.36)
N	12	12	11	27	12	12	86	14	15	14	14	14	157

*95% Confidence Limits.

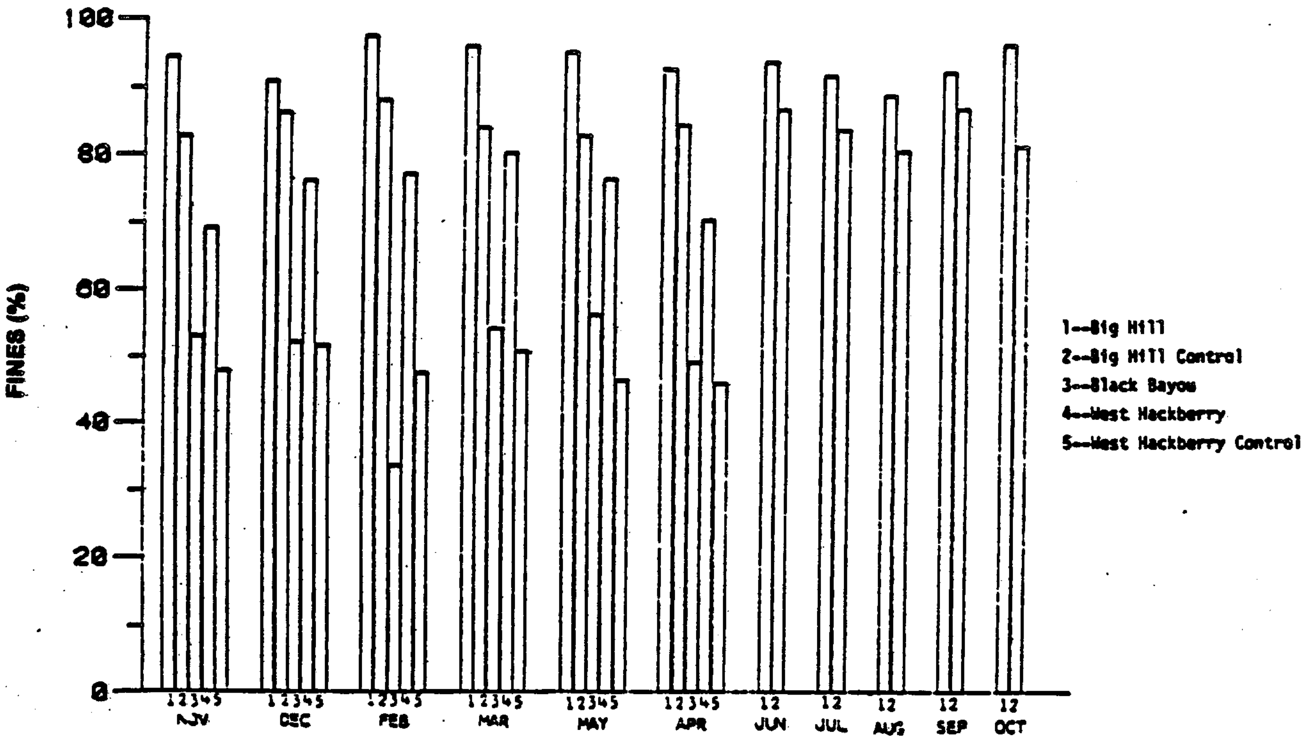
**N = Number of Samples.

Table F-28. Cruise by site means for percent sand for five sites in the Texoma region (November 1977 to October 1978)

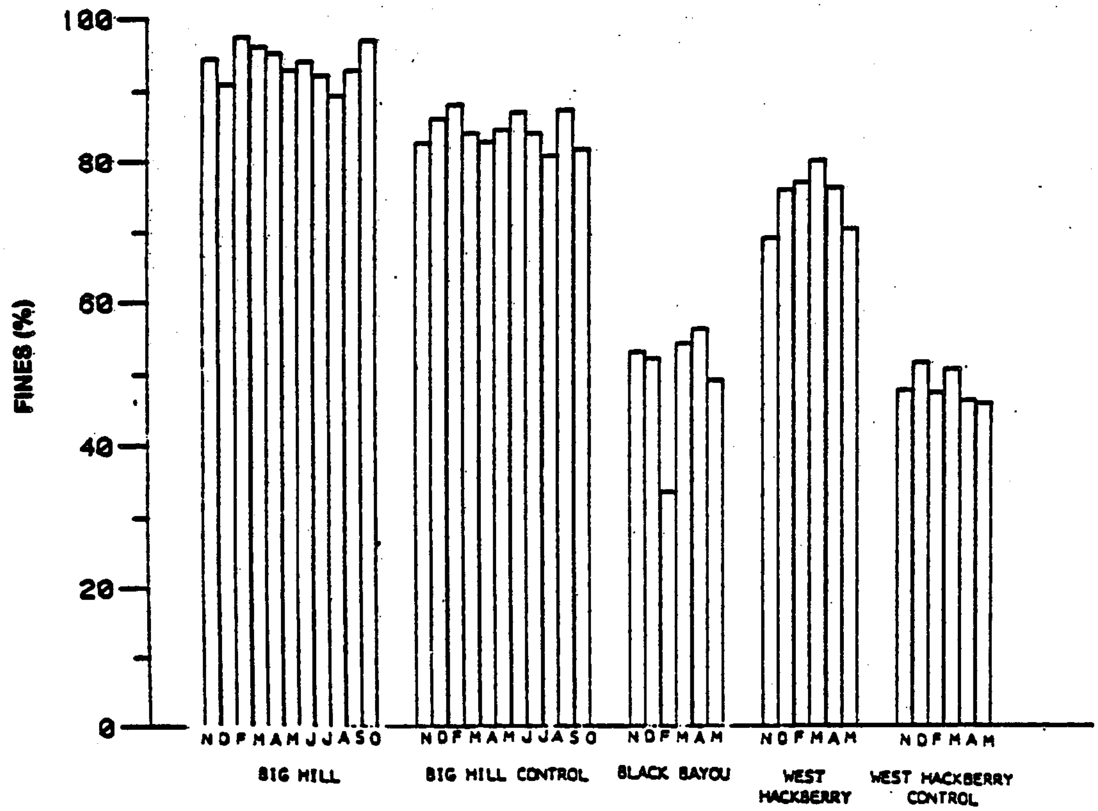
Site	NOV	DEC	JAN/FEB	MAR	APR	MAY	Overall	JUN	JUL	AUG	SEP	OCT	Overall
	Month							Month					
Big Hill	5.58	8.99	2.38	3.84	4.61	7.06	4.99	5.99	7.33	10.65	7.33	2.90	5.73
CI*							(3.79-6.81)						(4.91-6.44)
N**	7	7	6	17	7	7	51	9	10	9	9	9	97
Big Hill Control	17.27	13.72	11.83	15.91	16.98	15.26	15.23	12.83	15.79	18.93	12.52	18.14	15.36
CI							(12.83-17.66)						(14.00-16.37)
N	5	5	5	10	5	5	35	5	5	5	5	5	60
Black Bayou	46.98	47.84	66.40	45.66	43.68	50.80	47.41	NO SAMPLES					
CI							(44.07-50.86)						
N	5	5	1	10	5	5	31						
West Hackberry	30.81	23.78	22.73	19.60	23.55	29.44	23.60	NO SAMPLES					
CI							(19.76-28.19)						
N	11	12	5	34	12	12	86						
West Hackberry Control	52.11	48.33	52.55	49.19	53.51	53.95	50.90	NO SAMPLES					
CI							(47.09-53.82)						
N	6	6	4	19	6	6	47						
Over Five Sites	27.85	25.61	18.61	23.21	24.82	28.44	24.70	NO SAMPLES					
CI	(22.37-34.46)	(18.60-33.21)	(11.50-27.69)	(18.94-27.30)	(19.13-30.71)	(22.37-34.46)	(21.81-27.58)						
N	34	35	21	90	35	35	250						
Over Three East Sites	40.29	34.89	38.36	31.78	35.18	40.10	35.37	NO SAMPLES					
CI	(33.20-46.90)	(26.90-43.20)	(25.10-52.50)	(23.90-32.50)	(27.40-43.30)	(33.30-47.00)	(32.70-38.00)						
N	22	23	10	63	23	23	164						
Over Two West Sites	9.76	10.86	5.84	7.44	8.92	10.14	8.54	8.16	9.84	13.38	9.04	6.97	8.92
CI	(6.08-14.51)	(5.37-18.62)	(3.41-8.42)	(5.15-10.56)	(5.16-13.13)	(6.96-13.29)	(6.95-10.70)	(5.51-11.32)	(6.96-13.29)	(9.71-16.86)	(7.35-11.46)	(3.92-11.17)	(7.83-9.68)
N	12	12	11	27	12	12	86	14	15	14	14	14	157

*95% Confidence Limits.

**N Number of Samples.



(a)



(b)

Figure F-55. Histogram plot of monthly mean percent fines over the period November 1977 to October 1978 in the Texoma study region: (a) by cruise, (b) by site.

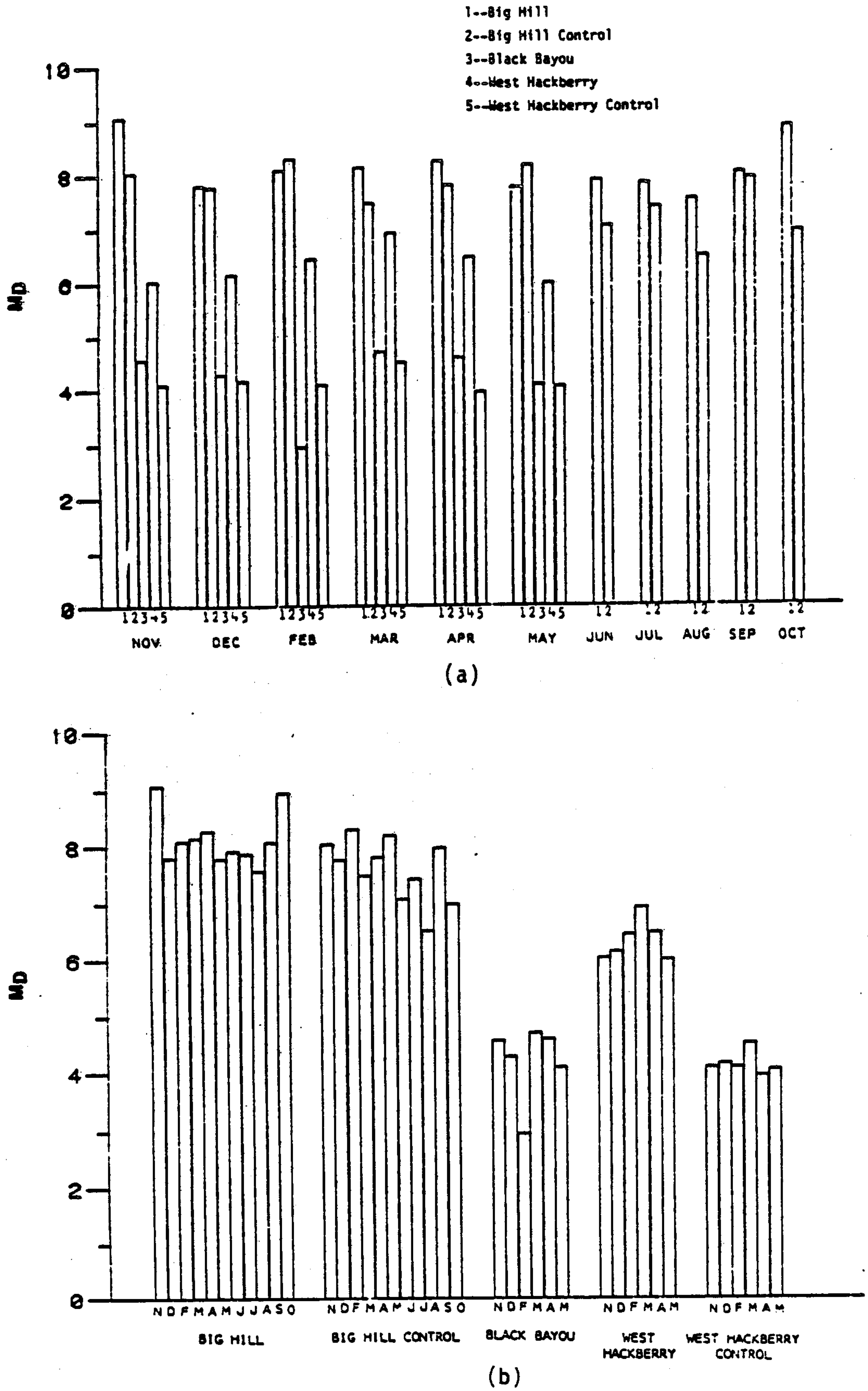
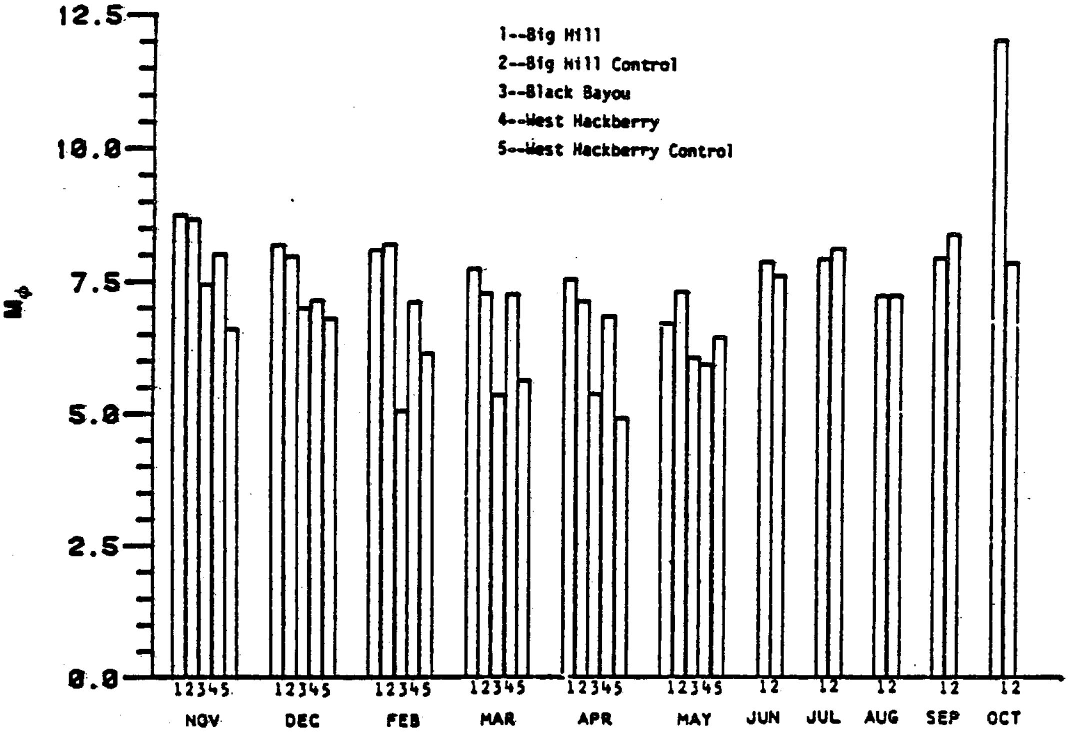
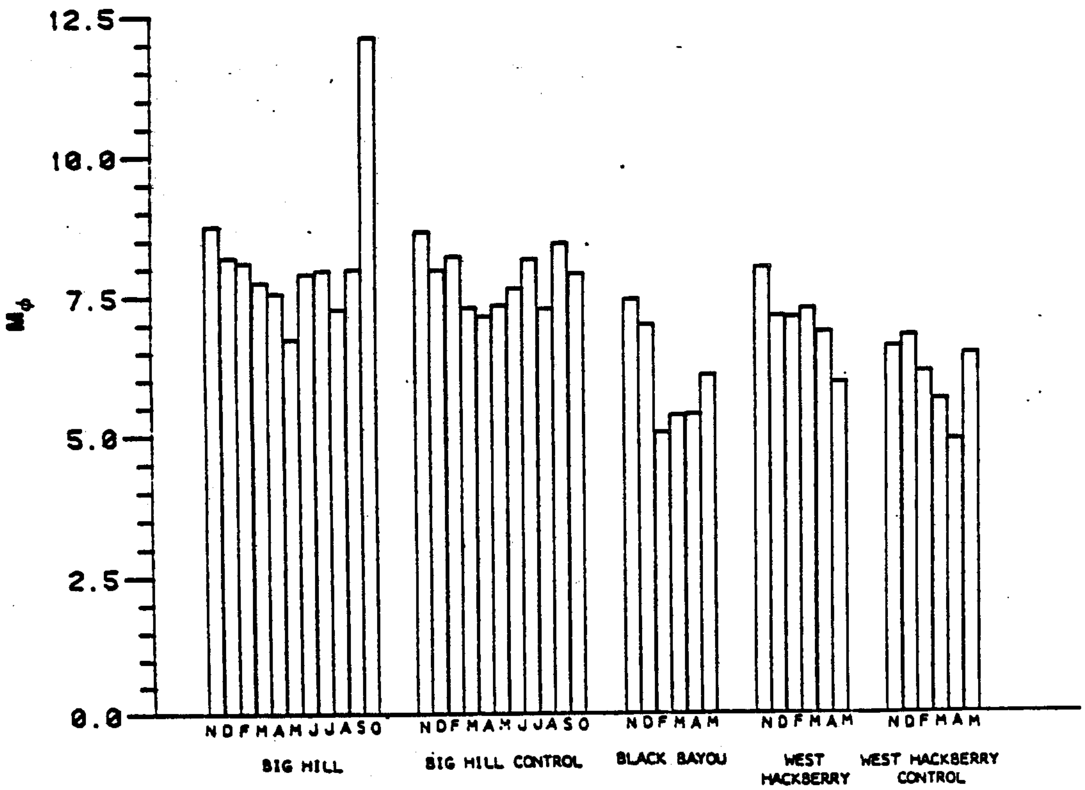


Figure F-56. **Histogram plot of monthly mean M_D over the period November 1977 to October 1978 in the Texoma study region: (a) by cruise, (b) by site.**



(a)



(b)

Figure F-57. Histogram plot of monthly M_ϕ over the period November 1977 to October 1978 in the Texoma study region: (a) by cruise, (b) by site.

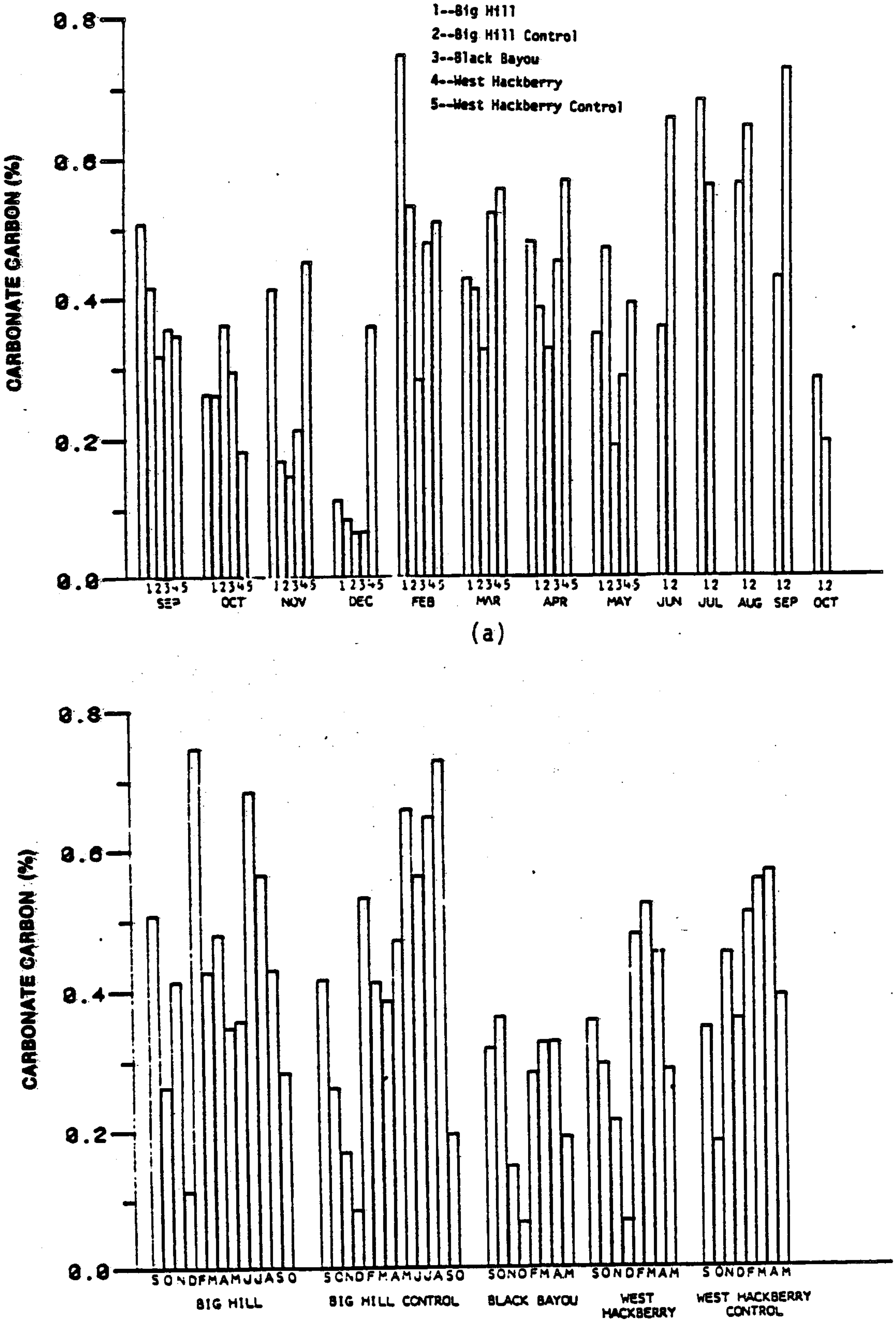
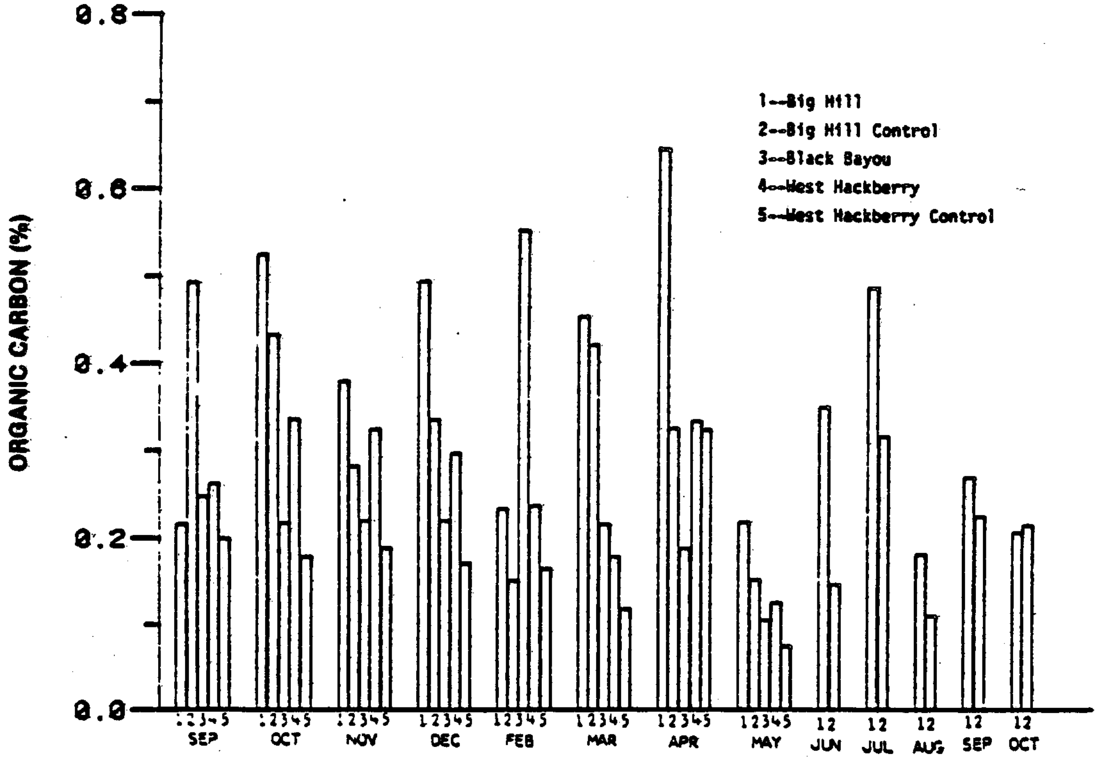
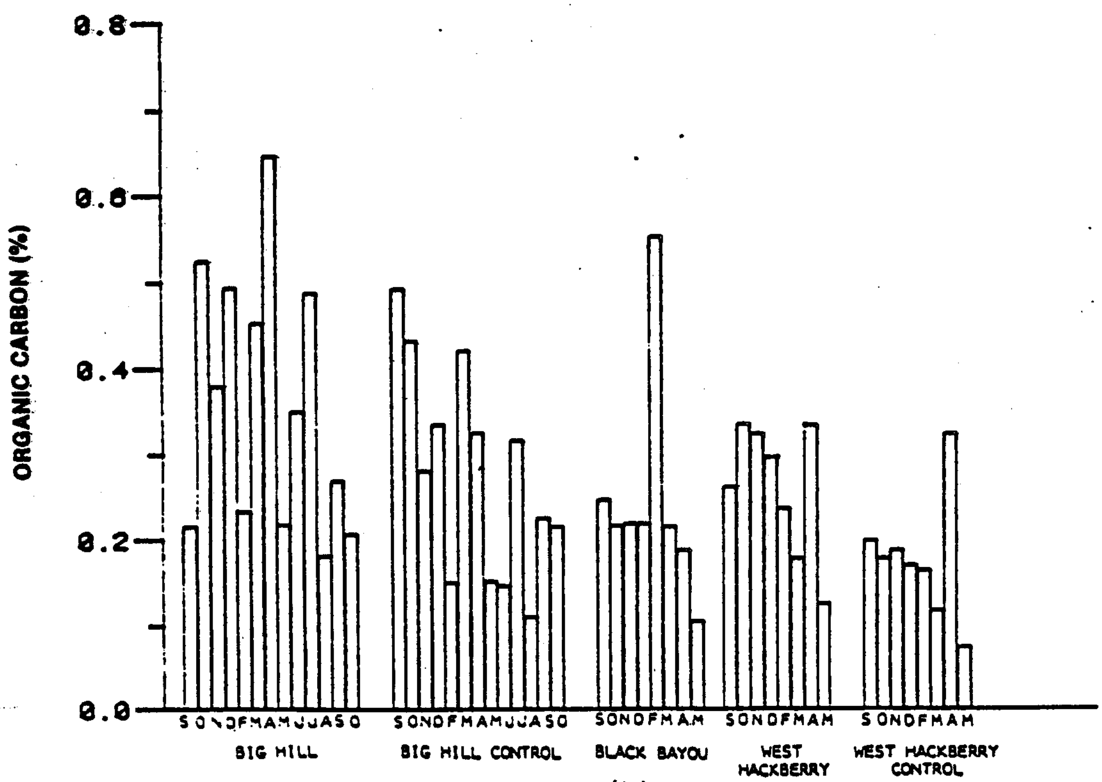


Figure F-58. Histogram plot of monthly mean percent carbonate carbon over the period November 1977 to October 1978 in the Texoma study region: (a) by cruise, (b) by site.



(a)



(b)

Figure F-59. **Histogram plot of monthly mean percent organic carbon over the period November 1977 to October 1978 in the Texoma study region: (a) by cruise, (b) by site.**

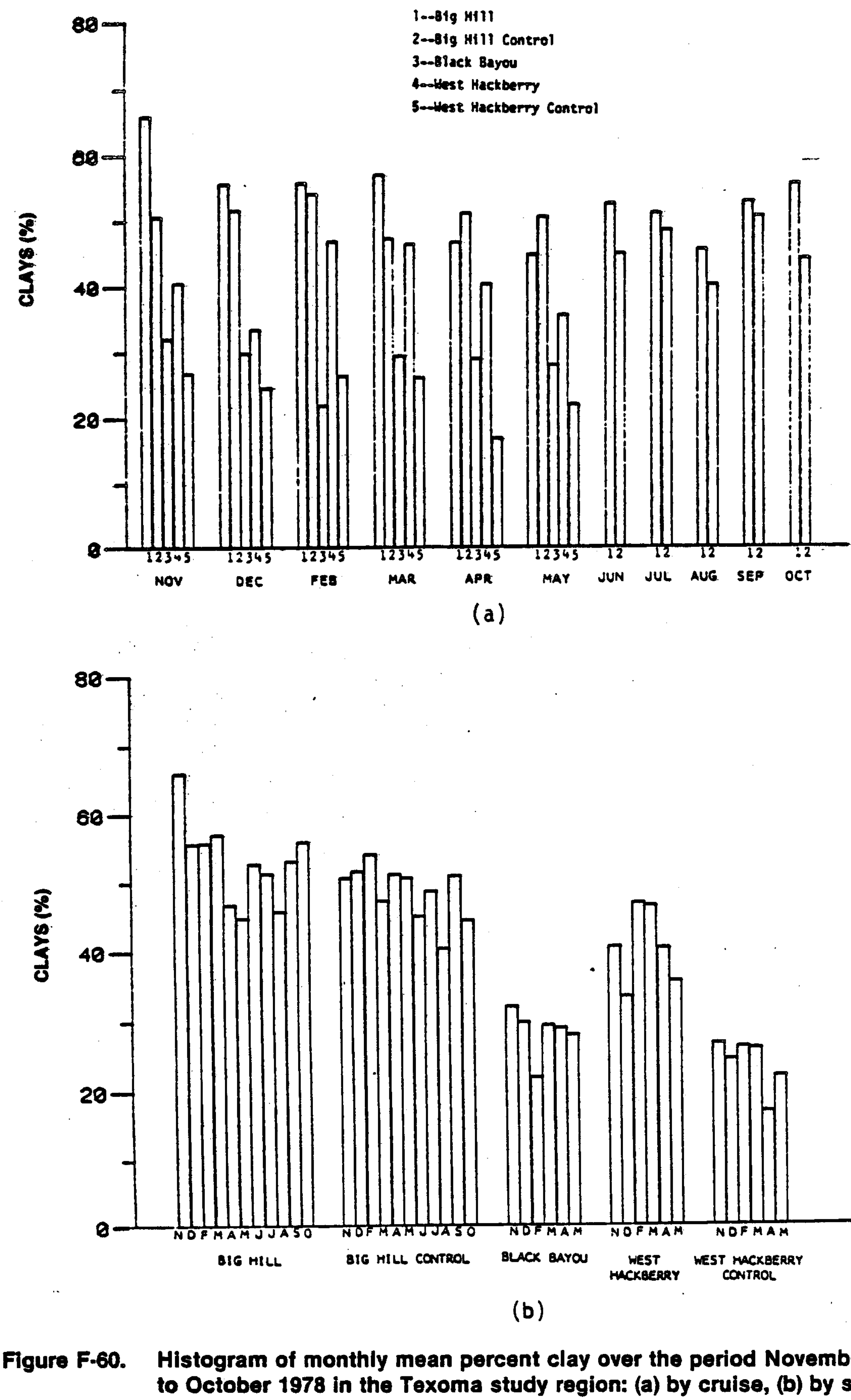
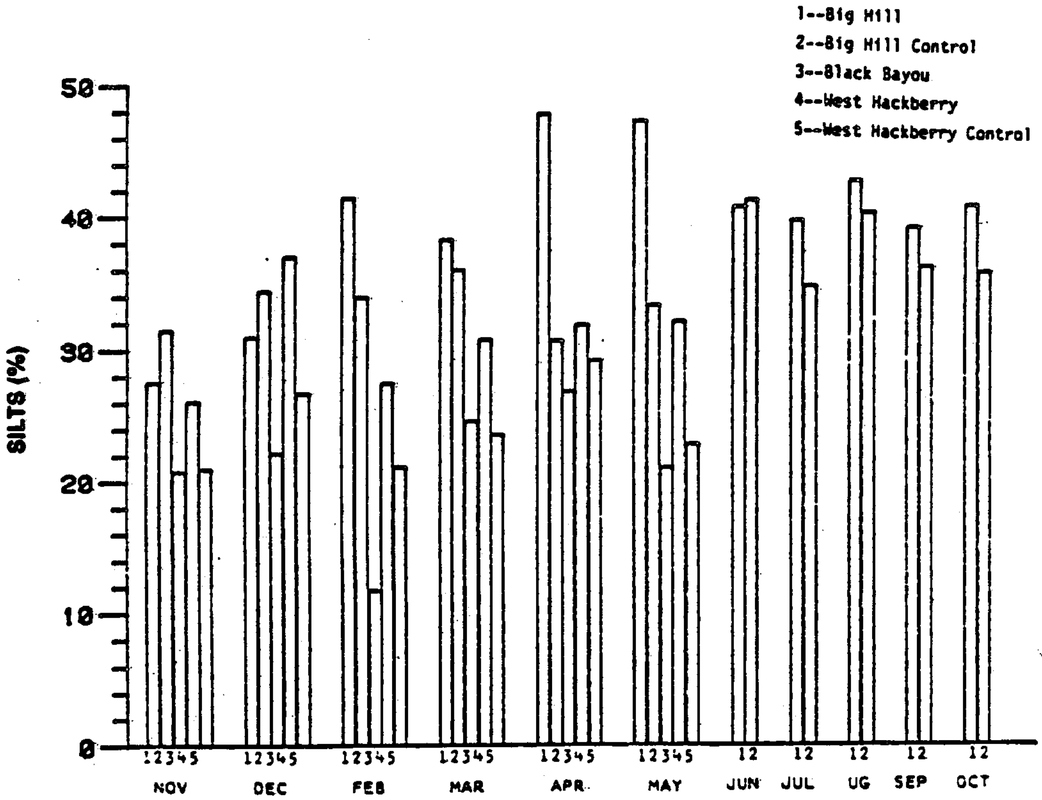
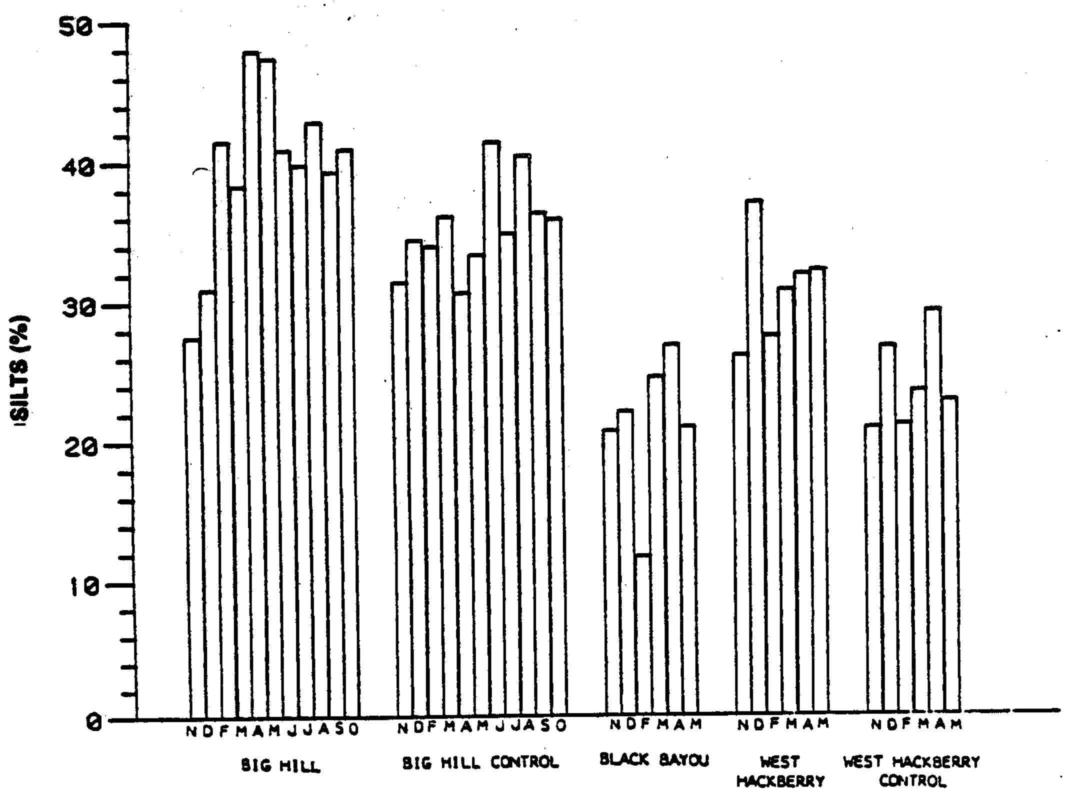


Figure F-60. **Histogram of monthly mean percent clay over the period November 1977 to October 1978 in the Texoma study region: (a) by cruise, (b) by site.**

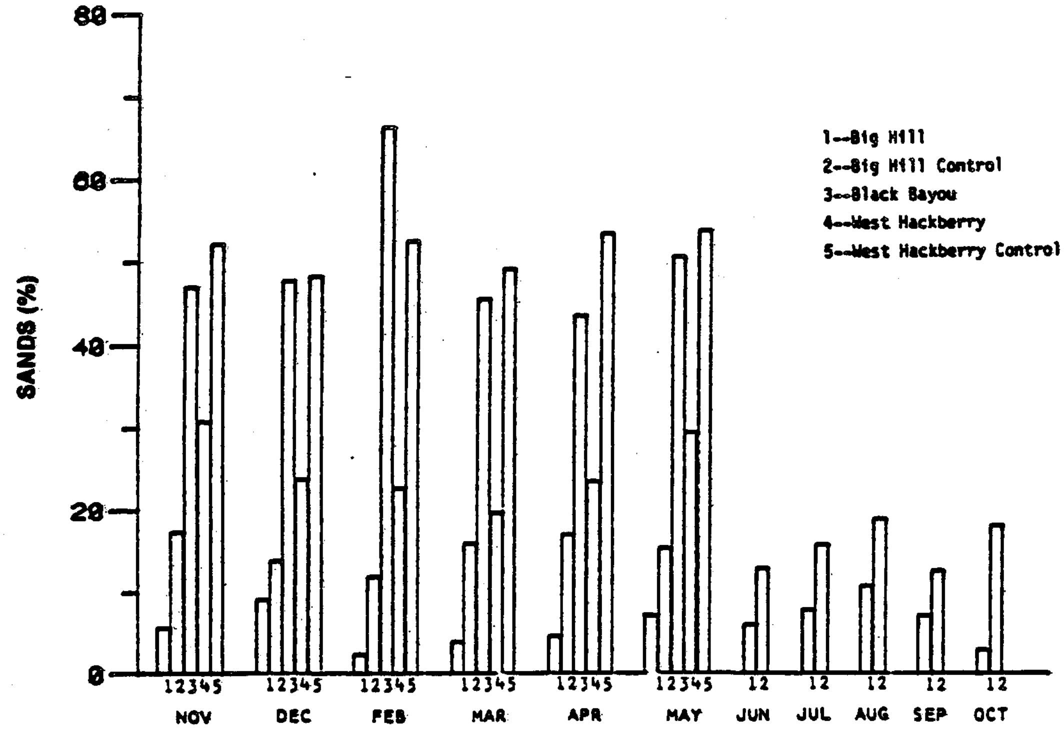


(a)

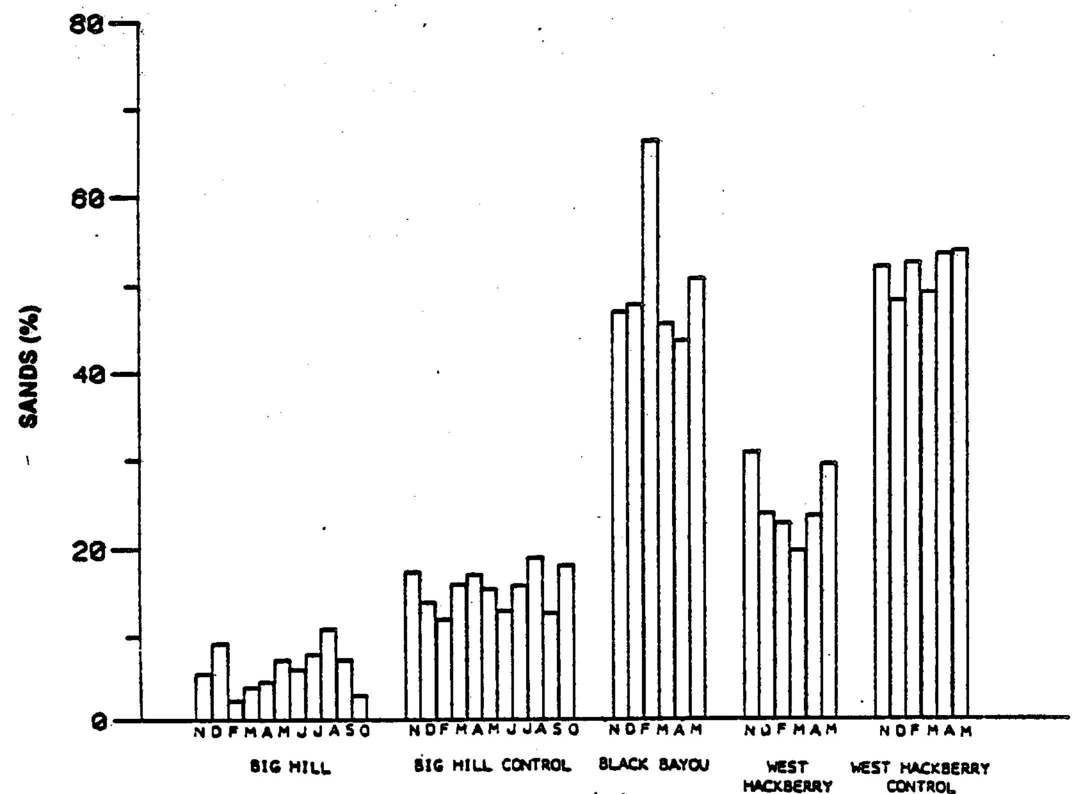


(b)

Figure F-61. **Histogram plot of monthly mean percent silt over the period November 1977 to October 1978 in the Texoma study region: (a) by cruise, (b) by site.**



(a)



(b)

Figure F-62. **Histogram plot of monthly mean percent sand over the period November 1977 to October 1978 in the Texoma study region: (a) by cruise, (b) by site.**

Table F-29. Results of analyses of variance for sediment parameters for five sites in the Texoma region

Parameters	Cruise	Site	Cruise/Site Interaction
Cruises 3-8			
M_ϕ	.0001*	.0001*	.2083
M_D	.3000	.0001*	.8608
% Fines**	.1053	.0001*	.9912
% Clay**	.0077*	.0001*	.4902
% Sand**	.1051	.0001*	.9912
% Silt**	.0273*	.0001*	.2738
% Organic Carbon**	.0001*	.0001*	.0019*
% Carbonate Carbon**	.0001*	.0001*	.2428
Cruises 1-8			
% Organic Carbon**	.0001*	.0001*	.0001*
% Carbonate Carbon**	.0001*	.0054*	.0400*

*Significant at 0.05 level

**Arcsine $\sqrt{x/100}$ transformation

Source: Comiskey et al. (1979).

Table F-30. **Results of multiple means tests for sediment parameters for five sites in the Texoma region (cruises 3 through 8)**

Parameter	Highest				Lowest
% Silt*	BHC	BH	WH	WHC	BB
M_D	BH	BHC	WH	BB	WHC
% Fines*	BH	BHC	WH	BB	WHC
% Clay*	BH	BHC	WH	BB	WHC
M_ϕ	BH	BHC	WH	BB	WHC
% Sand*	WHC	BB	WH	BHC	BH
% Carbonate Carbon*	WHC	BH	BHC	WH	BB

*Arcsine $\sqrt{x/100}$ transformation

Tukey's t = 2.73

Note: Underlines connect sites which are not significantly different

Source: Comiskey et al. (1979).

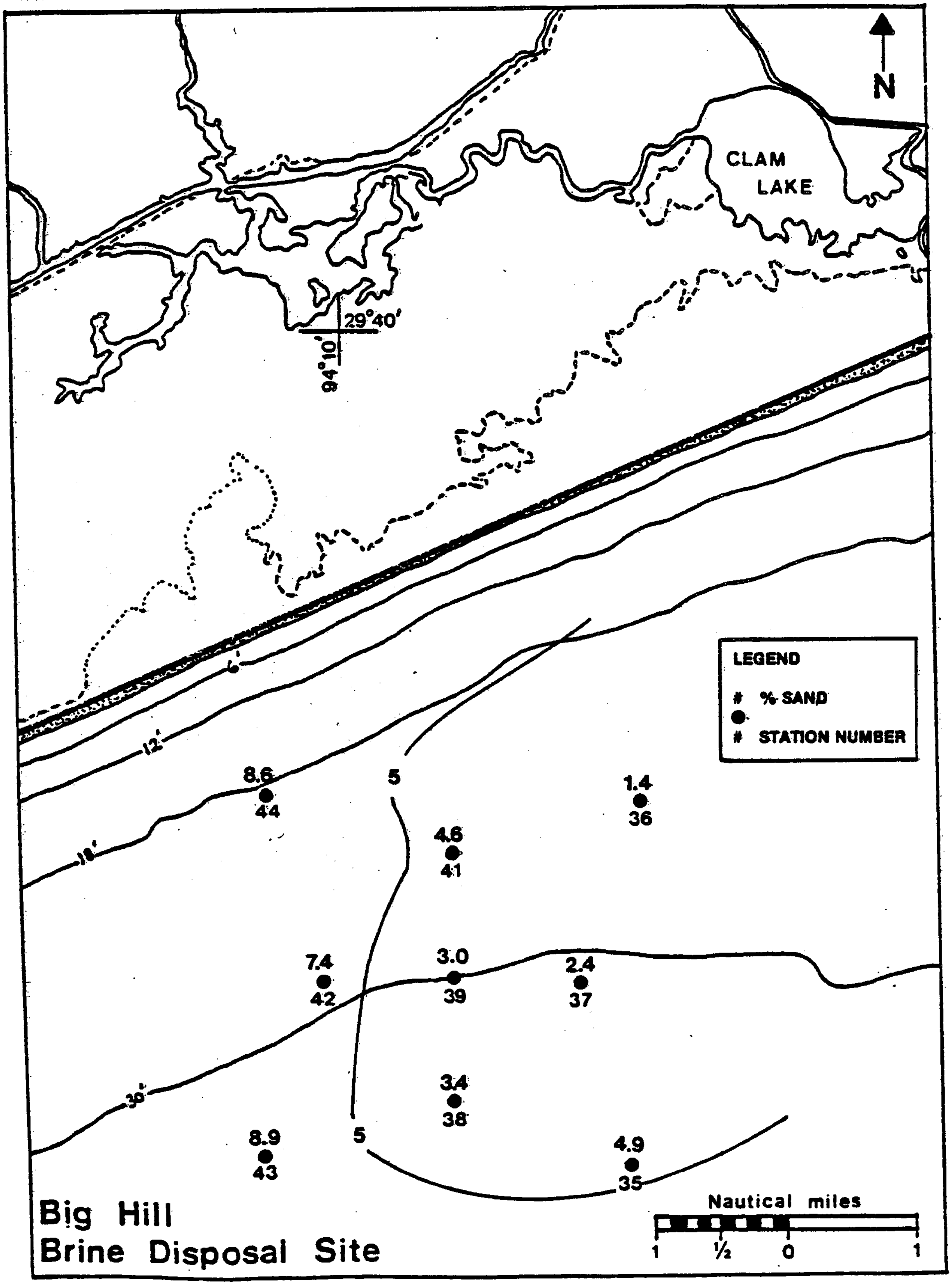


Figure F-63. **Mean percent sand for each station (over all cruises) at the Big Hill brine disposal site for the period November 1977 to May 1978. Not every station was sampled on every cruise. Source: Comiskey et al. (1979).**

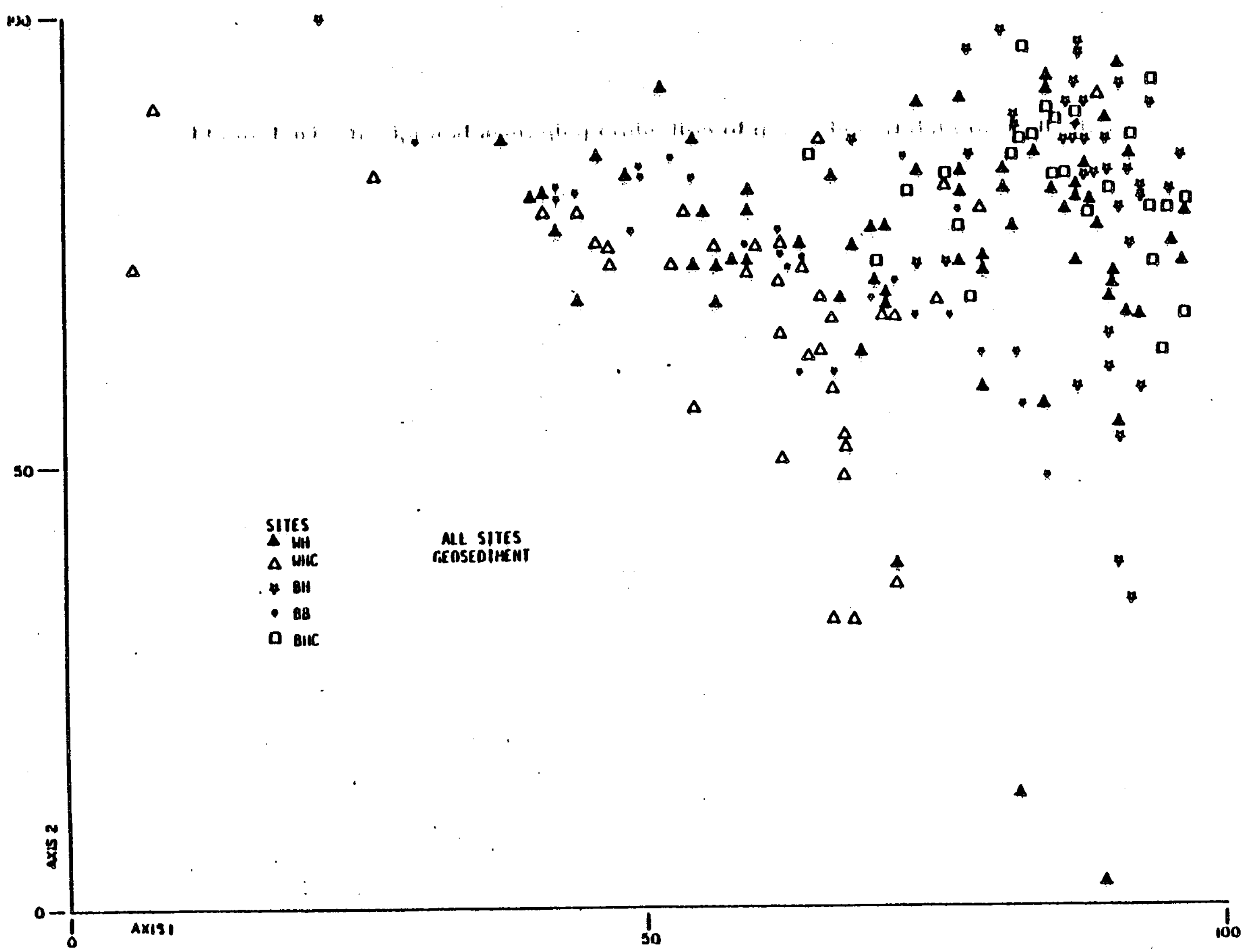


Figure F-64. Reciprocal averaging ordination of geosediment data over all sites.

The more variable nature of the West Hackberry samples is confirmed by cluster analysis of March 1978 samples (Figs. F-65 and F-66), which shows three cluster groups at the Big Hill site compared with five at the West Hackberry site. The groups at the Big Hill site are oriented longshore and onshore-offshore, consistent with the gradients seen in grain size distribution (see Fig. F-63). Group B1, which encompasses most of the area (including the diffuser site), had the finest-grained sediments. Groups B1 to B3 are the three finest-grained groupings resulting from the cluster analysis.

Benthic Megafauna

For the 8-month period during which samples were taken at all five sites in the Texoma region, monthly mean densities for total megafauna (Table F-31 and Fig. F-67) varied from a high of 1,653 individuals/m^2 at the Black Bayou site in February 1978 to a low of 71 individuals/m^2 at the Big Hill site in October 1977. Monthly means over all sites (for the September 1977 to May 1978 period) increased consistently from the lows of September and October 1977 (205 and 171 individuals/m^2, respectively) to a high of 1,123 individuals/m^2 in May 1978, the overall change being an order of magnitude. Over the eight cruises from September 1977 to May 1978, Big Hill had the lowest mean density (290 individuals/m^2), with peak density of 910 individuals/m^2 occurring in May 1978. The Big Hill sites consistently exhibited the lowest benthic standing crops in the Texoma region.

In June through October, sampling was confined to the Big Hill and BHC sites. In general, total community numbers continued at relatively high levels (see Table F-31), with the mean for the two sites for June (964 individuals/m^2) being close to that for May (972 individuals/m^2). Means over both sites were highest in July (1,274 individuals/m^2) and October (1,410 individuals/m^2), with August and September densities being relatively lower (852 to 876 individuals/m^2). During this time, and consistent with results from September 1977 to May 1978, the BHC site generally had higher mean densities than did the Big Hill site (see Fig. F-67). However, in September 1978 this trend reversed; Big Hill had the higher mean density (900 versus 835 individuals/m^2). Peak populations for the entire 13-month period (1,245 individuals/m^2 at Big Hill and 1,763 individuals/m^2 at BHC) occurred during October 1978, the last month of the study. The mean at BHC for October was also the highest monthly site mean for the entire Texoma region during the study.

The fact that community numbers remained at high levels during the entire spring and summer indicates that the low numbers encountered the previous September to December were possibly due to an environmental perturbation which disrupted the benthic habitat sometime prior to the initiations of the Texoma sampling program. The change in mesh size used in the study could not account for these seasonal differences.

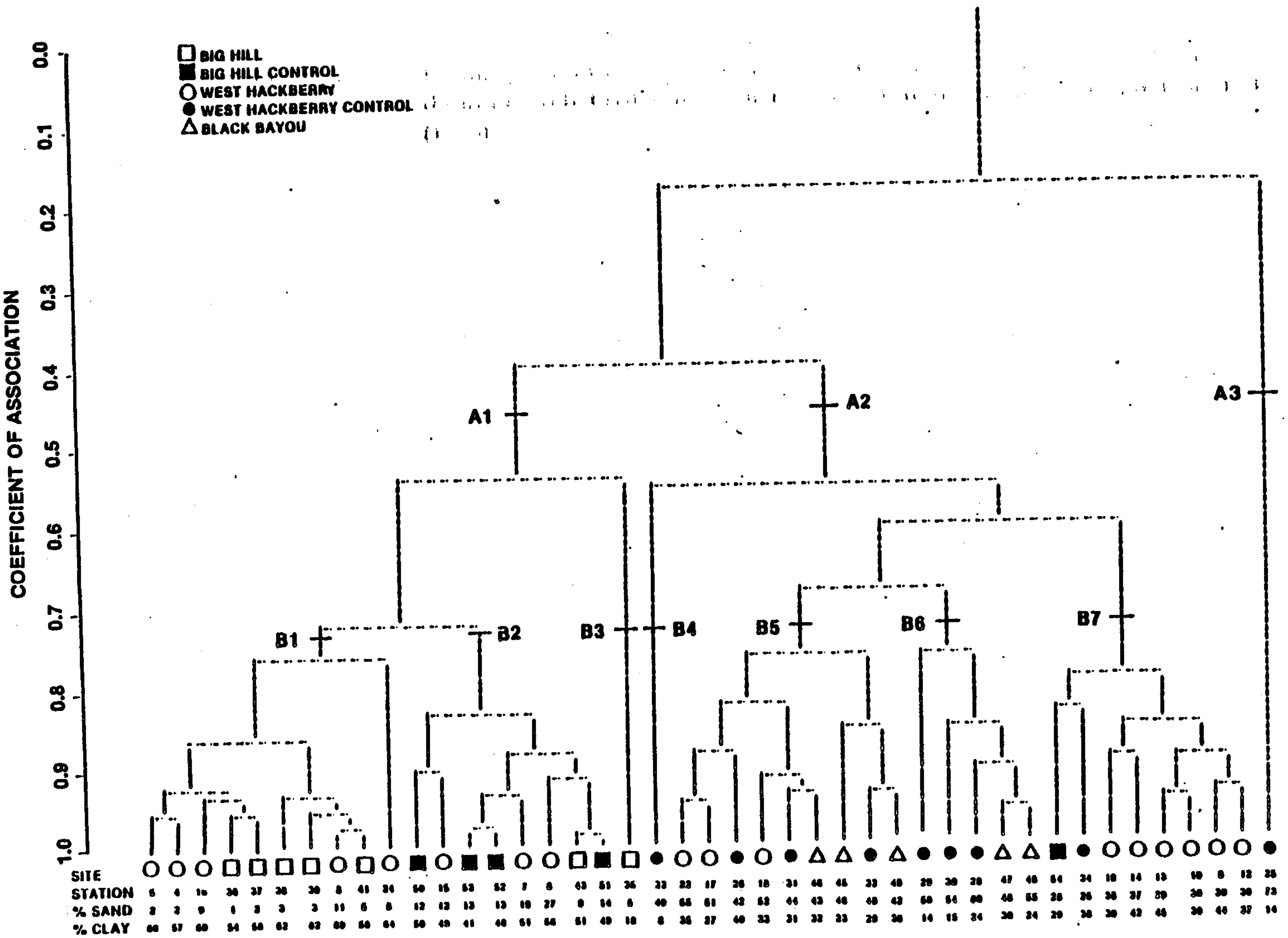


Figure F-65. Dendrogram of the cluster analysis of sediment samples collected during March 1978 across all Texoma stations. Source: Comiskey et al. (1979).

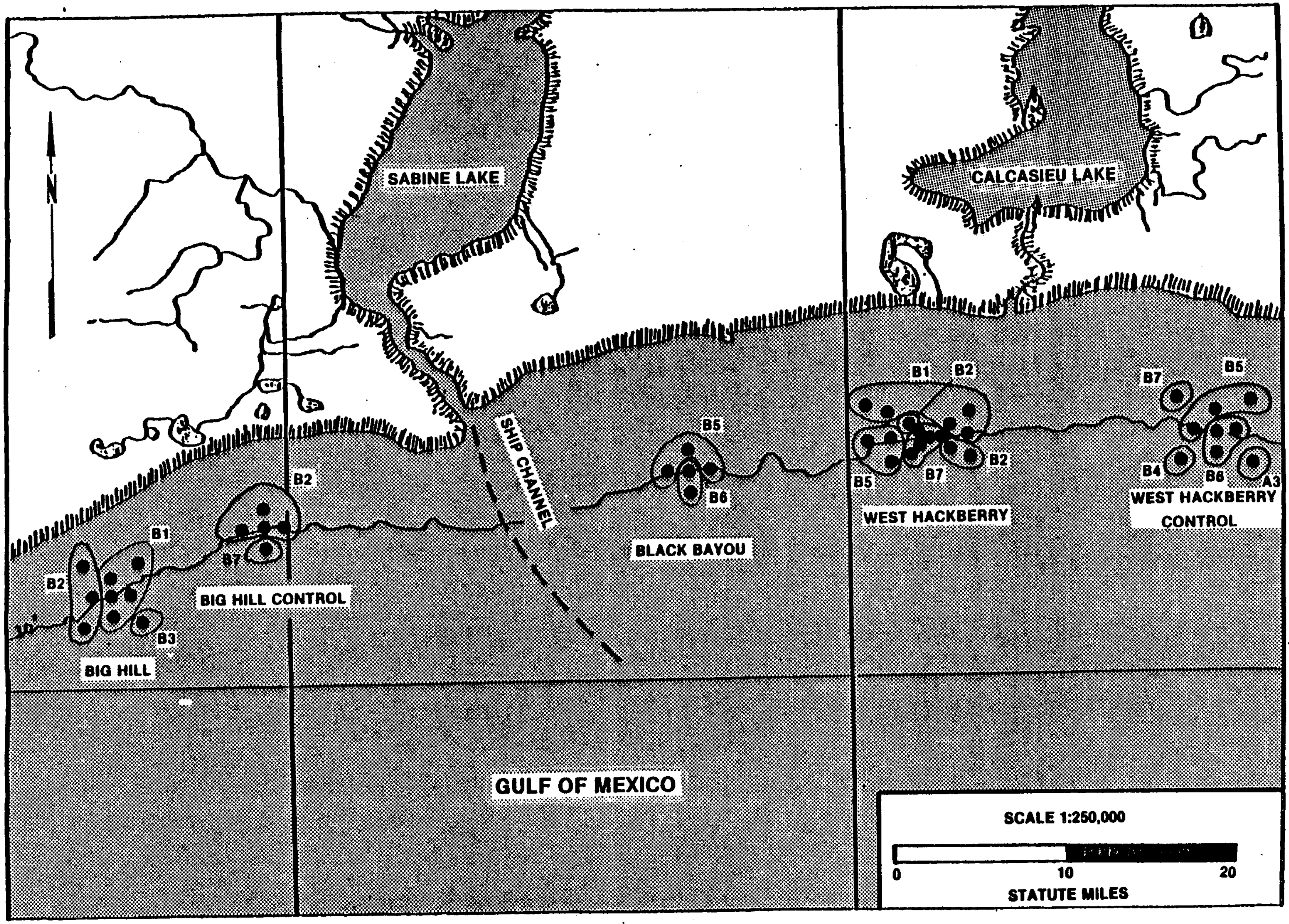


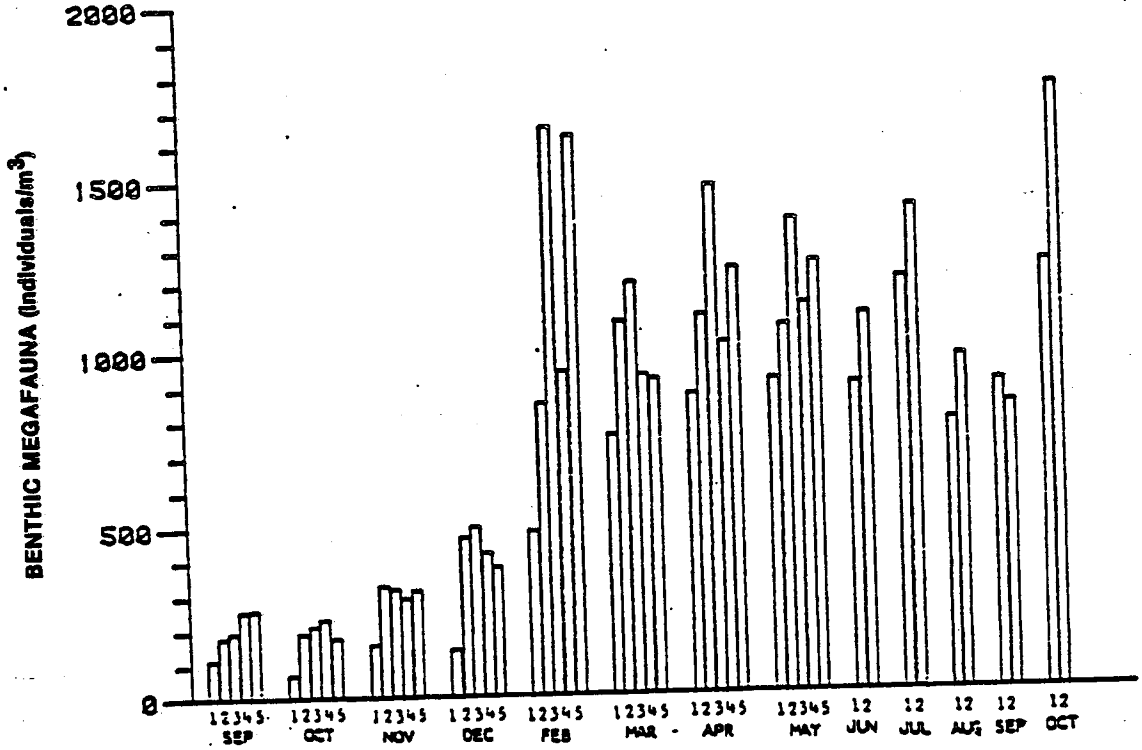
Figure F-66. Approximate location of Texoma benthic study sites and stations. Zones delineate sediment type clusters from dendrogram (see Fig. F-65).

Table F-31. Cruise by site means of total benthic megafauna (individuals/m^2) at five sites in the Texoma region

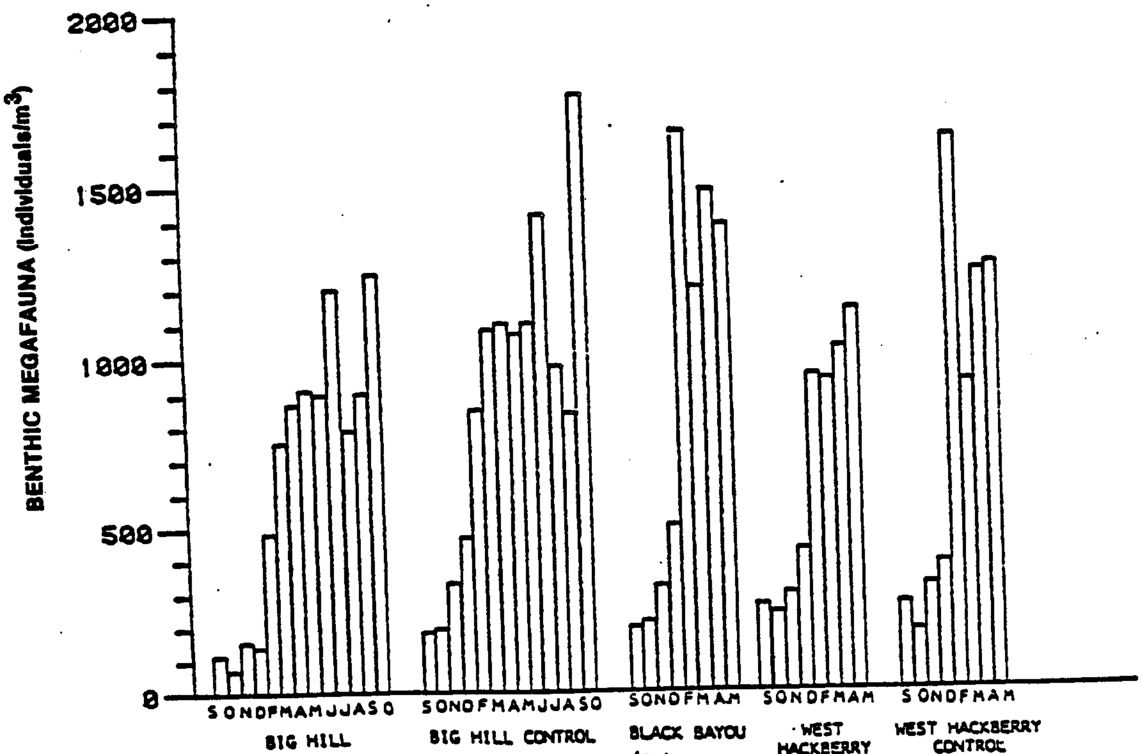
	Big Hill	Big Hill Control	Big Hill Cluster	Black Bayou	West Hackberry	W. Hackberry Control	W. Hackberry Cluster	Overall
September	114.64	179.65	135.07	194.69	257.05	261.94	247.10	204.83
N	9	5	14	6	16	10	31	46
October	71.10	192.40	103.63	212.00	231.69	176.85	210.20	170.74
N	9	5	14	5	17	10	32	46
November	157.56	327.85	215.24	317.86	293.71	314.30	304.14	270.46
N	7	5	12	5	12	6	23	35
December	139.72	464.42	234.30	496.76	421.75	380.24	425.47	347.76
N	7	5	12	6	12	6	23	35
Jan./Feb.	482.17	849.85	611.52	1652.98	939.41	1626.85	1239.15	844.48
N	7	5	12	1	5	4	10	22
March	754.79	1083.43	859.15	1196.98	925.10	914.85	959.86	928.05
N	9	5	14	5	17	10	32	46
April	870.24	1100.48	959.82	1477.50	1020.35	1235.78	1162.80	1088.88
N	7	5	12	5	12	6	23	35
May	909.87	1066.72	972.28	1375.77	1128.82	1252.32	1210.86	1123.24
N	7	5	12	5	12	6	23	35
Overall (1-8)	290.28	531.17	368.88	579.25	507.40	511.23	521.08	463.31
N	62	40	102	36	103	58	197	299
June	896.31	1098.56	963.98					963.98
N			14					
July	1203.73	1411.87	1274.35					1274.35
N			14					
August	789.49	975.36	851.53					851.53
N			14					
September	900.21	834.79	876.29					876.29
N			14					
October	1245.23	1762.70	1410.12					1410.12
N			14					
Overall (1-13)	490.78	722.44	568.40					542.71
N								

N - Number of Samples

Source: Comiskey et al. (1979).



(a)



(b)

Figure F-67. Abundance of benthic megafauna (individuals/m^2) for five sites in the Texoma region: (a) by cruise, (b) by site. Source: Comiskey et al. (1980).

A total of 171 taxa of benthic megafauna were collected in the Texoma study area during the course of the sampling program (Table F-32). The polychaetes (33 percent) and the arthropods (26 percent) were the most prevalent taxa. Table F-33 shows the percent composition by cruise and site for the numerically dominant species at the Texoma study sites. The majority of the 171 taxa recorded for the Texoma area were of modest importance to the community, and only 15 species constituted 10 percent of the community at any cruise/site stratum. Many of the characteristic species were present at all sites over the course of the entire study. There were, however, seasonal changes in the relative importance of these ubiquitous species.

During September 1977, Mulinia lateralis, Magelona sp., and Diopatra cuprea dominated the community. M. lateralis all but disappeared from the community after September, appearing again in the spring. During October and November, the assemblage was numerically dominated by Magelona sp., D. cuprea, and Lumbrineris tenuis. In December, D. cuprea was still present (as it was for the remainder of the study), but was relatively much less important. Magelona sp. and L. tenuis continued as major taxa. In February and March, Magelona sp. continued as the dominant organism, with Cossura delta also making a significant contribution to the community numbers. At this time, Paraprionospio pinnata first began to make a sizable contribution to the community. From April to October, P. pinnata and Magelona sp. were the dominant taxa, with C. delta, Sigambra tentaculata, and L. tenuis of irregular importance.

Four more or less distinct assemblages or components were identified by the factor analyses at all Texoma sites for the 8-month period from September 1977 to May 1978 (Table F-34). These are:

1. A September molluscan assemblage dominated by M. lateralis, Nassarius acutus, and Nuculana concentrica. No spatial trend was apparent. M. lateralis, which most defined the factor, also had a spring peak.

2. A polychaete group, consisting of Magelona sp., L. tenuis, Ancistrosyllis papillosa, and C. delta, that is not very well defined, but that is characterized by highest numbers during the midstudy months (November to March). The group is closely related to the groups defined by factors 1 and 2 and summarized below.

3. Factor 1 defined a larger spring group, mainly composed of polychaetes and best defined by Sabellides oculata, Cirratulis sp., S. tentaculata, and P. pinnata, but with the nemertean predator, Cerebratulus lacteus, and the mud anemone, Paranthus rapiformis, also important members. These species all show relatively even distribution over the Texoma area, but many members show a distinct trend toward occurrence in less coarse sediments in the area.

Table F-32. Taxonomic list and seasonal occurrence of the megafaunal taxa at the Texoma study sites, September 1977 to October 1978

PHYLUM/SUBPHYLUM/class/species	Sep	Oct	Nov	Dec	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
COELENTERATA													
Actiniaria									B			B	
Anthomedusae						B							
Bunodactis texaensis	W	W	W				W						
Calliactis tricolor							W						
Obelia sp.								W					
Paranthus rapiformis	WB	WB	WB	WB	W	WB	WB	WB	B	B		B	
PLATYHELMINTHES													
Polycladida	WB	WB		W		W	W	W	B				
Stylochus ellipticus								W	B	B	B		
Unidentified turbellarian	B			W									
NEMERTINEA													
Carinoma tremaphoros	WB	W	WB	WB	W	W	WB	WB				B	B
Cerebratulus lacteus	WB				WB	WB	WB	WB	B	B	B	B	B
Paleonemertea	B												
NEMATODA													
Dolichadorus heterocephalus				B	W								
Unidentified nematode	B	WB	WB	WB	WB	WB	WB	WB		B	B	B	B
MOLLUSCA													
Gastropoda													
Anachis obesa	W			B									
Cantharus cancellarius	W			W				W					
Circulus trilix	W			W									
Cyclostremiscus jeannae													
Cyclostremiscus pentagonus									B				
Epitonium angulatum	W												
Litiopa melanostoma	W												
Nassarius acutus	WB	B	B		B						B	B	
Nudibranchia								B					
Polinices hepaticus				B									
Sinum perspectivum				W		W							
Tectonatica pusilla	W												
Terebra protexta				W									
Turbonilla interrupta	W												
Vaivulella oxytata	W												
Pelecypoda													
Abra aequalis	W	W	W	W			W	W					
Anadara ovalis	W	W	W		W	W				B	B		
Anadara transversa	W	W		W					B			B	
Atrina serrata		W											
Callocardia texasiana	W	W	WB		WB			W			B		B
Chione intapurpurea				W									B
Corbula contracta	W							W					
Ensis minor	W						W	W					
Mulinia lateralis	WB	W	W	WB	W	W	WB	WB	B	B	B		B
Mysella planulata	W				W								
Nuculana acuta	WB												
Nuculana concentrica	WB	WB	WB	WB	WB	W	WB	WB					B
Pandora trilineata	W					W							
Petricola pholadiformis						B							

Table F-32 (continued)

PHYLUM/SUBPHYLUM/class/species	Month: Sep	Oct	Nov	Dec	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Raeta plicatella								W					
Solen viridis									B				
Tellina versicolor	W	W	W	W			W	W	B				
Veneridae						B					B		
Cephalopoda													
Lolliguncula brevis				B									
Octopus vulgarus						B							
SIPUNCULIDA													
Unidentified sipunculid	W		W	W	B	W		W	B				
Phascolion strombi	WB	WB			W								
ANNELIDA													
Polychaeta													
Aglaophamus verrilli	B	W	WB	W	WB	W	WB	WB					B
Ampharete sp.				W									
Amphitrite niveus	W												
Ancistrosyllis papillosa	WB	WB	WB	WB	WB	WB	WB	WB	B	B	B	B	B
Arenicola brasilinensis						W							
Aricidea jeffreysii	W												
Armandia agilis					B								
Branchiosyllis americana						W	W	W		B	B		B
Chaetopterus variopedatus		W		W	W	W		W					
Cirratulis sp.					W		WB	WB	B	B	B	B	B
Cistenides gouldi	W			W	W	W	B	B	B				B
Clymenella torquata	W	W	WB	WB	W	WB	WB	WB	B	B	B	B	B
Cossura delta	W	W	WB	WB	WB	WB	WB	WB	B	B	B	B	B
Dasybranchus sp.						W							
Dinophilidae	W												
Diopatra cuprea	WB	WB	WB	WB	WB	WB	WB	WB	B	B	B	B	B
Drilonereis longa	W			W	B								
Eteone heteropoda	W			W		W							
Eulima bifasciata	W												
Eunicidae		B		W									
Eusyllis sp.									B	B	B	B	B
Glycera americana			B			W	WB	W	B				
Glycera dibranchiata	W				WB	WB	WB	WB	B	B	B	B	B
Glycera tesselata						W	WB	W	B	B			
Glycera sp.	WB	W			WB	W					B		
Goniada maculata			B			W							
Harmothoe aculeata		B		WB		WB	WB	WB	B	B	B	B	B
Heterospionidae						W							
Lepidasthenia varia	W		WB	WB	WB		W				B		B
Lepidonotus squamatus	W						B			B		B	B
Linopherus ambigua						B					B		B
Lumbrineris tenuis	WB	WB	WB	WB	WB	WB	WB	WB	B	B	B	B	B
Magelona sp.	WB	WB	WB	WB	WB	WB	WB	WB	B	B	B	B	B
Maldane sarsi	WB					W	W	W					
Maldanopsis elongata							W	W					
Neanthes succinea	WB	WB	WB	WB	WB	WB	WB	WB	B	B	B	B	B
Nephthys incisa				B									
Nephthys picta						B	WB		B	B	B	B	B
Ninoe nigripes						WB	WB	WB	B	B	B	B	B
Notomastus sp.						W	W	WB	B	B	B	B	B
Onuphis eremita	W					W	W	WB					B
Owenia fusiformis	WB	WB	W	WB	WB	W	WB	W				B	
Paleanotus heteroseta						W	W	W			B	B	B
Paraprionospio pinnata	W		B		WB	WB	WB	WB	B	B	B	B	B
Pherusa sp.							W						B
Phyllochaetopterus sp.	W	W	W	W	W								

Table F-32 (continued)

PHYLUM/SUBPHYLUM/class/species	Sep	Oct	Nov	Dec	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
	Month												
Phyllodoce arenae							W	WB					B
Phyllodoce mucosa									B	B			
Pilargidae	W				W								
Polydora sp.							B						
Sabellides oculta						WB	WB	WB			B	B	
Serpulidae	W												
Sigambra tentaculata	W	WB	WB	W	WB	WB	WB	WB	B	B	B	B	B
Spiochaetopterus oculatus												B	
Sthenelais boa						WB	WB			B			
Streblospio benedicti	W												
Syllidae			W		W								
Unidentified spionid											B		
Oligochaeta													
Unidentified oligochaete	W	WB	W	WB	WB	WB	WB	WB					
ECHIURIDA													
Unidentified echiurid											B	B	B
Thalassema melitta					W	W	B	WB	B	B			
PRIAPULIDA													
Unidentified priapulid						W							
ARTHROPODA													
Crustacea													
Acartia tonsa												B	
Acetes americanus	W	B	W	WB	W	W	W	W			B		
Ampelisca sp.			W		WB	WB	WB	WB		B	B	B	B
Amphipoda	W	W		W									
Automate sp.											B		
Brachyuran zoea							W	WB		B	B		
Callianassa jamaicense									B				
Callianassa latispina	WB	W	WB	WB	WB	W	W	W					
Callianassa sp.						B					B		
Callinectes sapidus		W	W	W	W	W	WB	W					
Callinectes similis					B			WB					
Cerapus tubularis						B							
Cirolana sp.										B			
Corophiidae	W			W									
Corophium louisianum							W	W		B			B
Cyclopoida						W							
Cymadusa sp.						W							
Diastylis sp.							WB	W	B	B	B	B	
Euceramus praelongus				W		W		W					
Gammaridae		WB	W	W									
Labidocera aestiva							B	B				B	
Leptochelia serratorbita										B			B
Lucifer faxoni										B	B		
Lysiosquilla empusa	W		W	W				B					
Monoculodes gibbosus					B								
Unidentified mysid							W	B		B			
Neopanope texana sayi		W				W	W						
Ogyrides limicola						W							B
Paguristes sp.						W							
Pagurus pollicaris		W									B		
Pagurus sp.								W					
Panopeus herbstii	W	W	W	WB	W			B					
Penaeus setiferus						W	W	B		B			

Table F-32 (continued)

PHYLUM/SUBPHYLUM/class/species	Sep	Oct	Nov	Dec	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
	Month												
Persephona punctata aquilonaris		W	W		WB	W							
Pinnixa chaetopterana	W	W	W	W	W	W	WB	W	B	B	B	B	B
Pinnixa cristata	W	WB	W	W	W		B						
Pinnixa sayana	W	W		WB			W						
Pinnotheridae		W						WB					
Polinices duplicatus										B			
Polyonyx gibbesi			W		W	W							
Porcellana sayana			W										
Portunus gibbesi				W			WB						
Sagartia modesta								W					
Speocarcinus carolinensis								WB					
ECHINODERMATA													
Ophiuroidea													
Amphipholis squamata		W											
Hemipholis elongata	W												
Micropholis atra	WB	WB	WB	WB	WB	WB	WB	WB	B	B	B	B	B
Holothuroidea													
Apoda sp.						B	W		B	B			
Thyonella gemmata		W				W	W	WB					
Unidentified holothuroid											B		B
CHORDATA													
UROCHORDATA													
Ascidacea													
Synoicidae					W	W	W	WB					
Styelidae								W					
CEPHALOCHORDATA													
Unidentified cephalochordate (cf.)						B							
VERTEBRATA													
Anchoa mitchilli						B							
Larval fish	W		B	W	B			W					
Micropogon undulatus							W						
Stellifer lanceolatus			B	WB								B	
Myrophis punctatus													B

*W--West Hackberry cluster of sites.

B--Big Hill cluster of sites.

WB--Both clusters.

Table F-33. Seasonal and site patterns of megafaunal community dominance in the Texoma study area (September 1977 to October 1978)

	Big Hill Cluster				West Hackberry Cluster					
	Big Hill		Big Hill Control		Black Bayou		West Hackberry		West Hackberry Control	
SEP	(13)[b]		(10)		(8)		(27)		(20)	
	21.13	Nuculana concentrica	18.75	Nuculana concentrica	17.61	Magelona sp.	20.72	Mulinia lateralis	22.59	Magelona sp.
	20.88	Mulinia lateralis	14.25	Diopatra cuprea	13.66	Micropholis atra	11.93	Diopatra cuprea	14.74	Diopatra cuprea
	15.79	Diopatra cuprea	12.92	Micropholis atra	9.97	Diopatra cuprea	8.65	Lumbrineris tenuis	12.71	Lumbrineris tenuis
	9.75	Nassarius acutus	12.38	Lumbrineris tenuis	9.82	Mulinia lateralis	7.24	Magelona sp.	8.81	Micropholis atra
	7.54	Aglaophamus verrilli	12.22	Mulinia lateralis	8.33	Clymenella torquata	6.66	Nuculana concentrica	7.67	Owenia fusiformis
	6.09	Owenia fusiformis	11.06	Magelona sp.	6.67	Carinoma tremaphoros	6.51	Micropholis atra	5.99	Mulinia lateralis
	5.77	Nuculana acuta	5.00	Callianassa latispina	6.25	Ancistrosyllis papillosa	4.09	Neanthes succinea	4.50	Sipunculida
	3.53	Lumbrineris tenuis	2.22	Polycladida (flatworms)	3.57	Nassarius acutus	3.99	Acetes americanus	3.36	Neanthes succinea
	2.56	Micropholis atra	2.14	Maldane sarsi	3.57	Pinnixa chaetopterana	3.82	Owenia fusiformis	2.97	Cossura delta
	1.28	Paranthus rapiformis	2.00	Paleonemertea	3.13	Sipunculida	3.39	Clymenella torquata	2.05	Tellina versicolor
	1.28	Callianassa latispina	1.67	Carinoma tremaphoros	3.13	Owenia fusiformis	2.29	Nassarius acutus	1.83	Ancistrosyllis papillosa
	1.28	Phascolion strombi	1.67	Ancistrosyllis papillosa	3.13	Serpulidae	1.85	Polycladida (flatworms)	1.71	Carinoma tremaphoros
			1.18	Nematoda	2.50	Lumbrineris tenuis	1.72	Pinnixa sayana	1.49	Paranthus rapiformis
			1.11	Glycera sp.	2.50	Sigambra tentaculata	1.54	Cerebratulus lacteus	1.21	Nuculana concentrica
					2.50	Callianassa latispina	1.41	Paranthus rapiformis		
					2.08	Panopeus herbstii	1.19	Callianassa latispina		
					1.14	Nuculana concentrica	1.09	Onuphis eremita		
							1.06	Anachis obesa		
OCT	(16)		(9)		(10)		(34)		(20)	
	18.85	Magelona sp.	31.57	Magelona sp.	21.54	Magelona sp.	38.42	Magelona sp.	15.67	Diopatra cuprea
	18.54	Diopatra cuprea	24.45	Lumbrineris tenuis	18.03	Clymenella torquata	15.34	Diopatra cuprea	15.40	Magelona sp.
	17.45	Ancistrosyllis papillosa	19.74	Diopatra cuprea	13.00	Nuculana concentrica	14.29	Lumbrineris tenuis	14.54	Micropholis atra
	13.96	Nuculana concentrica	7.78	Nuculana concentrica	12.14	Lumbrineris tenuis	9.92	Clymenella torquata	13.67	Lumbrineris tenuis
	8.02	Lumbrineris tenuis	6.69	Ancistrosyllis papillosa	8.85	Micropholis atra	4.56	Micropholis atra	5.86	Nuculana concentrica
	6.25	Owenia fusiformis	3.39	Nematoda	6.72	Diopatra curea	4.26	Neanthes succinea	5.00	Mulinia lateralis
	3.13	Paranthus rapiformis	1.47	Micropholis atra	5.88	Owenia fusiformis	2.76	Ancistrosyllis papillosa	4.96	Clymenella torquata
	3.13	Neanthes succinea	1.11	Neanthes succinea	3.21	Sigambra tentaculata	2.29	Sigambra tentaculata	4.85	Owenia fusiformis
	3.13	Acetes americanus	1.01	Phascolion strombi,	3.13	Panopeus herbstii	1.08	Bunodactis texaensis	3.52	Neanthes succinea
	2.86	Nematoda			2.50	Pinnixa chaetopterana	1.00	Owenia fusiformis	2.17	Paranthus rapiformis
	1.56	Gammaridae			1.25	Anchistrosyllis papillosa			1.83	Gammaridae
	1.56	Pinnixa cristata			1.11	Cossura delta			1.42	Phyllochaetopterus sp.
									1.25	Tellina versicolor
									1.25	Anadara ovalis
									1.25	Glycera sp.
									1.17	Amphipoda
NOV	(14)		(10)		(10)		(23)		(12)	
	29.79	Magelona sp.	60.27	Magelona sp.	30.01	Magelona sp.	22.63	Magelona sp.	36.87	Magelona sp.
	19.81	Paraprionospio pinnata	11.08	Lumbrineris tenuis	18.16	Lumbrineris tenuis	20.15	Lumbrineris tenuis	15.32	Diopatra cuprea
	13.85	Diopatra cuprea	5.19	Cossura delta	13.78	Clymenella torquata	12.05	Diopatra cuprea	12.56	Lumbrineris tenuis
	9.26	Lumbrineris tenuis	4.74	Ancistrosyllis papillosa	7.28	Diopatra cuprea	9.21	Clymenella torquata	6.50	Micropholis atra
	3.39	Nuculana concentrica	3.33	Nassarius acutus	6.47	Micropholis atra	6.03	Neanthes succinea	5.54	Cossura delta
	2.89	Sigambra tentaculata	2.79	Nematoda	4.87	Cossura delta	3.73	Ancistrosyllis papillosa	4.13	Clymenella torquata
	2.86	Stellifer lanceolatus	2.46	Micropholis atra	3.11	Nuculana concentrica	3.04	Cossura delta	3.40	Neanthes succinea
	2.85	Nematoda	2.45	Lepidasthenia varia	2.97	Neanthes succinea	2.91	Nuculana concentrica	1.83	Callianassa sp.
	2.49	Lepidasthenia varia	2.17	Clymenella torquata	2.00	Callianassa latispina	2.79	Lepidasthenia varia	1.39	Paranthus rapiformis
	2.40	Ancistrosyllis papillosa	1.54	Nuculana concentrica	1.62	Ampelisca sp.	2.71	Micropholis atra	1.39	Polyonyx gibbesi
	2.08	Neanthes succinea	1.18	Glycera americana	1.43	Lepidasthenia varia	2.67	Carinoma tremaphoros	1.39	Phyllochaetopterus sp.
	1.70	Paranthus rapiformis					1.49	Gammaridae	1.36	Callianassa latispina
	1.43	Callocardia texasiana					1.19	Acetes americanus	1.30	Ancistrosyllis papillosa
	1.36	Cossura delta					1.11	Callianassa sp.	1.13	Abra aequalis
	1.19	Carinoma tremaphoros							1.11	Panopeus herbstii
	1.10	Aglaophamus verrilli							1.04	Oligochaete

Table F-33 (continued)

	Big Hill Cluster				West Hackberry Cluster					
	Big Hill		Big Hill Control		Black Bayou		West Hackberry		West Hackberry Control	
DEC	(13)		(10)		(10)		(24)		(12)	
	36.03	Magelona sp.	52.77	Magelona sp.	34.62	Magelona sp.	32.57	Magelona sp.	27.35	Magelona sp.
	12.08	Nuculana concentrica	15.59	Lubrineris tenuis	16.16	Lumbrineris tenuis	9.37	Lumbrineris tenuis	13.76	Lumbrineris tenuis
	11.00	Lumbrineris tenuis	6.43	Cossura delta	13.67	Clymenella torquata	9.36	Diopatra cuprea	10.13	Micropholis atra
	8.52	Diopatra cuprea	5.02	Ancistrosyllis papillosa	4.34	Ancistrosyllis papillosa	6.19	Ancistrosyllis papillosa	9.62	Acetes americanus
	3.93	Lepidasthenia varia	3.20	Diopatra cuprea	4.07	Micropholis atra	5.69	Cossura delta	7.67	Diopatra cuprea
	3.42	Acetes americanus	3.12	Clymenella torquata	3.99	Neanthes succinea	4.58	Clymenella torquata	7.18	Neanthes succinea
	3.42	Dolichadorus heterocephalus	2.87	Neanthes succinea	3.78	Diopatra cuprea	4.15	Micropholis atra	3.06	Cossura delta
	3.03	Carinoma tremaphoros	2.43	Nuculana concentrica	3.63	Gammeridae	2.87	Sigambra tentaculata	1.85	Callianassa latispina
	2.78	Micropholis atra	1.46	Goniada maculata	3.50	Cossura delta	2.82	Owenia fusiformis	1.65	Paranthus rapiformis
	2.56	Nematoda	1.22	Mulinia lateralis	3.25	Acetes americanus	2.68	Neanthes succinea	1.61	Nuculana concentrica
	1.92	Lolliguncula brevis	1.15	Acetes americanus	1.75	Owenia fusiformis	2.61	Lepidasthenia varia	1.39	Ancistrosyllis papillosa
	1.71	Cossura delta	1.02	Stellifer lanceolatus	1.25	Oligochaete	2.31	Oligochaete	1.33	Owenia fusiformis
	1.54	Paranthus rapiformis					1.85	Mulinia lateralis	1.07	Pinnixa chaetopterana
	1.54	Callianassa latispina					1.77	Acetes americanus	1.04	Lepidasthenia varia
	1.54	Ancistrosyllis papillosa					1.46	Nuculana concentrica	1.02	Clymenella torquata
							1.25	Callianassa sp.		
							1.01	Callianassa latispina		
FEB.	(14)		(10)		(2)		(10)		(8)	
	29.51	Paraprionospio pinnata	32.54	Magelona sp.	25.80	Clymenella torquata	18.94	Magelona sp.	39.61	Magelona sp.
	21.17	Magelona sp.	18.21	Nematoda	10.88	Paraprionospio pinnata	13.87	Paraprionospio pinnata	13.66	Cossura delta
	11.83	Cossura delta	16.41	Paraprionospio pinnata	10.78	Nematoda	13.70	Nematoda	11.32	Nematoda
	6.77	Nematoda	10.69	Cossura delta	8.57	Magelona sp.	12.04	Cossura delta	7.59	Lumbrineris tenuis
	6.68	Drilonereis longa	9.65	Lumbrineris tenuis	6.51	Owenia fusiformis	6.87	Diopatra cuprea	4.05	Paraprionospio pinnata
	4.76	Lepidasthenia varia	2.73	Lepidasthenia varia	6.34	Lumbrineris tenuis	6.79	Lumbrineris tenuis	3.94	Neanthes succinea
	4.32	Nuculana concentrica	1.97	Nuculana concentrica	5.88	Ampelisca sp.	5.72	Ancistrosyllis papillosa	2.81	Micropholis atra
	3.28	Lumbrineris tenuis	1.16	Diopatra cuprea	4.38	Oligochaete	3.45	Clymenella torquata	2.16	Ancistrosyllis papillosa
	2.55	Ancistrosyllis papillosa			4.11	Cossura delta	3.36	Neanthes succinea	1.92	Lepidasthenia varia
	2.04	Diopatra cuprea			2.94	Diopatra cuprea	2.82	Pilargidae	1.85	Cerebratulus lacteus
	1.84	Larval fish			2.94	Ancistrosyllis papillosa	2.16	Cerebratulus lacteus	1.82	Diopatra cuprea
	1.72	Sigambra tentaculata			2.86	Neanthes succinea	2.13	Lepidasthenia varia	1.46	Oligochaete
	1.23	Callocardia texasiana			1.88	Lepidasthenia varia	1.33	Ampelisca sp.	1.41	Owenia fusiformis
					1.61	Micropholis atra	1.27	Sigambra tentaculata		
							1.04	Micropholis atra		
MAR.	(18)		(10)		(10)		(34)		(20)	
	39.73	Paraprionospio pinnata	23.38	Magelona sp.	19.46	Magelona sp.	34.47	Paraprionospio pinnata	21.40	Magelona sp.
	17.62	Cossura delta	19.36	Nematoda	12.22	Lumbrineris tenuis	17.57	Magelona sp.	20.14	Paraprionospio pinnata
	13.99	Magelona sp.	15.74	Cossura delta	11.40	Cossura delta	10.49	Cossura delta	14.45	Cossura delta
	6.70	Sigambra tentaculata	6.51	Lumbrineris tenuis	8.93	Clymenella torquata	5.92	Lumbrineris tenuis	7.17	Lumbrineris tenuis
	5.72	Sabellides oculata	5.19	Ancistrosyllis papillosa	7.63	Paraprionospio pinnata	4.16	Clymenella torquata	4.72	Neanthes succinea
	2.57	Nematoda	3.56	Sigambra tentaculata	4.73	Nematoda	4.01	Ancistrosyllis papillosa	3.66	Nematoda
	2.40	Ancistrosyllis papillosa	1.98	Sabellides oculata	4.64	Ampelisca sp.	3.39	Sigambra tentaculata	3.35	Micropholis atra
	1.85	Petricola pholadiformis	1.53	Micropholis atra	4.02	Ancistrosyllis papillosa	2.72	Nematoda	3.05	Diopatra cuprea
	1.74	Lumbrineris tenuis	1.30	Sthenelais boa	3.39	Maldane sarsi	2.47	Neanthes succinea	2.08	Sthenelais boa
	1.14	Diopatra cuprea	1.21	Harmothoe aculeata	3.24	Neanthes succinea	2.10	Diopatra cuprea	1.83	Sigambra tentaculata
	1.07	Cerebratulus lacteus	1.07	Diopatra cuprea	2.44	Owenia fusiformis	1.25	Ampelisca sp.	1.82	Clymenella torquata
					2.16	Micropholis atra	1.08	Carinoma tremaphoros	1.81	Owenia fusiformis
					1.67	Sigambra tentaculata	1.03	Sabellides oculata	1.57	Aglaophamus verrilli
					1.61	Glycera dibranchiata			1.57	Ancistrosyllis papillosa
					1.50	Diopatra cuprea			1.47	Harmothoe aculeata
					1.32	Sthenelais boa				
					1.08	Cerebratulus lacteus				
					1.07	Callianassa latispina				
					1.03	Callianassa sp.				

Table F-33 (continued)

	Big Hill Cluster		West Hackberry Cluster		
	Big Hill	Big Hill Control	Black Bayou	West Hackberry	West Hackberry Control
APR	(14)	(10)	(10)	(24)	(12)
	33.31 Paraprionospio pinnata	34.81 Paraprionospio pinnata	22.98 Clymenella torquata	31.23 Paraprionospio pinnata	19.98 Paraprionospio pinnata
	12.16 Sabellides oculata	16.43 Magelona sp.	15.52 Paraprionospio pinnata	10.13 Magelona sp.	18.82 Magelona sp.
	10.65 Magelona sp.	10.17 Sabellides oculata	10.46 Ampelisca sp.	7.83 Sabellides oculata	11.36 Sabellides oculata
	9.64 Cossura delta	10.15 Cossura delta	9.49 Magelona sp.	6.80 Cossura delta	8.50 Cossura delta
	6.39 Paranthus rapiformis	6.97 Paranthus rapiformis	8.59 Cossura delta	6.75 Paranthus rapiformis	4.86 Bunodactis taxaensis
	6.37 Sigambra tentaculata	5.30 Lumbrineris tenuis	4.87 Lumbrineris tenuis	5.73 Clymenella torquata	4.12 Diastylis sp.
	5.38 Ancistrosyllis papillosa	2.27 Sigambra tentaculata	3.44 Ancistrosyllis papillosa	3.83 Lumbrineris tenuis	3.83 Lumbrineris tenuis
	3.95 Cirratulis sp.	1.85 Mulinia lateralis	3.44 Sabellides oculata	3.62 Sigambra tentaculata	3.80 Cerebratulus lacteus
	2.03 Cerebratulus lacteus	1.77 Cerebratulus lacteus	2.35 Sigambra tentaculata	3.36 Cirratulis sp.	3.51 Ancistrosyllis papillosa
	1.73 Carinoma tremaphoros	1.68 Ancistrosyllis papillosa	2.27 Harmothoe aculeata	2.88 Ancistrosyllis papillosa	2.49 Neanthes succinea
	1.27 Glycera dibranchiata	1.42 Cirratulis sp.	1.93 Neanthes succinea	2.25 Ampelisca sp.	1.74 Brachyuran zoea
		1.11 Ninoe nigripes	1.52 Cerebratulus lacteus	2.01 Neanthes succinea	1.66 Ampelisca sp.
		1.08 Glycera dibranchiata	1.42 Micropholis atra	1.93 Cerebratulus lacteus	1.46 Micropholis atra
			1.34 Glycera tesselata	1.78 Diopatra cuprea	1.34 Glycera tesselata
			1.04 Pinnixa chaetopterana	1.38 Carinoma tremaphoros	1.17 Aglaophamus verrilli
MAY	(14)	(10)	(10)	(24)	(12)
	34.39 Paraprionospio pinnata	17.52 Paraprionospio pinnata	16.22 Ampelisca sp.	18.06 Paraprionospio pinnata	16.02 Nematoda
	10.07 Notomastus sp.	14.78 Cossura delta	11.80 Paraprionospio pinnata	15.06 Nematoda	12.67 Magelona sp.
	6.29 Cirratulis sp.	13.55 Nematoda	7.39 Nematoda	6.40 Sabellides oculata	9.89 Paraprionospio pinnata
	6.28 Cossura delta	13.20 Magelona sp.	7.30 Clymenella torquata	6.05 Notomastus sp.	9.06 Cossura delta
	5.67 Sabellides oculata	5.92 Lumbrineris tenuis	6.66 Magelona sp.	5.45 Clymenella torquata	5.79 Mulinia lateralis
	5.65 Magelona sp.	5.70 Sigambra tentaculata	5.23 Ancistrosyllis papillosa	4.72 Ampelisca sp.	4.88 Harmothoe aculeata
	5.55 Sigambra tentaculata	4.31 Ancistrosyllis papillosa	4.35 Corophium louisianum	4.41 Cossura delta	4.64 Lumbrineris tenuis
	5.01 Cerebratulus lacteus	4.12 Sabellides oculata	3.85 Lumbrineris tenuis	4.40 Magelona sp.	4.26 Sabellides oculata
	2.93 Paranthus rapiformis	3.60 Paranthus rapiformis	3.79 Cossura delta	4.27 Sigambra tentaculata	3.41 Clymenella torquata
	2.82 Ancistrosyllis papillosa	3.14 Notomastus sp.	3.50 Sigambra tentaculata	3.62 Cirratulis sp.	3.38 Notomastus sp.
	2.60 Nematoda	2.63 Cerebratulus lacteus	3.13 Paranthus rapiformis	3.31 Lumbrineris tenuis	2.70 Micropholis atra
	2.32 Lumbrineris tenuis	1.86 Cirratulis sp.	3.04 Diastylis sp.	2.26 Ancistrosyllis papillosa	2.63 Cerebratulus lacteus
	1.90 Mulinia lateralis	1.24 Carinoma tremaphoros	2.93 Neanthes succinea	2.18 Pinnotheridae	2.60 Ampelisca sp.
	1.57 Pinnotheridae	1.24 Ampelisca sp.	2.82 Sabellides oculata	1.89 Paranthus rapiformis	1.94 Sigambra tentaculata
	1.19 Thalassema melitta		2.63 Diopatra cuprea	1.56 Harmothoe aculeata	1.35 Paranthus rapiformis
			2.17 Cerebratulus lacteus	1.47 Cerebratulus lacteus	1.32 Diopatra cuprea
			1.75 Micropholis atra	1.40 Glycera dibranchiata	1.10 Glycera dibranchiata
			1.73 Notomastus sp.	1.38 Mulinia lateralis	1.06 Ancistrosyllis papillosa
			1.07 Mulinia lateralis	1.32 Diopatra cuprea	1.02 Cirratulis sp.
			1.01 Harmothoe aculeata	1.16 Micropholis atra	
				1.09 Neanthes succinea	

Table F-33 (continued)

	Big Hill Cluster		West Hackberry Cluster		
	Big Hill	Big Hill Control	Black Bayou	West Hackberry	West Hackberry Control
JUN	(10) 17.24 Paraprionospio pinnata 15.91 Mulinia lateralis 13.57 Magelona sp. 11.48 Cossura delta 10.16 Notomastus sp. 7.20 Lumbrineris tenuis 6.06 Cerebratulus lacteus 4.90 Ancistrosyllis papillosa 4.12 Sigambra tentaculata 2.14 Ninoe nigripes 1.19 Paranthus rapiformis 1.13 Neanthes succinea	(18) 17.38 Paraprionospio pinnata 14.62 Notomastus sp. 12.36 Magelona sp. 8.81 Sigambra tentaculata 8.48 Cirratulis sp. 7.91 Lumbrineris tenuis 6.83 Cossura delta 4.76 Thalassema melitta 3.29 Cerebratulus lacteus 2.84 Mulinia lateralis 2.59 Ancistrosyllis papillosa 2.22 Cyclostremiscus pentagonus 1.50 Diopatra cuprea 1.11 Hermathoe aculeata	NO SAMPLES	NO SAMPLES	NO SAMPLES
JUL	(10) 38.02 Paraprionospio pinnata 16.75 Magelona sp. 8.28 Cossura delta 6.37 Sigambra tentaculata 4.86 Lumbrineris tenuis 4.41 Cirratulis sp. 4.23 Mulinia lateralis 3.66 Glycera dibranchiata 1.92 Cerebratulus lacteus 1.72 Neanthes succinea 1.68 Notomastus sp. 1.06 Diopatra cuprea 1.04 Ancistrosyllis papillosa	(18) 37.60 Paraprionospio pinnata 13.66 Sigambra tentaculata 9.58 Magelona sp. 6.53 Notomastus sp. 6.28 Cossura delta 4.86 Cirratulis sp. 3.06 Cerebratulus lacteus 2.25 Lumbrineris tenuis 2.02 Thalassema melitta 1.78 Lepidonotus squamatus 1.67 Nephtys picta 1.33 Glycera dibranchiata 1.06 Apoda (holothuriidea) 1.06 Eusyllis sp.	NO SAMPLES	NO SAMPLES	NO SAMPLES
AUG	(10) 22.17 Magelona sp. 10.65 Lumbrineris tenuis 8.47 Cossura delta 7.03 Paraprionospio pinnata 6.93 Sigambra tentaculata 5.88 Glycera dibranchiata 4.98 Cerebratulus lacteus 4.07 Microphelis atra 2.73 Pinnixa chaetopterana 2.33 Spionidae 2.29 Lepidasthenia varia 2.13 Ninoe nigripes 2.09 Cirratulus sp. 2.07 Notomastus sp. 2.03 Echiurida 1.96 Ancistrosyllis papillosa 1.90 Diastylis sp. 1.29 Neanthes succinea 1.04 Clymenella torquata	(18) 22.03 Magelona sp. 12.36 Sigambra tentaculata 9.16 Cossura delta 6.73 Cirratulis sp. 6.28 Paraprionospio pinnata 5.53 Lumbrineris tenuis 5.27 Notomastus sp. 4.49 Echiurida 4.26 Cerebratulus lácteus 3.39 Diastylis sp. 2.22 Ninoe nigripes 2.09 Pinnixa chaetopterana 1.83 Glycera dibranchiata 1.83 Lepidasthenia varia 1.79 Mulinia lateralis 1.52 Diopatra cuprea 1.23 Ancistrosyllis papillosa 1.15 Microphelis atra 1.07 Hermathoe aculeata	NO SAMPLES	NO SAMPLES	NO SAMPLES
SEP	(9) 47.76 Paraprionospio pinnata 14.35 Magelona sp. 6.77 Cossura delta 4.56 Diopatra cuprea 3.86 Glycera dibranchiata 3.81 Cirratulis sp. 3.35 Sigambra tentaculata 2.65 Lumbrineris tenuis 2.00 Nematoda 1.96 Microphelis atra 1.43 Clymenella torquata 1.12 Cerebratulus lacteus 1.06 Actiniaria sp.	(18) 37.12 Paraprionospio pinnata 13.27 Magelona sp. 10.20 Cerebratulus lacteus 6.87 Sigambra tentaculata 6.16 Cossura delta 5.03 Glycera dibranchiata 2.42 Microphelis atra 1.98 Notomastus sp. 1.95 Nematoda 1.92 Diopatra cuprea 1.86 Lumbrineris tenuis 1.64 Ancistrosyllis papillosa 1.55 Cirratulis sp. 1.50 Pinnixa chaetopterana 1.28 Echiurida	NO SAMPLES	NO SAMPLES	NO SAMPLES
OCT	(10) 20.53 Paraprionospio pinnata 16.85 Magelona sp. 11.01 Sigambra tentaculata 9.89 Cirratulis sp. 5.73 Carinoma tremaphoros 5.34 Cossura delta 4.53 Lumbrineris tenuis 3.74 Glycera dibranchiata 2.92 Cerebratulus lacteus 2.38 Diopatra cuprea 1.99 Notomastus sp. 1.95 Linopherus ambigua 1.80 Microphelis atra 1.80 Lepidasthenia varia 1.77 Ninoe nigripes 1.38 Echiurida 1.11 Ampelisca sp.	(18) 22.16 Paraprionospio pinnata 17.91 Magelona sp. 13.83 Cirratulis sp. 9.35 Sigambra tentaculata 5.74 Cossura delta 4.24 Lumbrineris tenuis 4.04 Cerebratulus lacteus 3.87 Notomastus sp. 3.69 Linopherus ambigua 2.99 Ancistrosyllis papillosa 1.77 Microphelis atra 1.61 Diopatra cuprea 1.61 Eusyllis sp. 1.51 Glycera dibranchiata	NO SAMPLES	NO SAMPLES	NO SAMPLES

[a]Only species comprising 1% or more of the community are shown.

[b]Number in parentheses is the number of samples on which composition is based.

Table F-34. **Results of R-mode factor analysis for macrobenthos collected at the Texoma study sites from September 1977 to May 1978**

Species	Factor 1	Factor 2	Factor 3
Paranthus rapiformis	0.61795	-0.14354	0.11735
Cerebratulus lacteus	0.56710	0.11734	0.01968
Diopatra cuprea	-0.29133	0.32901	0.15956
Glycera dibranchiata	0.44612	0.29541	0.26234
Acetes americana	-0.23630	0.13436	-0.07743
Nematoda	0.29436	0.26248	-0.05988
Ancistrosyllis papillosa	0.32962	0.19738	-0.25813
Cossura delta	0.53834	0.18641	-0.35839
Paraprionospio pinnata	0.80999	-0.04950	-0.15047
Sigambra tentaculata	0.66680	-0.04185	-0.13907
Carinoma tremaphoros	0.23741	-0.08159	-0.02779
Sabellides oculata	0.73879	-0.05688	0.04378
Cirratulus sp.	0.56347	-0.18269	0.00462
Neanthes succinea	-0.11486	0.85087	0.02284
Owenia fusiformis	-0.10987	0.68156	0.20832
Ampelisca sp.	0.29515	0.50920	-0.03951
Micropholis atra	0.23270	0.50864	0.03456
Clymenella torquata	-0.00939	0.65580	-0.13927
Lumbrineris tenuis	-0.16897	0.52648	-0.39768
Nassarius acutus	0.00636	0.09201	-0.57213
Mulinia lateralis	0.19050	0.31804	0.76975
Nuculana concentrica	-0.11716	0.10724	0.54345
Magelona sp.	-0.02353	0.23299	0.57128
Callianassa latispina	-0.15534	0.19111	-0.07556
Aglaophamus verrilli	0.03146	0.10201	0.05741
Drilonereis longa	-0.03312	-0.00257	0.03613

4. Factor 2 defines another group primarily comprised of polychaetes, including Neanthes succinea, Clymenella torquata, L. tenuis, and Owenia fusiformis. An Ampeliscid amphipod, Ampelisca sp., and the brittle star, Micropholis atra, were also important. This group is present much of the year, but with greater numbers in the late winter to spring. However, the most consistent trend displayed by this group is the lower standing stocks at the Big Hill and BHC sites, where the texture of the sediments is finest.

Figures F-68 and F-69 show the four major station groupings (B3, B4, B6, and B7) and three outlier samples (B1, B2, and B5) that define results of the Q-mode cluster analysis of megabenthos data from March 1978. The two most aberrant samples (B1 and B5) come from stations with very fine sediment textures and depauperate fauna. The major cluster groups (and subgroups) correspond quite well to sediment grain size distribution with secondary spatial considerations, possibly based on proximity to other stations. The most divergent of the major groups is composed of stations at West Hackberry Control and Black Bayou, which had the coarsest sediment texture. The next group is composed mainly of Big Hill samples, but also includes fine-textured samples from other sites, especially West Hackberry. The two groups most closely related, but still quite distinct, are those from West Hackberry (fine to medium texture) and those from coarse-textured sites from West Hackberry, West Hackberry Control, and Black Bayou. There are several samples which, according to either sediment composition or location, appeared to cluster with the wrong group. Most of these are BHC samples, but the one from station 13 at West Hackberry is the most puzzling.

The results of the R-mode cluster analysis for these same March benthos data for the Texoma region are shown in Fig. F-70. Four major groupings emerge, one (A2) consisting of only one species Petricola pholadiformis, a known clay-bottom species that was found only at the Big Hill site.

Group A3 contains only two faunal groups, Nematoda and Sabellides oculata. Since the level of association of these two species is not high, they do not form a well-defined ecological grouping. However, an investigation of their spatial pattern reveals their greater relative importance at the Big Hill stations, although there were exceptions, including presence at several stations with coarse sediments. S. oculata showed the stronger tendency for occurrence at the Big Hill stations. Little published information is available regarding the sediment preference of this tentaculate surface deposit feeding polychaete.

Group A4 consists of six species (P. pinnata, Magelona sp., C. delta, S. tentaculata, Callianassa latispina, and Aglaophamus verrilli). This major grouping is distinguished as generally not showing any sediment preference, with four species (P. pinnata, Magelona sp., C. delta, and S. tentaculata) demonstrating neither sediment nor spatial preference. In March 1978, these four species were the true generalists of the Texoma study area.

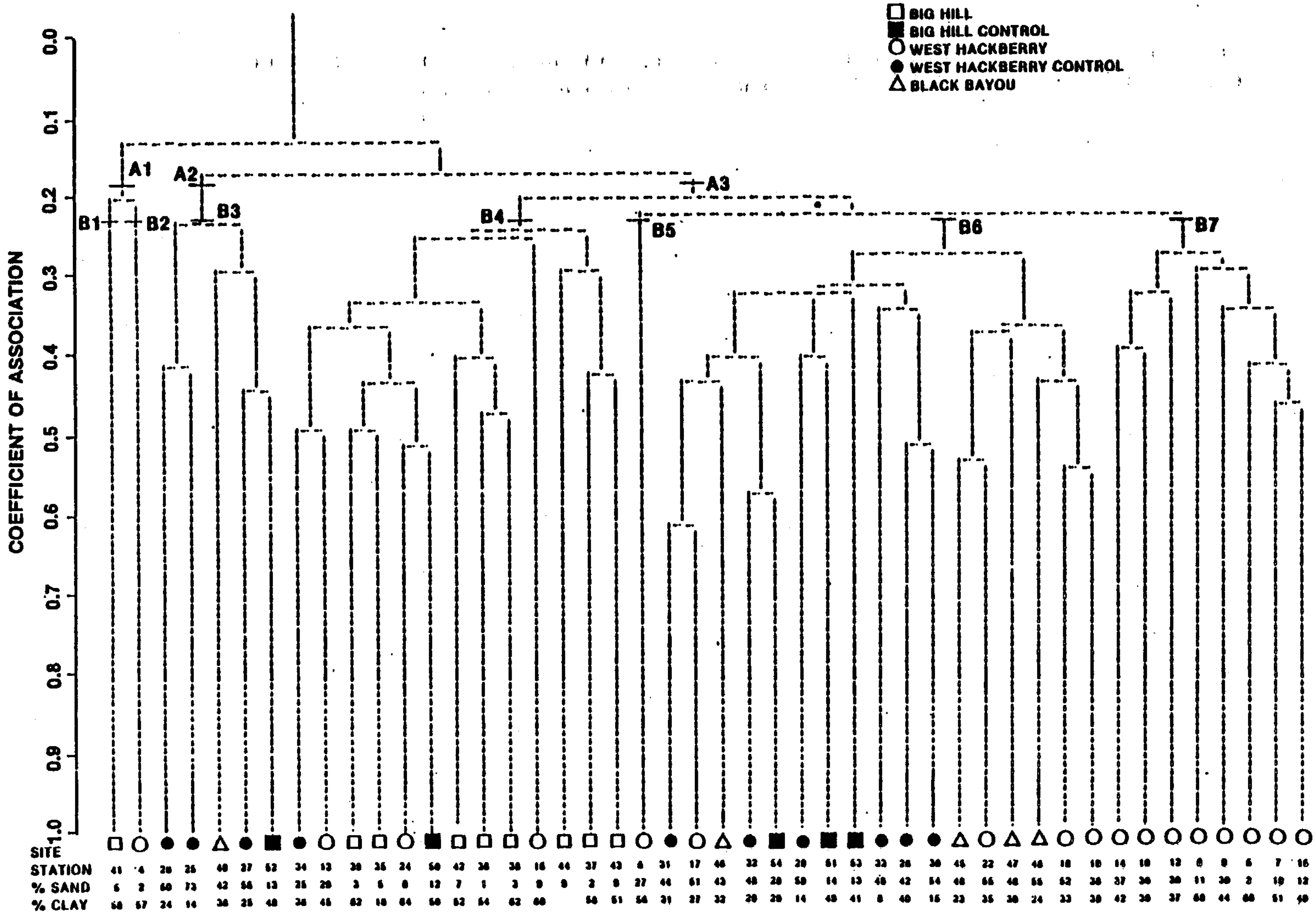


Figure F-68. Dendrogram of the cluster analysis of macrobenthic species collected during March 1978 across all Texoma stations. Source: Comiskey et al. (1979).

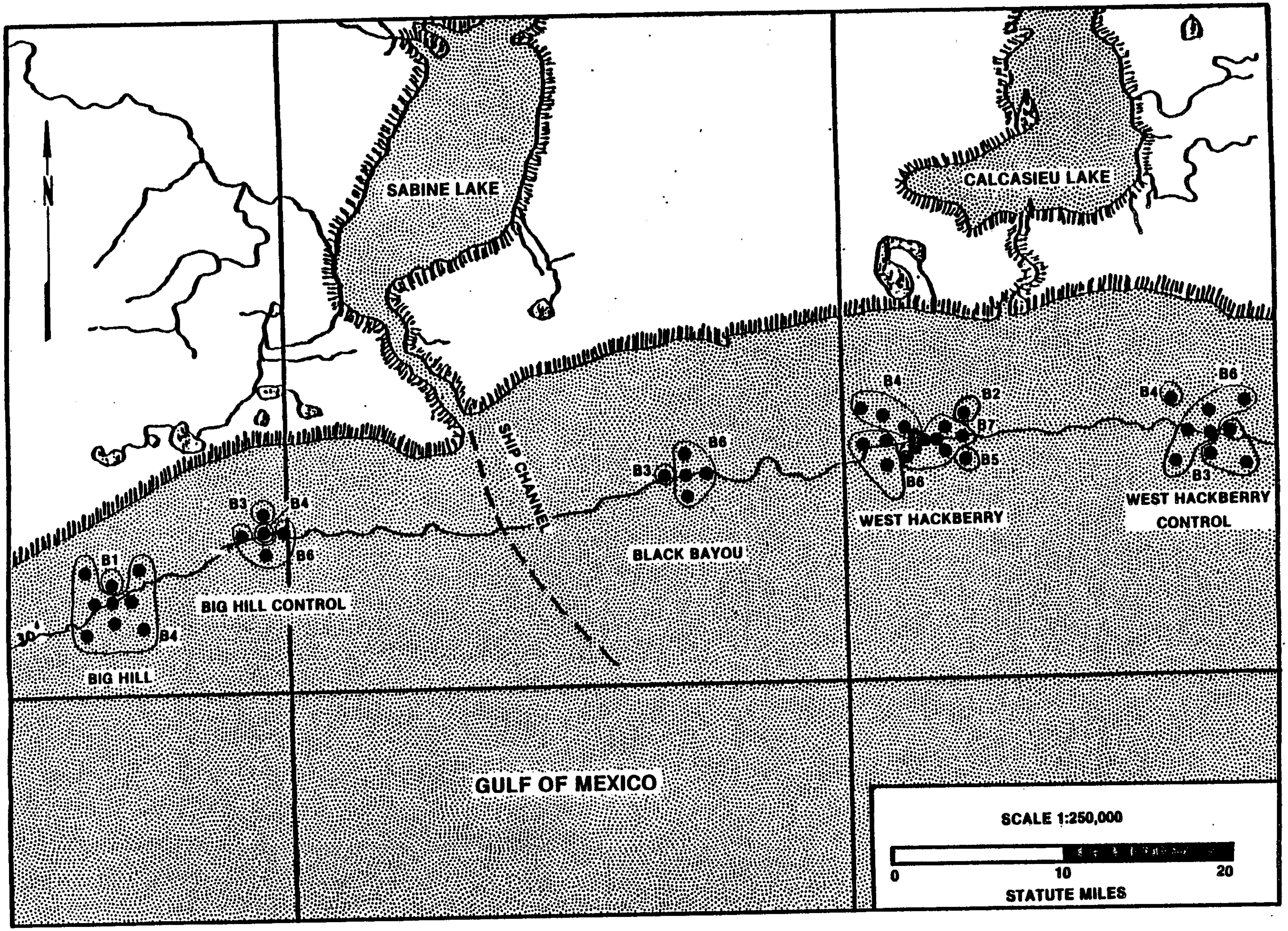


Figure F-69. Approximate location of Texoma benthic study sites and stations. Zones delineate macrobenthic species clusters from dendrogram (see Fig. F-68).

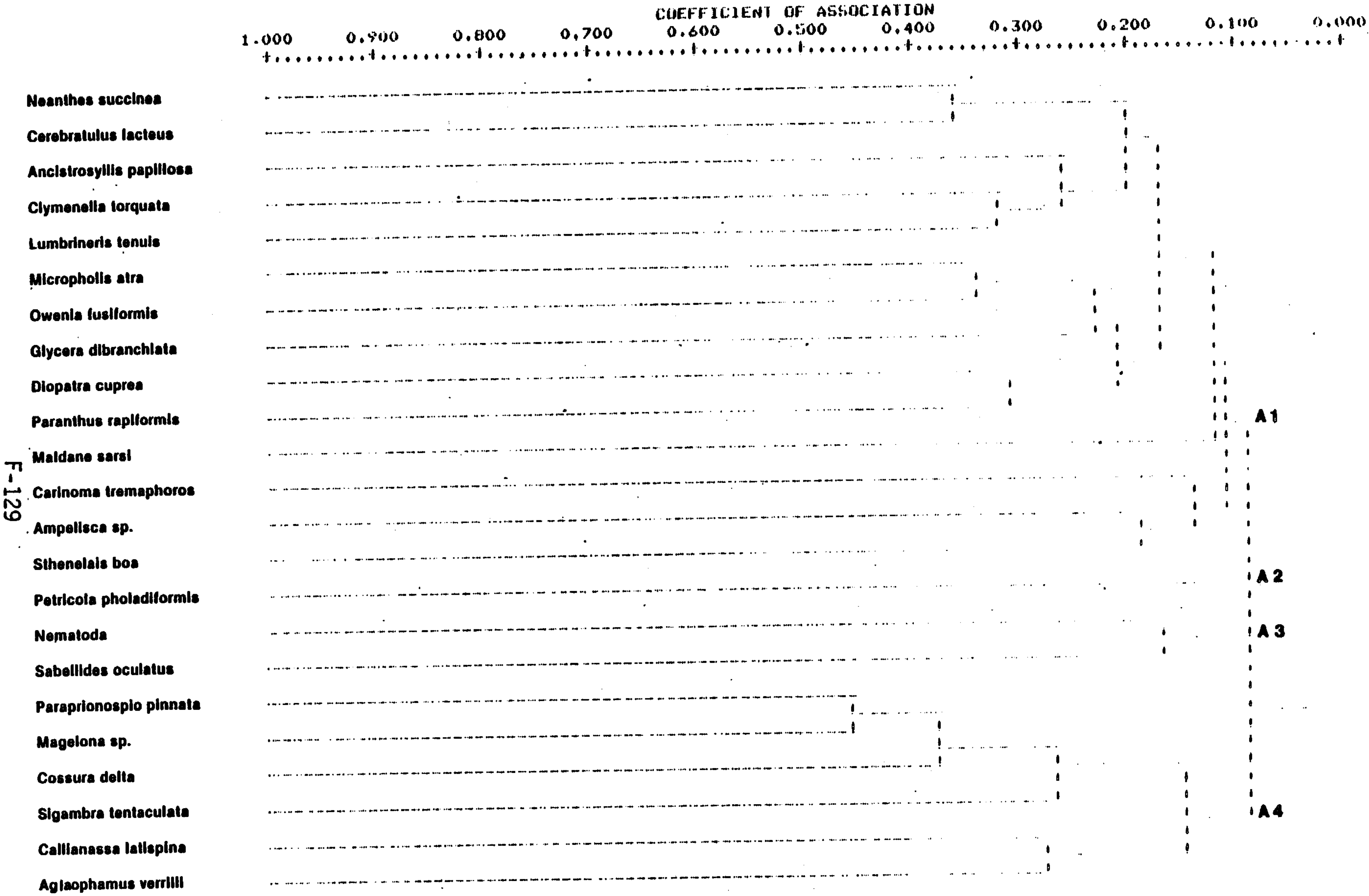


Figure F-70. Dendrogram of the cluster analysis of macrobenthic species collected during March 1978 across all Texoma stations. Source: Comiskey et al. (1979).

Group A1, the largest group, consists of the remaining 14 species, most of which were polychaetes, including N. succinea, A. papillosa, Harmothoe aculeata, C. torquata, L. tenuis, O. fusiformis, Glycera dibranchiata, and D. cuprea, as well as the brittle star, Micropholis atra, and the nemertean, Cerebratulus lacteus. Maldane sarsi showed the strongest tendency to occur at stations with the coarsest-textured sediments. In general the results for the cluster analyses and factor analysis identified similar trends.

The relationships of total benthos and temperature, salinity, and dissolved oxygen are shown in Figs. F-71 to F-73. A distinct dissolved oxygen minimum was observed during the June cruise and is documented above. Because frequency of sampling was only monthly, the exact duration of this phenomenon is not known. Figure F-73 shows the behavior of the benthic megafauna during this time. There is no indication that there was even a temporary disruption of the benthic community due to the dissolved oxygen minimum. The populations at Big Hill and BHC during June and July were as high or higher than those at the same sites in May (see Fig. F-67).

Nekton

Unlike most trawl surveys in the Gulf, which utilize commercial-type gear to collect large demersal organisms, this study used a small mesh net (4-mm stretch) to sample less motile and possibly more sensitive juveniles and smaller individuals that inhabit the near-shore region.

A total of 112 species was collected in the vicinity of the Big Hill site (Table F-35). Approximately 40 percent were fish, 30 percent crustaceans, 13 percent molluscs, and 8 percent coelenterates. The remaining taxa consisted of echinoderms, polychaetes, ctenophores, and nematodes. Throughout the study, anchovies, squid, white shrimp, sergestid shrimp, and sciaenid fishes dominated the catch. During specific seasons, certain taxa became particularly abundant (Table F-36). Larval and juvenile sciaenids were common during the fall months as was the sea bob shrimp.

Results of factor analysis on the Texoma nekton data collected over the five sites for cruises 1 through 8 (September to May) are presented in Table F-37. Eight factors were retained for oblique rotation. Analyses were performed using SAS 79 procedures with Promax oblique capabilities. As expected, the results generally described temporal trends over the three seasons: fall, winter, and spring.

Factor 1 defined a strong fall (November) association, including Peprilus paru (0.84), larval sciaenids (0.79), Chiropsalmus quadrumanus (0.67), Syngnathus louisianae (0.58), and Portunus gibbesi (0.48). Examination of Table F-36 indicates that several of these taxa made significant contributions during November. The catch distribution of larval sciaenids and P. gibbesi are shown in Figs. F-74 and F-75. Both exhibit maximum catches in the fall and specifically November. Of these taxa loadings on factor 1, C. quadrumanus displayed a significant loading on another factor, indicating that it contributed to another important trend in the data set.

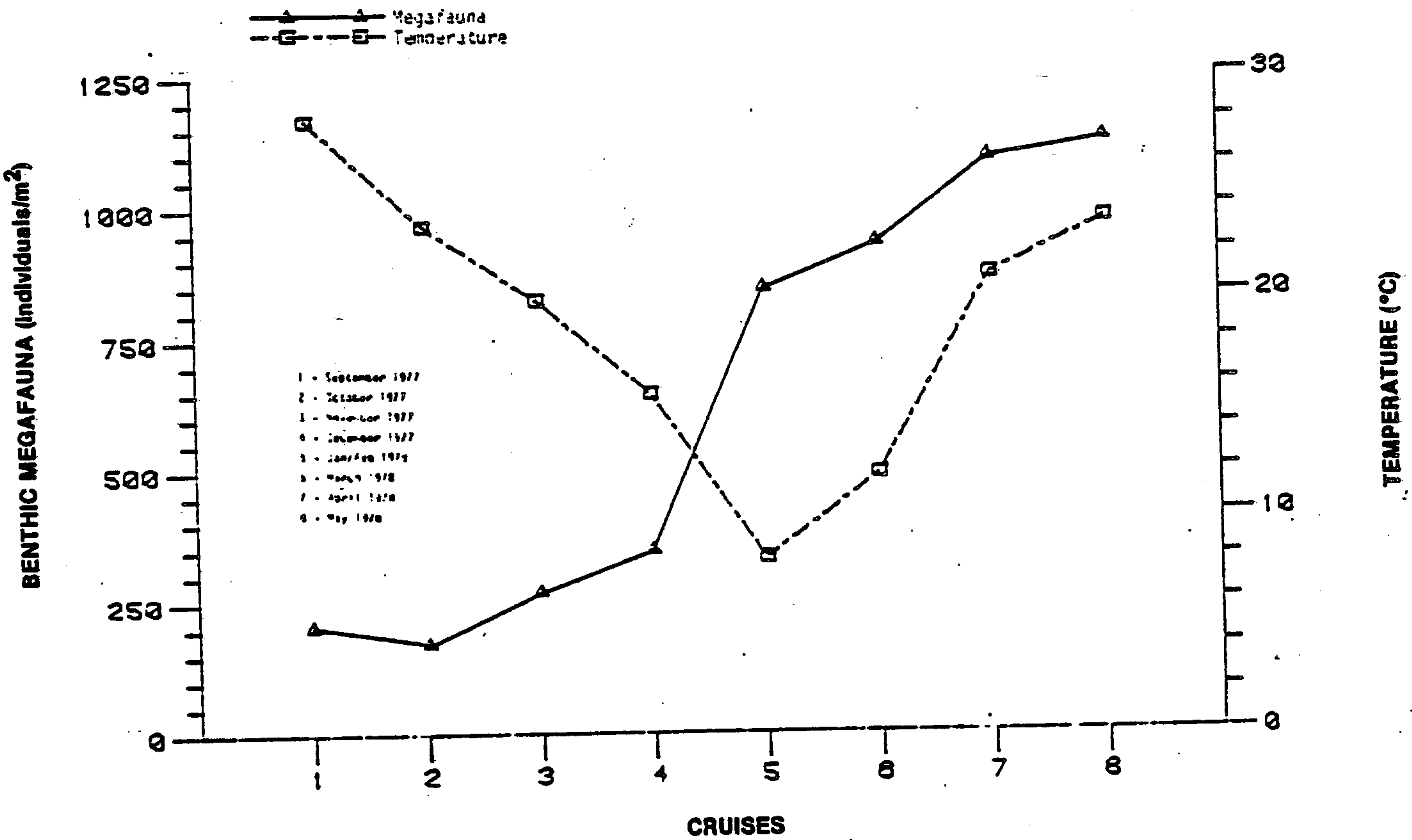


Figure F-71. Plot of monthly mean values (over all sites) of total benthic megafauna (individuals/m^2) and near-bottom temperature (°C) in the Texoma study region for the period September 1977 to May 1978.

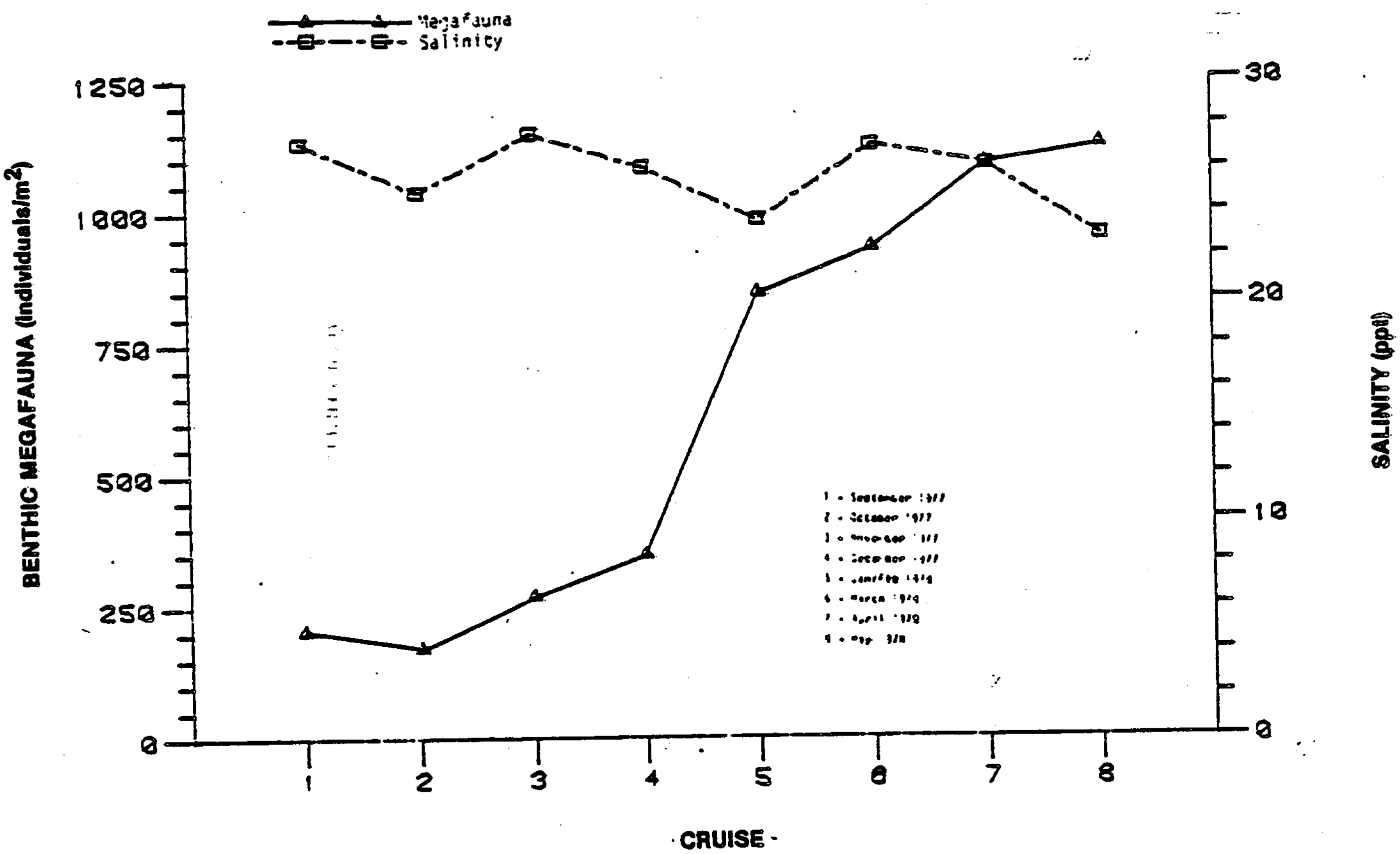


Figure F-72. Plot of monthly mean values (over all sites) of total benthic megafauna (individuals/m^2) and near-bottom salinity in the Texoma study region for the period September 1977 to May 1978. Source: Comiskey et al. (1979).

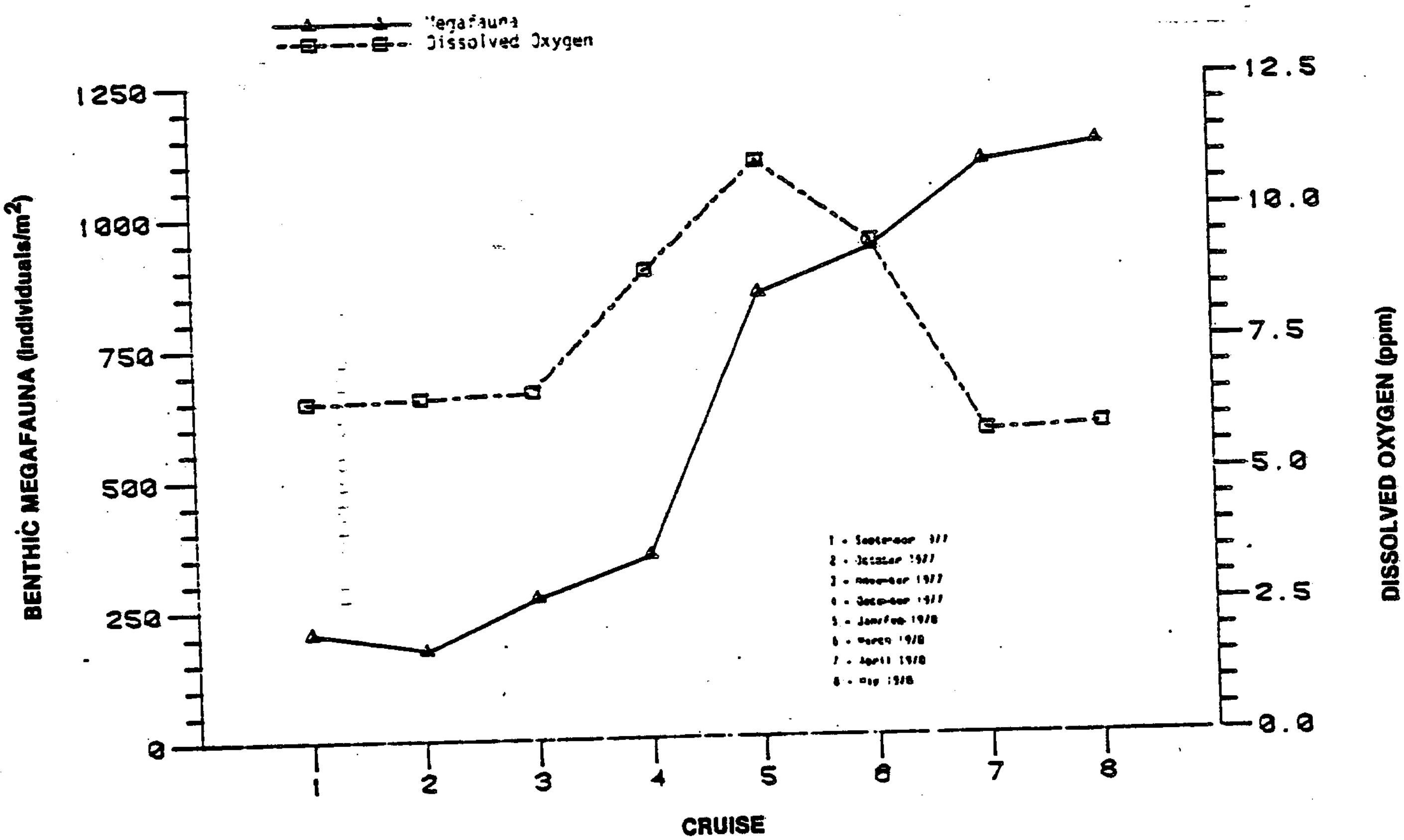


Figure F-73. Plot of monthly mean values (over all sites) of total benthic megafauna (number of individuals/m^2) and near-bottom dissolved oxygen (ppm) in the Texoma study region for the period September 1977 to May 1978.

Table F-35. Seasonal distribution of organisms taken by otter trawls at the Texoma study sites, September 1977 to October 1978

PHYLUM/Species	Month												
	Sep	Oct	Nov	Dec	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
COELENTERATA													
Aurelia aurita			WB						B		B	B	B
Bunodactis texaensis		B		W								B	
Calliactis tricolor	WB	WB	WB	WB	WB	WB	WB	WB	B			B	
Chiropsalmus quadrumanus	W	W	WB	W				W				B	
Minyas olivacea			W										
Paranthus rapiformis		B	B	B	WB	WB	B	WB	B				
Stomolophis meleagris							B						
Unidentified anthomedusid					B	WB							
Unidentified anthozoan						W							
CTENOPHORA													
Unidentified ctenophore				B									
NEMERLINA													
Carinoma tremaphoros							B						
MOLLUSCA													
Abra aequalis			W			WB					B	B	B
Anadara ovalis	B			B	B	WB	B	B		B	B	B	B
Anadara transversa					W						B		
Busycon contrarium										B			
Callocardia texasiana					W						B	B	
Cantharus cancellarius				W	WB	W	WB				B	B	
Chione cancellata												B	B
Lolliguncula brevis	WB	WB	WB	WB	W	B	WB	WB		B	B	B	B
Mulinia lateralis				B	B	B	B	W	B	B	B	B	B
Nassarius acutus	B	W			B						B	B	
Nuculana concentrica			W	B	B	B	B			B	B	B	B
Polinices duplicatus												B	B
Solen viridis	WB	B	W		WB	WB	WB	B					
Tellina versicolor									B				
Thais haemastoma	B					B	B				B	B	
ANNELIDA													
Chaetopterus variopedatus			W		W	W	W	W					
Diopatra cuprea			W	W				B					
Neanthes succinea	W	B											
ARTHROPODA													
Acetes americanus	WB	WB	WB	WB	W		WB	W			B	B	B
Arenaeus cribrarius							B						
Callianassa minima		B	W										
Callinectes sapidus								B				B	B
Callinectes similis	B		WB	WB				WB					
Cirolana obtruncata		B											
Cirolana parva		WB	WB	WB	B								
Cirolana sp.					W		WB						
Hepatus epheliticus		W	WB	W	W	WB	WB	WB	B				
Hepatus pudibundus						W							
Hexapanopeus angustifrons								W					
Isopoda											B	B	
Libinia dubia	W	WB	WB	W	WB	WB	WB	W					
Lysiosquilla empusa	WB	WB	WB	WB	WB	WB	WB	WB		B	B	B	B
Neopanope texana				W		WB		WB					
Ovalipes floridanus						W	B						
Paguristes moorei							W					B	

Table F-35 (continued)

PHYLUM/Species	Sep	Oct	Nov	Dec	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
	Month												
Pagurus pollicaris	B	B	B		W	W	W				B	B	
Palaemonetes pugio				W									
Penaeus aztecus	W	WB	B				WB	B		B	B	B	B
Penaeus setiferus	WB	WB	WB	WB	WB	WB	WB	WB		B	B	B	B
Persephona mediterranea	WB	WB	WB	B	B	WB	WB	WB	B		B	B	B
Pinnixa chaetopterana					W	W							
Polyonyx gibbesi						WB							
Portunus gibbesi	WB	WB	WB	WB	WB	WB					B	B	B
Portunus sayi	WB	WB										B	
Sicyonia brevirostris	B		B										B
Sicyonia dorsalis	W	WB	WB	W									
Speocarcinus lobatus								W					
Sphaeroma quadridentatum		B											B
Trachypenaeus similis		B	B		W						B		
Unidentified isopod													
Xiphopenaeus kroyeri													
ECHINODERMATA													
Astropecten antillensis													
Luidia clathrata		B		B									
Micropholis atra									B				
Unidentified holothuroid									B				
CHORDATA													
Achirus lineatus		B											
Anchoa hepsetus	WB	WB		W							B	B	
Anchoa mitchilli	WB	WB	Wb	WB	WB	WB	WB	WB				B	B
Arius felis		W	B				WB	WB			B	B	
Astroscopus y-graecum			W	WB									
Bagre marinus	WB	WB									B		
Brevoortia patronus	W				B		B					B	
Caranx hippos	B	W											
Caranx ruber	B	B	WB										
Chaetodipterus faber	W		B	W		B						B	
Chloroscombrus chrysurus	WB	W	W						B	B	B	B	B
Citharichthys spilopterus		B					WB						
Cynoscion arenarius	W	B	WB	WB	B	B	WB	WB		B	B	B	B
Cynoscion nebulosus	B	W	W					W				B	
Cynoscion nothus	WB	WB	WB	WB		WB	WB	WB				B	
Etropus crossotus				W									
Harengula pensacolae	W												
Larimus fasciatus			W	B		B	WB	B		B			
Larval anchovies												B	
Larval sciaenids	W		WB	WB								B	B
Leiostomus xanthurus		W		WB	WB	WB	WB	WB			B	B	
Leptocephalus larvae				W	W	WB							
Menticirrhus americanus					WB	WB	W	W					
Micropogon undulatus	WB	WB	WB	B	WB	B	WB	WB		B	B	B	
Mugil cephalus					B								
Myrophis punctatus				B				B					
Ophichthus gomesi											B		
Ophidion welshi	WB	WB	WB		B			WB					
Opisthonema oglinum	WB	W			B								
Orthopristis chrysoptera												B	
Peprilus burti					W	W	WB						B
Peprilus paru	W	W	B							B	B	B	
Polydactylus octonemus	WB	B					WB	W		B	B	B	B
Porichthys porosissimus	B	WB	WB	B							B	B	B

Table F-35 (continued)

PHYLUM/Species	Sep	Oct	Nov	Dec	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
	Month												
Prionotus rubio		W	WB	WB	B	B	WB	W					
Scomberomorus cavalla	B												
Sphoeroides parvus	WB	WB	WB	W				B				B	
Sphyraena guachancho	W												
Stellifer lanceolatus	WB	WB	WB	WB	B	WB	WB			B	B		
Symphurus plagiusa		WB	WB	WB	WB	WB	WB	WB			B		
Syngnathus louisianae		B	WB		WB	WB							
Synodus foetens	W												
Trichiurus lepturus		W	W				W						B
Umbrina coroides		WB											
Urophycis floridanus						B	WB						

*W--West Hackberry site
B--Big Hill site
WB--Both sites.

Table F-36. Seasonal and site patterns of otter trawl community dominance

	Big Hill cluster		West Hackberry cluster		
	Big Hill	Big Hill Control	Black Bayou	West Hackberry	West Hackberry Control
SEP	(3)[a] 27.07 Xiphopenaeus kroyeri 23.25 Acetes americanus 13.17 Penaeus setiferus 8.31 Micropogon undulatus 4.95 Cynoscion nebulosus 4.00 Cynoscion nothus 3.97 Anchoa mitchilli 3.48 Anchoa hepsetus 3.32 Stellifer lanceolatus 2.65 Lolliguncula brevis 1.42 Lysiosquilla empusa	(1) 94.94 Acetes americanus 1.49 Lolliguncula brevis	(2) 76.95 Anchoa mitchilli 14.64 Lolliguncula brevis 3.38 Acetes americanus 1.56 Micropogon undulatus	(3) 58.72 Acetes americanus 18.59 Penaeus setiferus 17.11 Micropogon undulatus 1.81 Cynoscion arenarius	(2) 33.46 Anchoa mitchilli 26.20 Lolliguncula brevis 11.93 Chloroscombrus chrysurus 7.17 Penaeus setiferus 6.45 Acetes americanus 3.70 Anchoa hepsetus 3.55 Ophidion welshi 2.73 Chiropsalmus quadrumanus 2.60 Calliactis tricolor
OCT	(3) 34.74 Acetes americanus 33.96 Xiphopenaeus kroyeri 16.85 Stellifer lanceolatus 2.67 Penaeus setiferus 2.62 Cynoscion nothus 1.81 Sicyonia dorsalis 1.60 Portunus sayi 1.01 Portunus gibbesi	(2) 3.49 Acetes americanus 5.43 Cynoscion arenarius 5.29 Xiphopenaeus kroyeri 1.53 Lolliguncula brevis 1.38 Penaeus setiferus	(2) 39.52 Acetes americanus 34.69 Anchoa mitchilli 7.21 Lolliguncula brevis 5.77 Cynoscion nothus 3.53 Penaeus setiferus 1.77 Portunus gibbesi 1.66 Sphoeroides parvus 1.36 Chloroscombrus chrysurus 1.01 Stellifer lanceolatus	(3) 81.74 Acetes americanus 7.20 Xiphopenaeus kroyeri 2.27 Lolliguncula brevis 1.58 Leiostomus xanthurus 1.23 Penaeus setiferus 1.18 Stellifer lanceolatus	(3) 47.98 Anchoa mitchilli 16.94 Lolliguncula brevis 14.66 Penaeus setiferus 6.13 Anchoa hepsetus 3.46 Portunus gibbesi 3.01 Cynoscion nebulosus 1.86 Lysiosquilla empusa 1.20 Sicyonia dorsalis 1.00 Cynoscion nothus
NOV	(3) 27.44 Xiphopenaeus kroyeri 18.89 Larval sciaenids 14.28 Stellifer lanceolatus 12.52 Acetes americanus 12.39 Penaeus setiferus 6.18 Lolliguncula brevis 1.53 Calliactis tricolor 1.41 Portunus gibbesi	(2) 41.58 Larval sciaenids 26.20 Lolliguncula brevis 12.32 Penaeus setiferus 3.04 Chiropsalmus quadrumanus 2.58 Peprilus paru 2.01 Micropogon undulatus 1.79 Calliactis tricolor 1.53 Cynoscion nothus 1.48 Portunus gibbesi 1.00 Stellifer lanceolatus	(2) 47.49 Acetes americanus 16.46 Larval sciaenids 7.68 Micropogon undulatus 7.49 Lolliguncula brevis 6.73 Cynoscion nothus 4.80 Cynoscion arenarius 2.00 Anchoa mitchilli 1.47 Penaeus setiferus 1.11 Portunus gibbesi	(3) 17.76 Penaeus setiferus 16.31 Acetes americanus 11.44 Anchoa mitchilli 8.68 Stellifer lanceolatus 7.72 Callinectes similis 6.20 Portunus gibbesi 5.41 Micropogon undulatus 4.88 Cynoscion nothus 4.16 Lolliguncula brevis 3.87 Lysiosquilla empusa 2.76 Cynoscion nebulosus 1.54 Larval sciaenids 1.46 Xiphopenaeus kroyeri 1.05 Porichthys porosissimus	(3) 69.33 Acetes americanus 10.25 Cynoscion nothus 7.25 Lolliguncula brevis 3.65 Portunus gibbesi 3.51 Larval sciaenids 1.62 Penaeus setiferus
DEC	(3) 36.40 Xiphopenaeus kroyeri 29.72 Acetes americanus 10.38 Larval sciaenids 4.89 Lolliguncula brevis 4.62 Penaeus setiferus 3.14 Stellifer lanceolatus 2.99 Calliactis tricolor 1.05 Cynoscion nothus 1.03 Symphurus plagi[illegible]a 1.01 Lysiosquilla empusa	(2) 91.31 Acetes americanus 2.36 Cynoscion nothus 2.22 Lolliguncula brevis 1.50 Anchoa mitchilli	(2) 45.03 Acetes americanus 29.56 Larval sciaenids 13.79 Anchoa hepsetus 3.49 Anchoa mitchilli 2.57 Lolliguncula brevis 1.54 Lysiosquilla empusa 1.08 Calliactis tricolor	(3) 76.08 Acetes americanus 12.61 Larval sciaenids 3.33 Anchoa mitchilli 2.10 Cynoscion nothus 1.33 Penaeus setiferus 1.12 Lolliguncula brevis	(3) 58.10 Anchoa mitchilli 26.25 Acetes americanus 10.45 Lolliguncula brevis 3.14 Larval sciaenids 1.79 Cynoscion nothus

Table F-36 (continued)

	Big Hill cluster				West Hackberry cluster					
	Big Hill		Big Hill Control		Black Bayou		West Hackberry		West Hackberry Control	
FEB	(3)		(2)		(1)		(3)		(2)	
	75.83	Anchoa mitchilli	61.10	Anchoa mitchilli	52.05	Penaeus setiferus	83.31	Anchoa mitchilli	67.45	Anchoa mitchilli
	9.52	Penaeus setiferus	25.28	Micropogon undulatus	29.45	Anchoa mitchilli	5.31	Penaeus setiferus	8.16	Lysiosquilla empusa
	7.89	Anthomedusid spp.	5.26	Brevoortia patronus	2.74	Ophidion welshi	2.18	Calliactis tricolor	6.09	Penaeus setiferus
	4.19	Micropogon undulatus	4.38	Penaeus setiferus	2.74	Symphurus plagiusa	1.23	Cantharus cancellarius	3.95	Peprilus burti
	1.07	Calliactis tricolor	2.36	Polinices duplicatus	2.05	Cantharus cancellarius	1.06	Symphurus plagiusa	3.78	Trachypenaeus similis
					2.05	Portunus gibbesi			3.19	Calliactis tricolor
					2.05	Micropogon undulatus			2.33	Polinices duplicatus
									1.13	Leiostomus xanthurus
MAR	(3)		(2)		(2)		(2)		(2)	
	33.91	Penaeus setiferus	7.10	Penaeus setiferus	61.35	Anthomedusid spp.	55.04	Anthomedusid spp.	54.03	Anchoa mitchilli
	13.08	Anthomedusid spp.	7.01	Anchoa mitchilli	3.20	Chaetodipterus faber	27.73	Anchoa mitchilli	13.69	Calliactis tricolor
	8.79	Anchoa mitchilli	1.55	Micropogon undulatus	3.20	Anthozoa	8.04	Penaeus setiferus	6.91	Neopanope texana
	5.37	Micropogon undulatus			4.38	Penaeus setiferus	4.51	Calliactis tricolor	4.09	Persephona mediterranea
	1.63	Symphurus plagiusa			1.76	Calliactis tricolor	1.26	Libinia dubia	3.66	Penaeus setiferus
	1.52	Stellifer lanceolatus			1.42	Polyonyx gibbesi			3.10	Polyonyx gibbesi
	1.17	Lolliguncula brevis			1.22	Hepatus epheliticus			2.95	Anthomedusid spp.
									1.93	Portunus gibbesi
									1.40	Pinnixa chaetopterana
									1.39	Cantharus cancellarius
									1.13	Lysiosquilla empusa
									1.13	Symphurus plagiusa
APR	(3)		(2)		(2)		(3)		(2)	
	25.12	Anchoa mitchilli	22.47	Micropogon undulatus	41.23	Anchoa mitchilli	29.16	Micropogon undulatus	38.66	Cynoscion nothus
	19.04	Micropogon undulatus	18.57	Cynoscion nothus	11.03	Lolliguncula brevis	14.26	Cynoscion nothus	14.60	Anchoa mitchilli
	15.86	Cynoscion nothus	14.18	Anchoa mitchilli	9.40	Cynoscion nothus	13.89	Penaeus setiferus	14.52	Cynoscion arenarius
	6.97	Acetes americanus	12.70	Penaeus setiferus	9.27	Arius felis	9.38	Calliactis tricolor	9.07	Acetes americanus
	6.14	Penaeus setiferus	7.95	Lolliguncula brevis	8.65	Calliactis tricolor	5.92	Symphurus plagiusa	3.41	Penaeus setiferus
	4.35	Mulinia lateralis	6.64	Persephona mediterranea	4.89	Acetes americanus	5.46	Anchoa mitchilli	3.41	Lysiosquilla empusa
	3.51	Calliactis tricolor	4.57	Arius felis	4.20	Peprilus burti	4.99	Lysiosquilla empusa	2.53	Calliactis tricolor
	2.89	Polydactylus octonemus	2.53	Lysiosquilla empusa	3.57	Polydactylus octonemus	2.81	Arius felis	2.29	Arius felis
	2.59	Leiostomus xanthurus	2.09	Polydactylus octonemus	2.38	Trichiurus lepturus	2.25	Persephona mediterranea	2.05	Lolliguncula brevis
	2.15	Trichiurus lepturus	1.78	Prionotus rubio	1.57	Libinia dubia	2.18	Pagurus pollicaris	2.01	Larimus fasciatus
	2.06	Arius felis	1.28	Stellifer lanceolatus	1.19	Citharichthys spilopterus	1.97	Urophycis floridanus	1.20	Leiostomus xanthurus
	1.66	Larimus fasciatus	1.05	Thais haemastoma			1.81	Polinices duplicatus	1.11	Hepatus epheliticus
	1.08	Symphurus plagiusa	1.05	Larimus fasciatus			1.55	Hepatus epheliticus	1.06	Micropogon undulatus
							1.31	Acetes americanus	1.50	Symphurus plagiusa
MAY	(3)		(2)		(2)		(3)		(2)	
	73.30	Callinectes similis	60.15	Callinectes similis	22.94	Anchoa mitchilli	46.73	Callinectes similis	33.56	Anchoa mitchilli
	8.32	Penaeus setiferus	13.59	Penaeus setiferus	17.87	Cynoscion arenarius	12.75	Micropogon undulatus	14.05	Callinectes similis
	46.1	Mulinia lateralis	10.79	Micropogon undulatus	14.29	Cynoscion nothus	10.84	Anchoa mitchilli	8.55	Polydactylus octonemus
	4.24	Micropogon undulatus	5.71	Anchoa mitchilli	13.39	Callinectes similis	7.13	Acetes americanus	7.60	Cynoscion nothus
	2.47	Anchoa mitchilli	3.19	Polydactylus octonemus	9.06	Micropogon undulatus	4.31	Cynoscion arenarius	6.08	Cynoscion arenarius
	1.25	Polydactylus octonemus	2.42	Cynoscion nothus	5.28	Polydactylus octonemus	2.67	Cynoscion nebulosus	4.87	Penaeus setiferus
	1.19	Stellifer lanceolatus			4.67	Peprilus burti	2.46	Polydactylus octonemus	4.85	Micropogon undulatus
	1.12	Calliactis tricolor			2.90	Calliactis tricolor	2.15	Penaeus setiferus	4.49	Lolliguncula brevis
					2.62	Penaeus setiferus	1.37	Cynoscion nothus	3.17	Peprilus burti
					2.56	Lysiosquilla empusa	1.29	Peprilus burti	2.84	Calliactis tricolor
							1.22	Lysiosquilla empusa	2.07	Acetes americanus
							1.07	Symphurus plagiusa		

Table F-36 (continued)

Month	Big Hill cluster: Big Hill		Big Hill cluster: Big Hill Control		West Hackberry cluster: Black Bayou	West Hackberry cluster: West Hackberry	West Hackberry cluster: West Hackberry Control
JUN		(3)		(2)	NO SAMPLES	NO SAMPLES	NO SAMPLES
	99.09	Paranthus rapiformis	97.86	Paranthus rapiformis			
			1.16	Chloroscombrus chrysurus			
JUL		(3)		(2)	NO SAMPLES	NO SAMPLES	NO SAMPLES
	84.82	Chloroscombrus chrysurus	39.02	Mulinia lateralis			
	6.48	Lolliguncula brevis	36.10	Chloroscombrus chrysurus			
	1.89	Penaeus aztecus	22.34	Anadara ovalis			
	1.75	Peprilus paru	1.06	Lolliguncula brevis			
	1.26	Mulinia lateralis	1.06	Lysiosquilla empusa			
AUG		(3)		(2)	NO SAMPLES	NO SAMPLES	NO SAMPLES
	19.60	Mulinia lateralis	79.16	Chloroscombrus chrysurus			
	15.97	Micropogon undulatus	5.47	Lolliguncula brevis			
	10.58	Cynoscion arenarius	4.73	Mulinia lateralis			
	6.21	Polydactylus octonemus	1.93	Anadara ovalis			
	5.59	Lolliguncula brevis	1.48	Penaeus aztecus			
	5.31	Anadara ovalis	1.01	Acetes americanus			
	5.13	Acetes americanus	1.01	Micropogon undulatus			
	4.28	Persephona mediterranea					
	3.19	Abra aequalis					
	2.11	Lysiosquilla empusa					
	1.57	Penaeus aztecus					
	1.45	Portunus gibbesi					
	1.30	Nassarius acutus					
	1.14	Penaeus setiferus					
SEP		(3)		(2)	NO SAMPLES	NO SAMPLES	NO SAMPLES
	49.35	Larval sciaenids	44.62	Acetes americanus			
	9.15	Aurelia aurita	19.93	Mulinia lateralis			
	7.65	Mulinia lateralis	5.31	Anchoa mitchilli			
	5.42	Chloroscombrus chrysurus	5.29	Chloroscombrus chrysurus			
	5.01	Abra aequalis	4.13	Polinices duplicatus			
	4.07	Penaeus setiferus	3.76	Bunodactis texaensis			
	3.22	Lysiosquilla empusa	2.39	Lysiosquilla empusa			
	2.42	Micropogon undulatus	1.94	Persephona mediterranea			
	2.28	Persephona mediterranea	1.91	Larval sciaenids			
	1.94	Cynoscion arenarius	1.59	Calliactis tricolor			
	1.31	Anadara ovalis	1.15	Thais haemastoma			
	1.03	Chaetodipterus faber	1.07	Chione cancellata			
			1.06	Penaeus aztecus			
			1.06	Penaeus setiferus			
OCT		(3)		(2)	NO SAMPLES	NO SAMPLES	NO SAMPLES
	43.11	Lolliguncula brevis	53.99	Lolliguncula brevis			
	30.66	Sphaeroma quadridentatum	29.85	Acetes americanus			
	12.75	Acetes americanus	6.45	Anchoa mitchilli			
	7.35	Anchoa mitchilli	2.04	Persephona mediterranea			
	1.34	Abra aequalis	1.80	Mulinia lateralis			
	1.19	Penaeus setiferus					
	1.18	Portunus gibbesi					

[1]Only species comprising 1% or more of the community are shown.

[2]Number in parentheses is the number of samples on which composition is based.

Table F-37. Results of factor analyses for major trawl groups in the Texoma region (cruises 1 through 8)

Species name	Principal loading	Loading on other factors	Seasonality (cruise)	Site
Factor 1				
Peprilus paru	0.84		3	W>E
Larval sciaenids	0.79		3,4	W>E
Chiropsalmus quadrumanus	0.67	7(0.42)	3	W=E
Syngnathus louisianae	0.58		2,3,4,6	
Portunus gibbesi	0.48		3	E>W
Factor 2				
Callinectes similis	0.79		3,8	E=W
Polydactylus octonemus	0.76		7,8	E=W
Cynoscion arenarius	0.59		1,2,3,7,8	E>W
Paranthus rapiformis	0.62		8(low #, all cr)	W=E
Peprilus burti	0.68		(5,7) 8	E>W
Mulinia lateralis	0.46		7,8	W>>E
Micropogon undulatus	0.35	3(0.39)	1 2 (3 4)	W>E
		7(0.33)	(5 6) (7=8)	
Factor 3				
Urophycis floridanus	0.67		6 7	E>W
Arius felis	0.58		2,3 7	E>W
Larimus fasciatus	0.61		3,4,6,8, 7	W>E
Cynoscion nothus	0.52	6(0.36)	1,2,3,4 7 8	E>W
Symphurus plagiusa	0.39	3(0.51)	2=3 4 5 6 7 8	E>W
Persephona mediterranea	0.47	4(0.36)	6 7 8	W>E
Pagurus policaris	0.39	4(0.38)	2 7	E>W
Hepatus epheliticus	0.38	4(0.42)	3,5,6, 7 8	E>W
Trichiurus lepturus	0.34		3,4 7 8	W>E
Micropogon undulatus	0.39	2(0.35)	1 2 (3 4)	W>E
		7(0.33)	(5 6) (7=8)	
Thais haemastoma	0.37		1,6 7	W>E
Polinices duplicatus	0.47		5=7	W>E
Factor 4				
Polyonyx gibbesi	0.74		6	E
Neopanope texana	0.69		6	E
Chaetopterus variopedatus	0.61		6-7, 8	E>W
Pinnixa chaetopterana	0.52		5,6	E
Leptocephalus larvae	0.46		(4 5) 6	
Hepatus epheliticus	0.42	3(0.38)	3,5,6, 7 8	E>W
Pagurus pollicaris	0.38	3(0.39)	2 7	E>W
Pesephona mediterranea	0.36	3(0.47)	6 7 8	W>E

Table F-37 (continued)

Species name	Principal loading	Loading on other factors	Seasonality (cruise)	Site
Factor 5				
Portunus sayi	0.87	8(0.30)	1 2	W>E
Sicyonia dorsalis	0.80	8(0.31)	1 2 3	W=E
Xiphopenaeus kroyeri	0.75		1 2 (3 4)	W>>E
Stellifer lanceolatus	0.62	7(0.34)	1 2=3 4,8	W>E
Acetes americanus	0.54		1 2 (3 4) (7,8)	W=E
Factor 6				
Sphoeroides parvus	0.73		2,3	E>W
Penaeus aztecus	0.67		2 3(7,8)	W>E
Bagre marinus	0.44		1,2	E=W
Symphurus plagiusa	-0.39	3(0.51)	2=3 4 5 6 7 8	E>W
Cynoscion nothus	0.36	3(0.52)	1 2 3 4 7 8	E>W
Chloroscombrus chrysurus	0.36	5(-0.31)	1 2,3	W>>E
Opisthonema oglinum	0.30		1 2	E>W
Acetes americanus	0.30	5(0.54)	1 2 (3 4) (7,8)	E=W
Factor 7				
Ophidion welshi	0.53		1 2 3=5=8	E>W
Sicyonia brevirostris	0.57		(1=3) 4	W>E
Porichthys porosissimus	0.48		5 6 7 8	W>E
Penaeus setiferus	0.52		1=2 (3 4) 5 6 7 8	W>E
Micropogon undulatus	0.33	2(0.35) 3(0.39)	3 4(5 6) (7=8)	W=E
Stellifer lanceolatus	0.33	5(0.62)	1 2=3 4,8	W>E
Cynoscion nebulosus	0.32		1 2=3, 8	E>W
Chiropsalmus quadrumanus	0.42	1(0.67)	3	W=E
Factor 8				
Libinia dubia	0.48		1 2=3 4 5 6 7 8	W=E
Sicyonia dorsalis	0.31	5(0.80)	1 2 3	W=E
Portunus sayi	0.31	5(0.87)	1 2	WJE
Nuculana concentrica	-0.44		3 4=5=6=7	WJE
Anadara olivaris	-0.40		1=4=5=6 7 8	WJJE
Cirolana parva	-0.35	1(0.30)	2=3 4	WJE

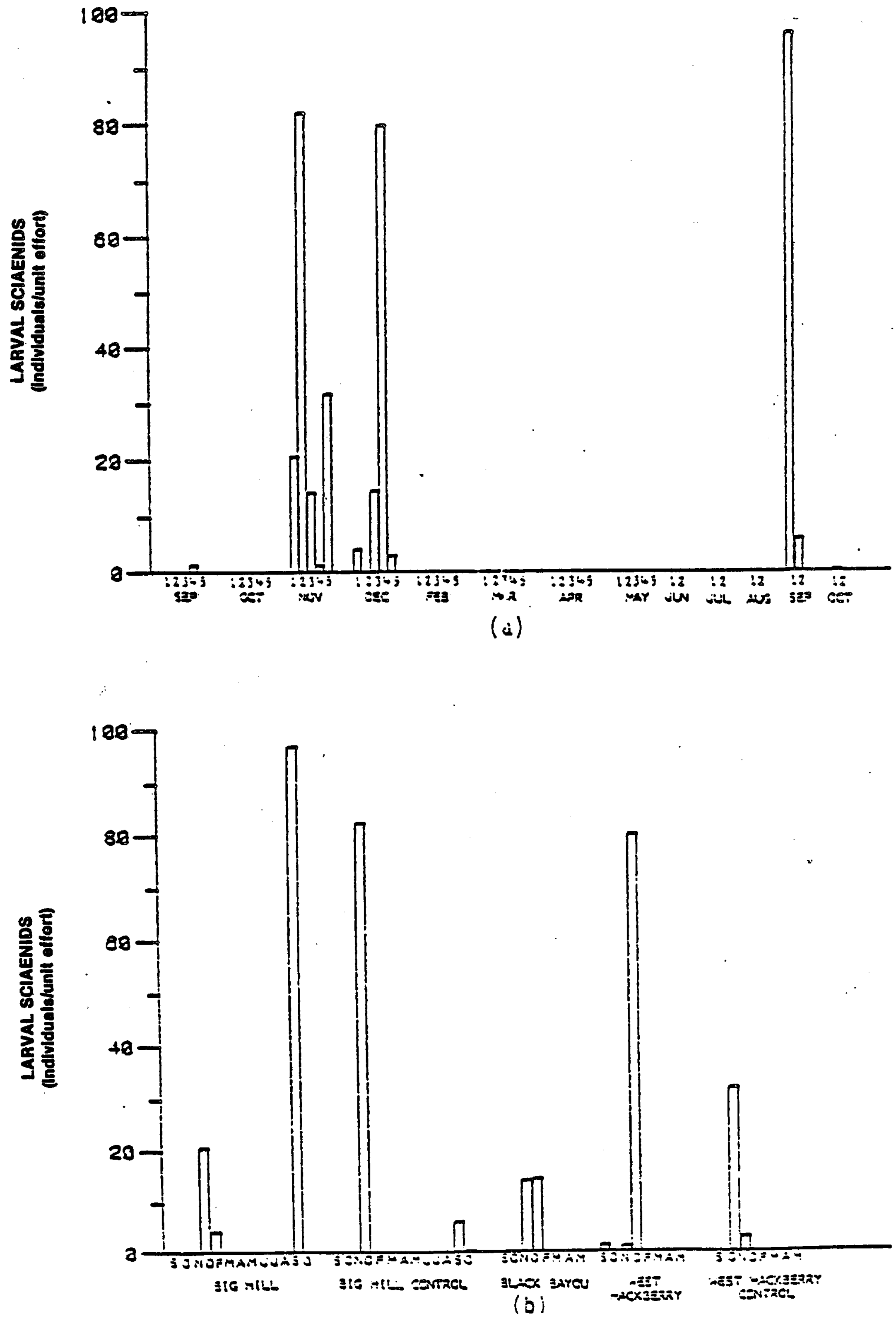


Figure F-74. Abundance of larval sciaenids (individuals/unit effort) at the Texoma sites in 1977 and 1978: (a) by cruise, (b) by site. Source: Comiskey et al. (1979).

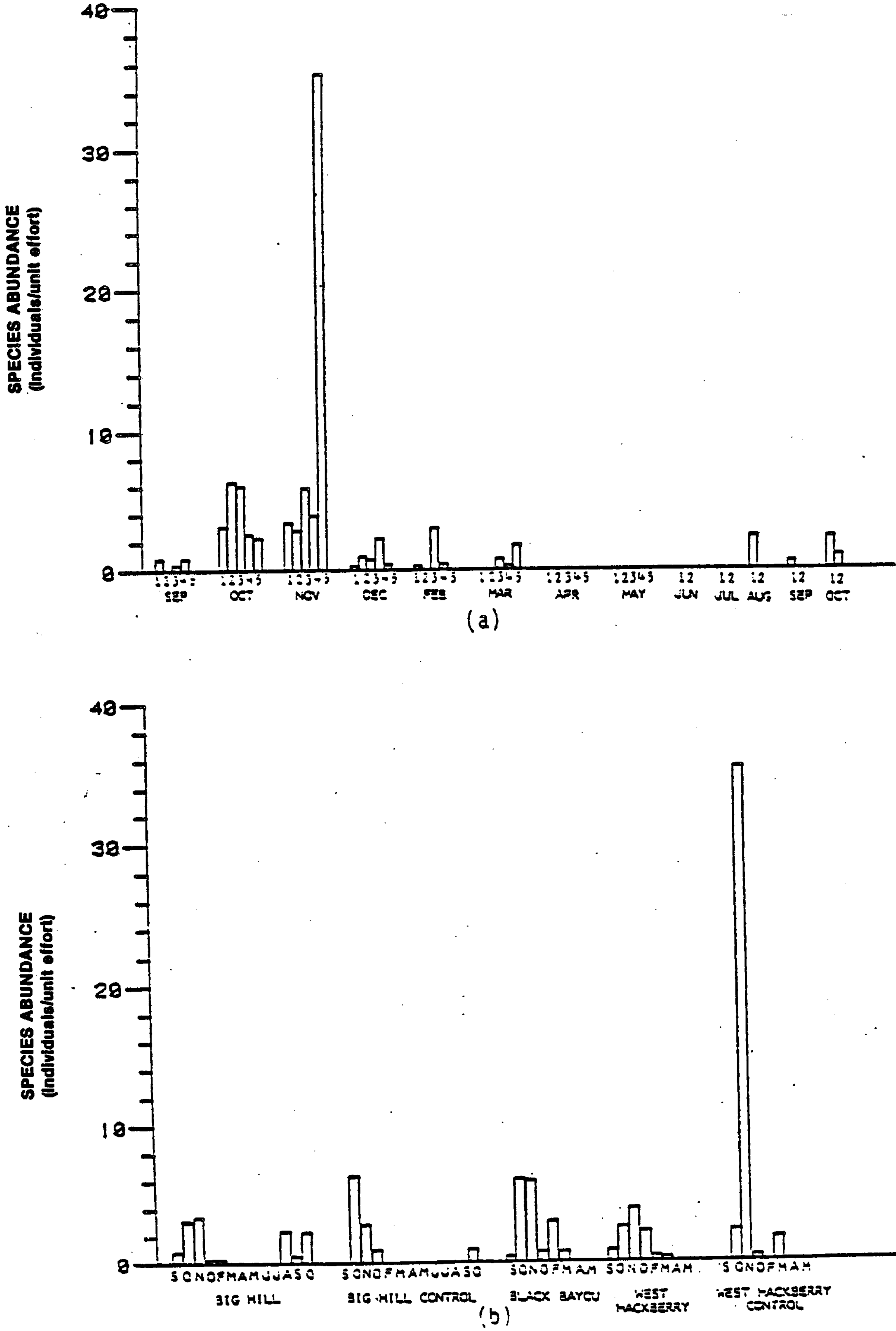


Figure F-75. Abundance of Portunus gibbesi (individuals/unit effort) at the Texoma sites in 1977 and 1978: (a) by cruise, (b) by site. Source: Comiskey et al. (1979).

Species loadings on factor 2 displayed a temporal trend characterized by highest densities in May. Six species exhibited salient loadings above 0.40 on factor 2. These were Callinectes similis (0.79), Polydactylus octonemus (0.76), Cynoscion arenarius (0.59), P. rapiformis (0.62), P. burti (0.68), and M. lateralis (0.46). Paranthus rapiformis was collected almost exclusively in May and June. This was followed by a 4-month period with no catch. One explanation of this occurrence might be increased vulnerability to the trawl with a change in behavior. P. rapiformis is a burrowing anemone with low susceptibility to trawls. However, these organisms may emerge from the substrate during periods of low dissolved oxygen as observed on the June sampling cruise. This would also explain their disappearance from the samples when more normal oxygen levels were restored. Shrimp have also been observed changing behavior patterns in the presence of low dissolved oxygen (Huddart and Arthur, 1971).

P. octonemus and C. similis both displayed spring-fall distributions. Low catches of P. octonemus during June and July probably reflect low dissolved oxygen values. Both taxa loaded heavily on factor 2 as a result of their predominance during May.

Micropogon undulatus exhibited a loading of 0.35 on factor 2 and was also significant on factors 3 and 7 as a result of its ubiquitous, but seasonally fluctuating, occurrences (Fig. F-76). The large catches in April and May were the result of spring recruitment of young-of-the-year croaker to the offshore region. No M. undulatus were captured in June at the Big Hill sites during an anoxic period. Overall abundance appeared lowest at the West Hackberry control site.

C. arenarius displayed a broad, variable distribution much like that of M. undulatus with peak abundance in the spring (May) due to new recruits. A second peak in the fall occurred with an influx of young adult fish. Low numbers in June and July may be the result of poor water quality, low dissolved oxygen, and high temperature.

A large group of species was characterized by factor 3 (see Table F-37). All occurred primarily during the April cruise. Loadings on this factor were not as strong as for the previous two factors. Six species had loadings above 0.40. These were Urophycis floridanus, Arius felis, Larimus fasciatus, Polinices duplicatus, Persephona mediterranea, and Cynoscion nothus. Examination of Fig. F-77 reveals the bimodal distribution of C. nothus, with a reduced abundance in February and March and during the summer at the Big Hill site.

Factor 4 loadings, along with those for factors 2 and 3, clearly demonstrate the dynamic nature of the winter-spring communities at the Texoma sites. This factor was characterized by a large group of invertebrates with common spring occurrences. These include P. gibbesi, Neopanope texana, Chaetopterus variopedatus, and Pinnixa chaetopterana. Three taxa had loadings greater than 0.38 on factor 3. This group defines an assemblage most common to the eastern sites in March.

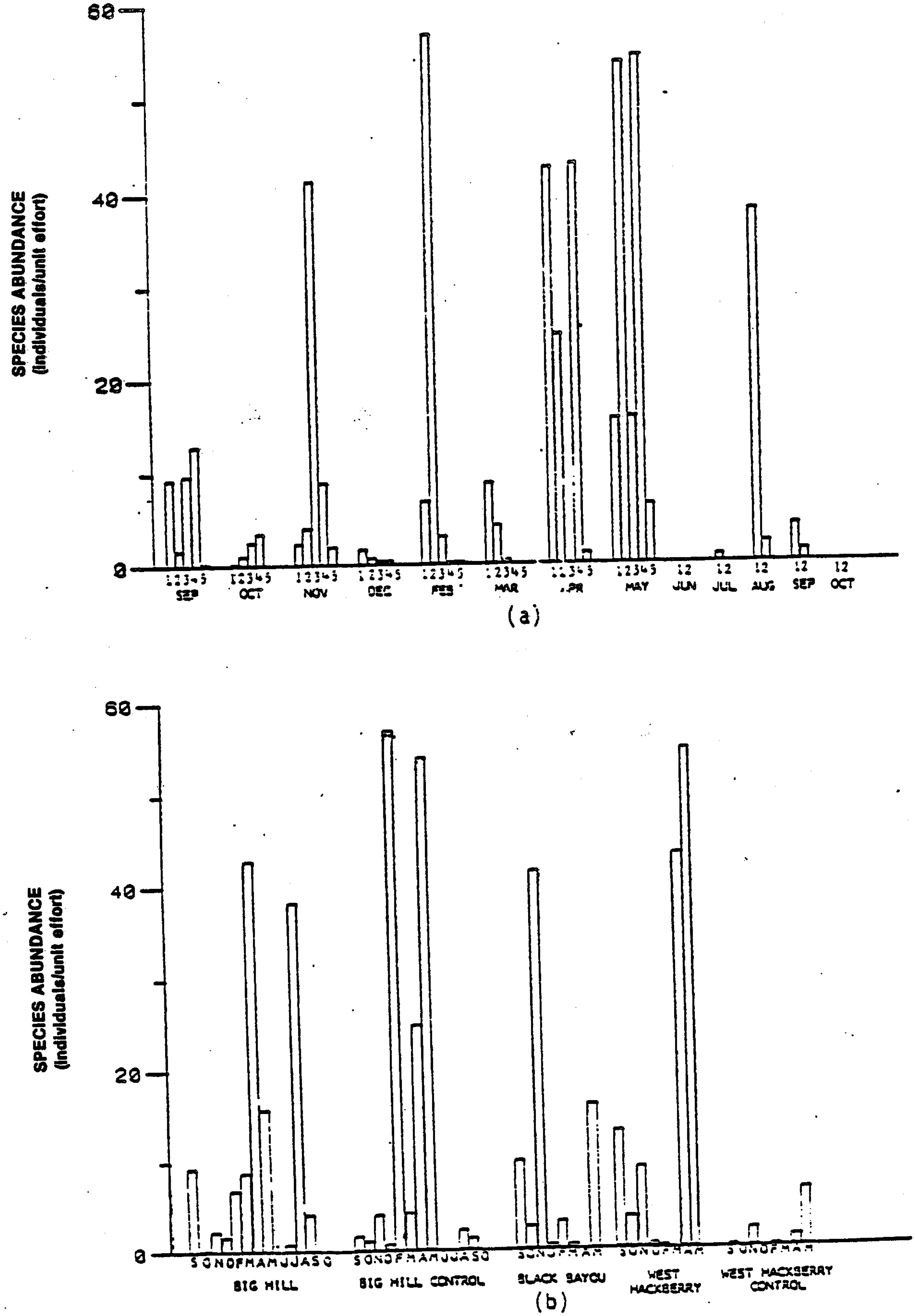


Figure F-76. Abundance of Micropogon undulatus (individuals/unit effort) at the Texoma sites in 1977 and 1978: (a) by cruise, (b) by site. Source: Comiskey et al. (1979).

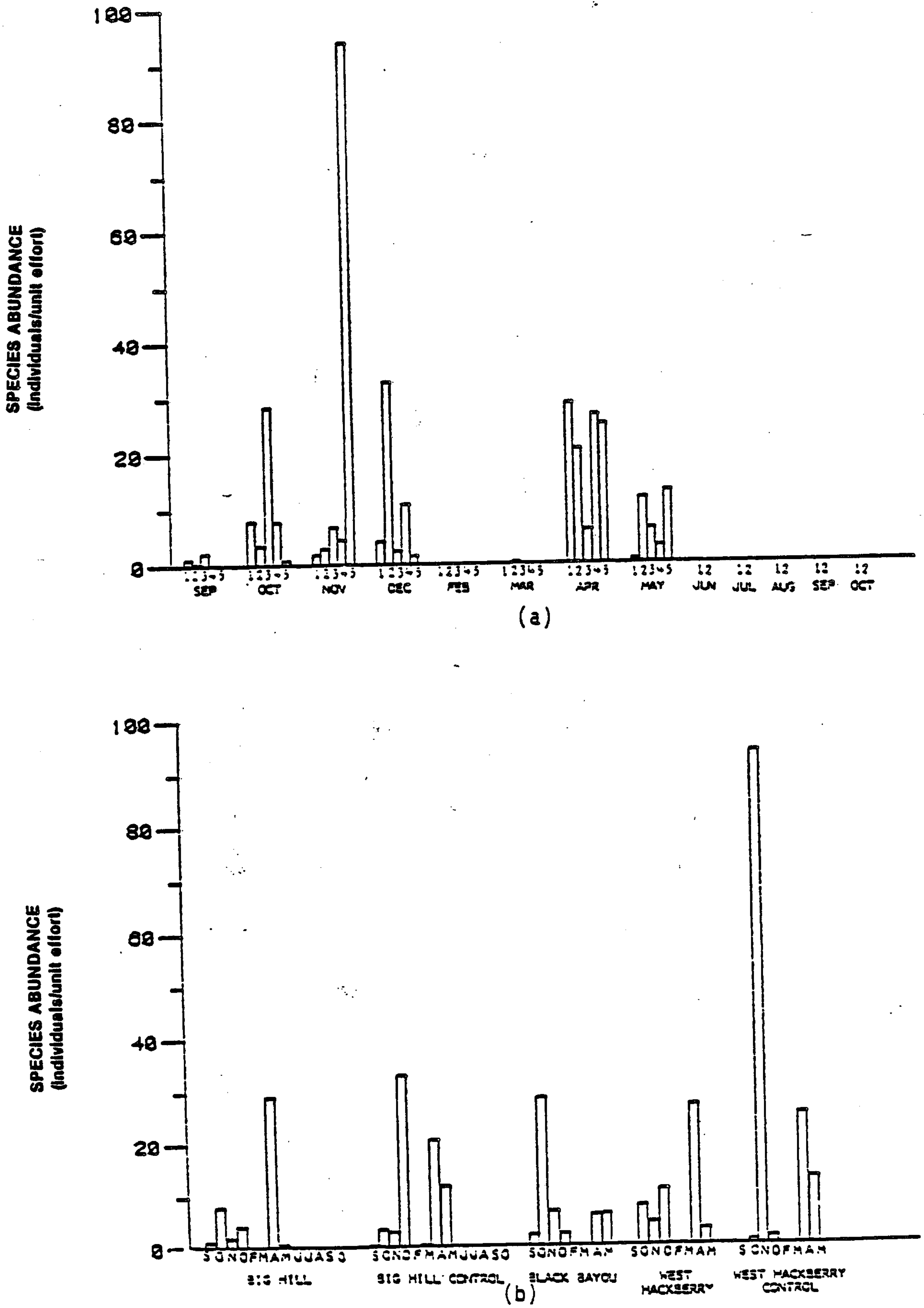


Figure F-77. **Abundance of <u>Cynoscion</u> <u>nothus</u> (individuals/unit effort) at the Texoma sites in 1977 and 1978: (a) by cruise, (b) by site. Source: Comiskey et al. (1979).**

A September to October group was described by factor 5. Five taxa were characterized by scores above 0.54. These were Portunus sayi (0.87), Sicyonia dorsalis (0.80), Xiphopenaeus kroyeri (0.75), Stellifer lanceolatus (0.62), and Acetes americanus (0.54). All were important members at the Big Hill sites. Abundance of Stellifer lanceolatus is shown in Fig. F-78. Peak catch occurred in October and November. A. americanus was collected primarily in the fall with a peak in October (Fig. F-79). The sea bob, X. kroyeri, exhibited a salient loading (0.75) on this factor. Examination of Fig. F-80 reveals that almost the entire catch was taken off Big Hill in fall 1977.

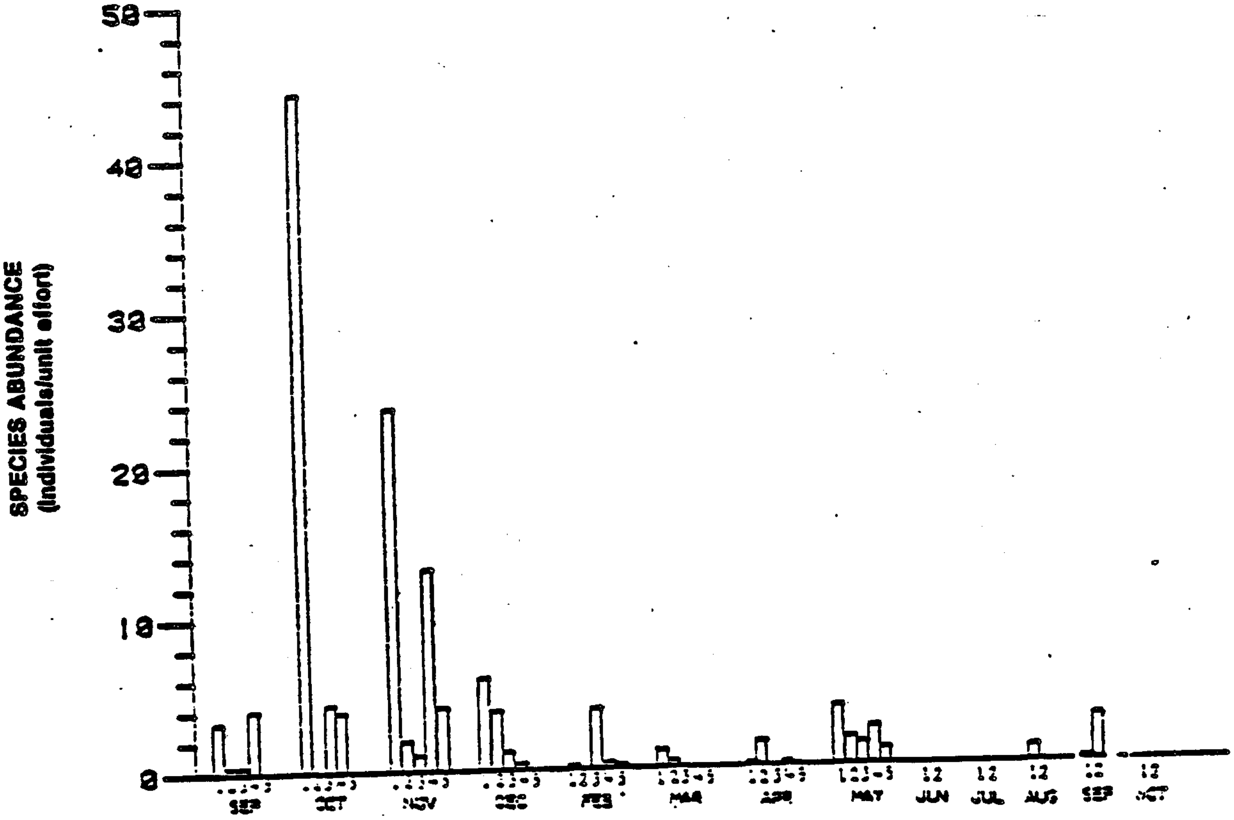
Factor 6 can be characterized as an early fall assemblage with greater dominance at the eastern sites. Three taxa, Sphoeroides parvus (0.73), Bagre marinus (0.44), and Penaeus aztecus (0.67), scored above 0.44. Two species, Symphurus plagiusa and C. nothus, were also characterized by factor 3, as well as the mixed-spring assemblage. These species appear to be seasonal migrants through the region during fall and spring periods.

Factor 7 describes a general assemblage of organisms that were consistently present throughout much of the study. Four species had salient loadings above 0.48. These were Ophidion welshi (0.53), Sicyonia brevirostris (0.57), Porichthys porosissimus (0.48), and Penaeus setiferus (0.52). The fact that P. setiferus was ubiquitous over space and time is consistent with the characterization of the diffuser area (30-ft contour) as the white shrimp grounds.

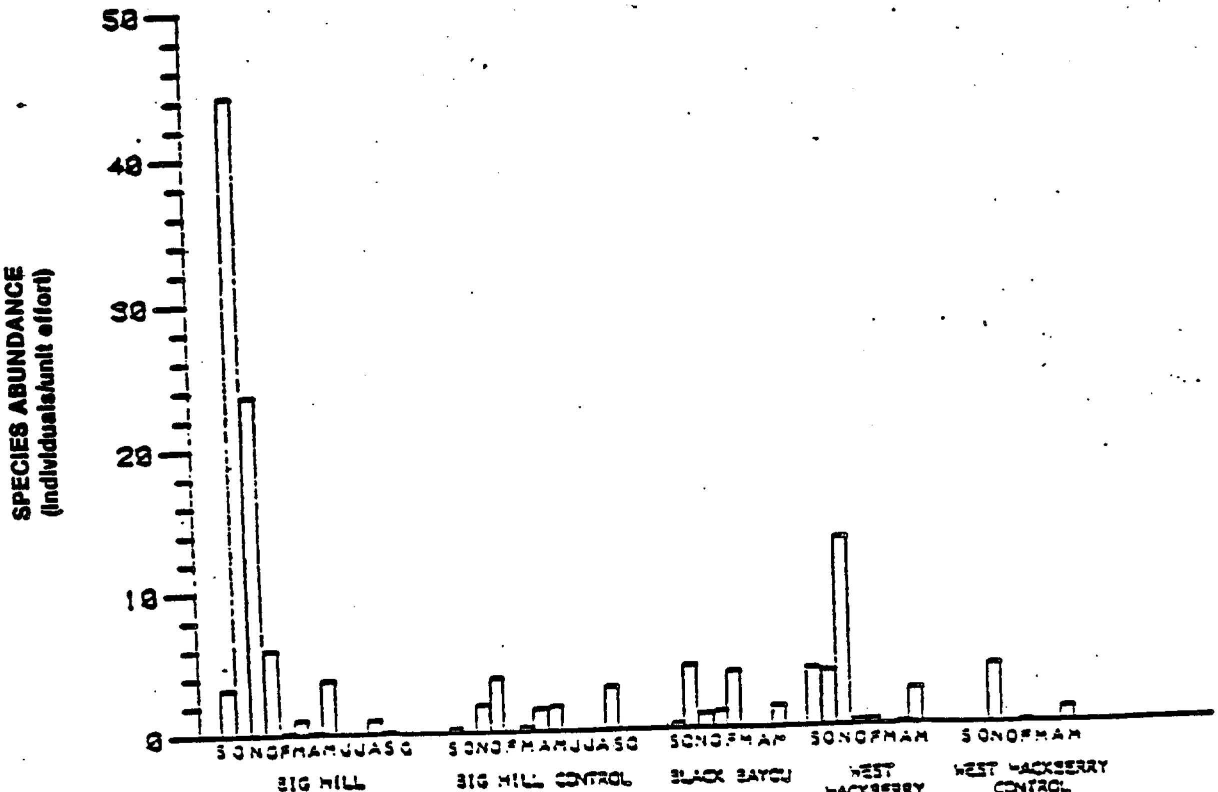
A second group of invertebrates, similar to those defined by factor 4 (east sites), were characterized by factor 8 for the western sites. Loadings were not strong, ranging from 0.30 to 0.48. Two taxa, S. dorsalis and P. sayi, had stronger loadings on factor 5, representing a peak fall (October) abundance. Three species, Nuculana concentrica, Anadara olivaris, and Cirolana parva, displayed negative loadings on factor 8 (see Table F-37). N. concentrica and A. olivaris both exhibited strong temporal (spring) trends. C. parva had a weak (0.30) loading on factor 1, which characterized a peak density for November through December.

For the period of analysis (September 1977 to May 1978), Chloroscombrus chrysurus was collected exclusively in the fall (Fig. F-81). During the remainder of the program, this species was captured in large numbers in summer at the Big Hill sites. Because of the absence of most demersal forms in June and the general lack of recovery in July, seasonal migration patterns are somewhat masked. In July, most of the trawl community was made up of C. chrysurus and molluscs. C. chrysurus was not present in December through June, making a sudden appearance in July and declining through September and into October. The low numbers in October were consistent for both years. This species is basically a seasonal member of the community. Gosselink et al. (1979) report C. chrysurus as a common member of shrimp trawl catches in summer months.

P. setiferus, which showed consistent numbers (6 to 21 individuals/unit effort) from September through May, disappeared in June and did not recover until September (Fig. F-82), following the normal pattern of

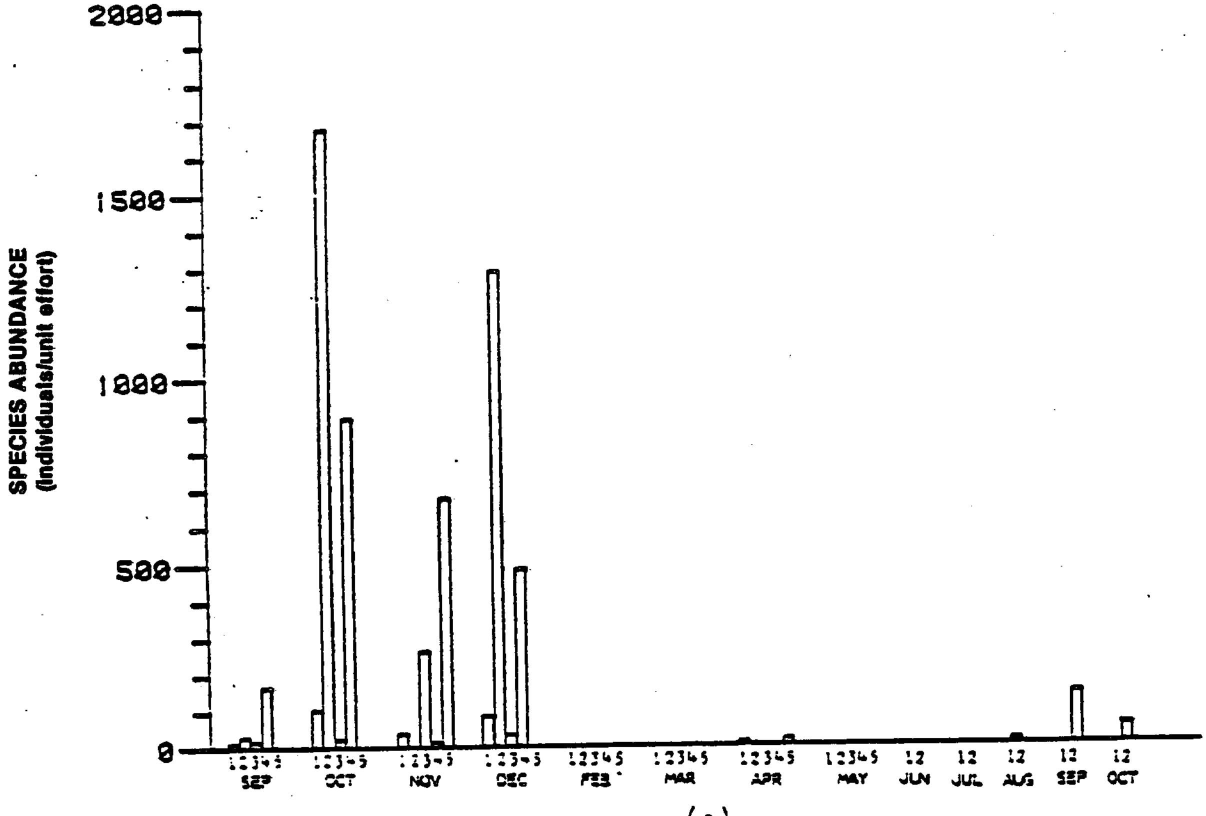


(a)

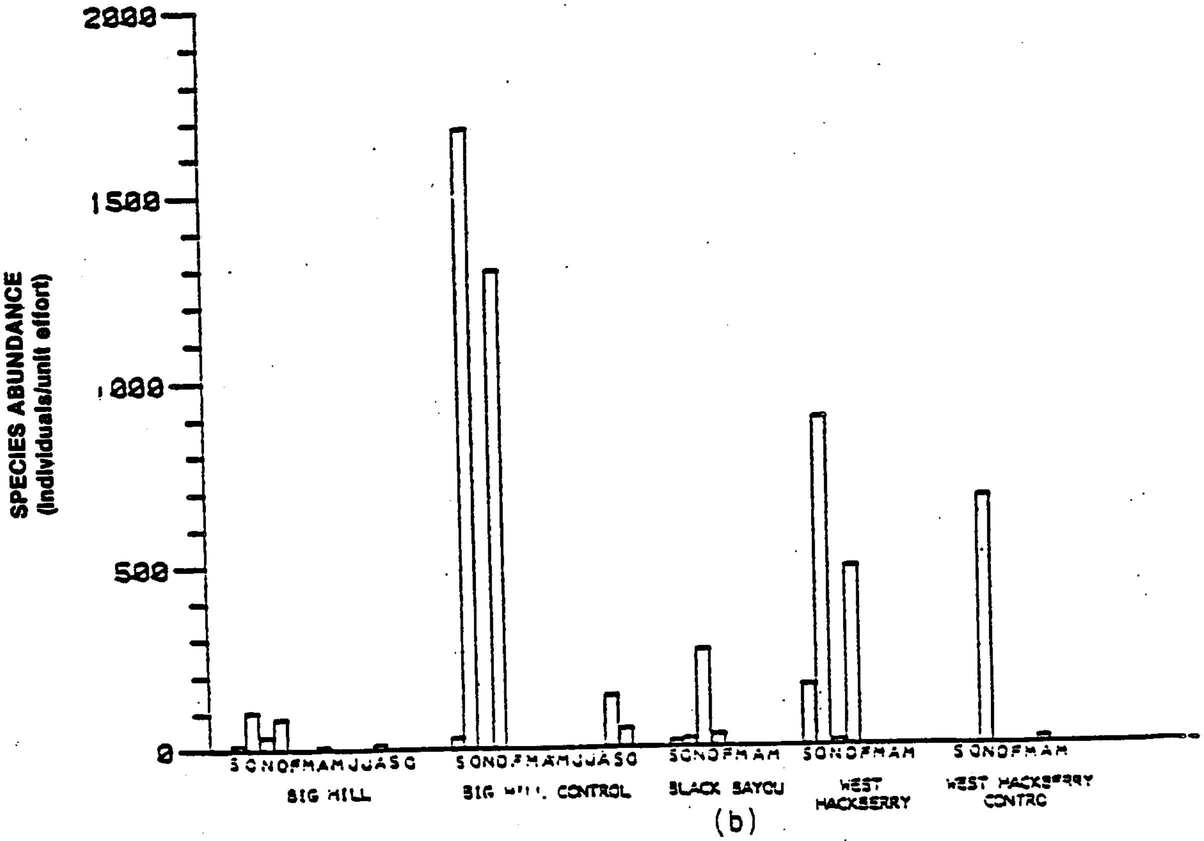


(b)

Figure F-78. **Abundance of Stellifer lanceolatus (individuals/unit effort) at the Texoma sites in 1977 and 1978: (a) by cruise, (b) by site. Source: Comiskey et al. (1979).**



(a)



(b)

Figure F-79. **Abundance of <u>Acetes</u> <u>americanus</u> (individuals/unit effort) at the Texoma sites in 1977 and 1978: (a) by cruise, (b) by site. Source: Comiskey et al. (1979).**

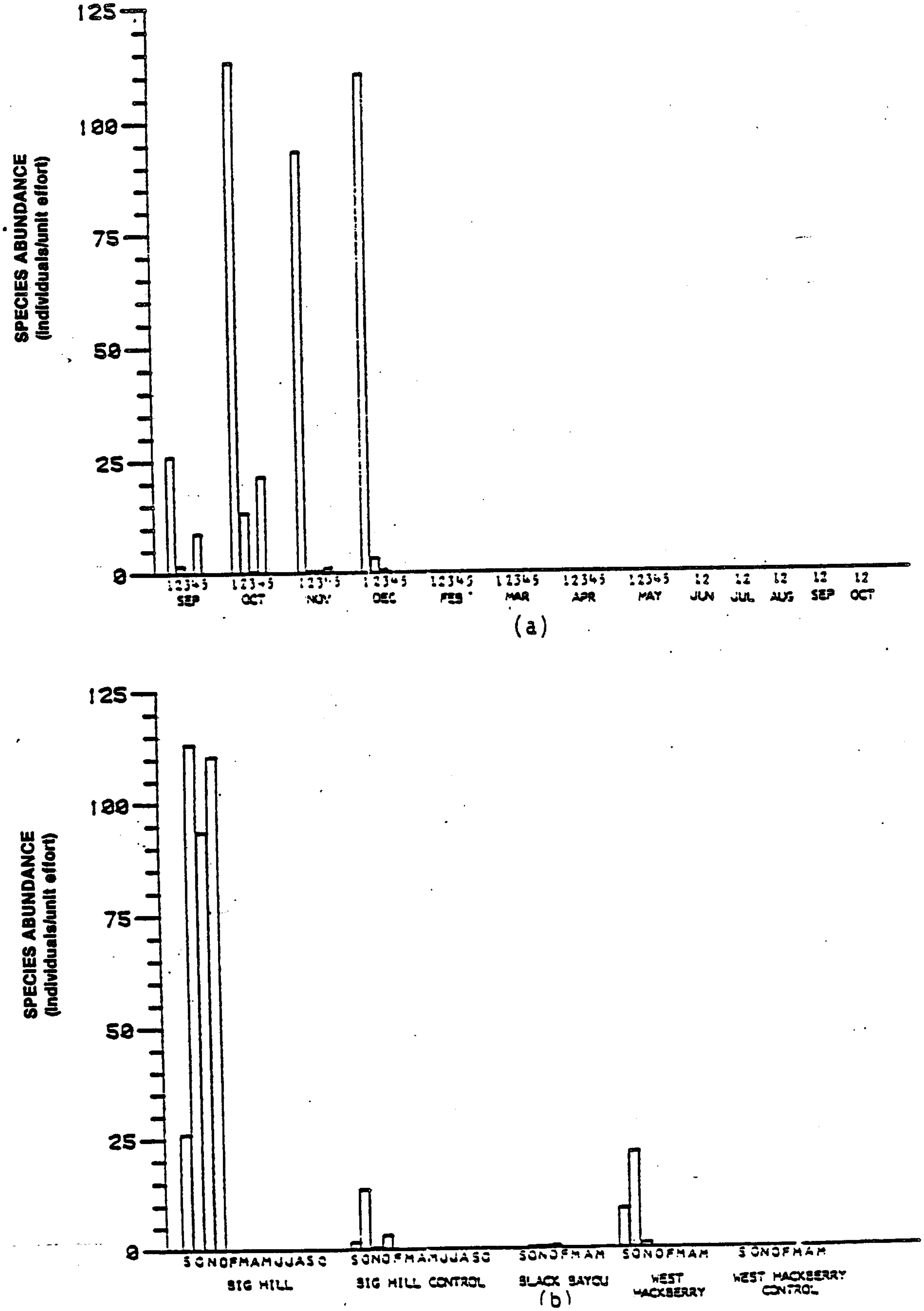
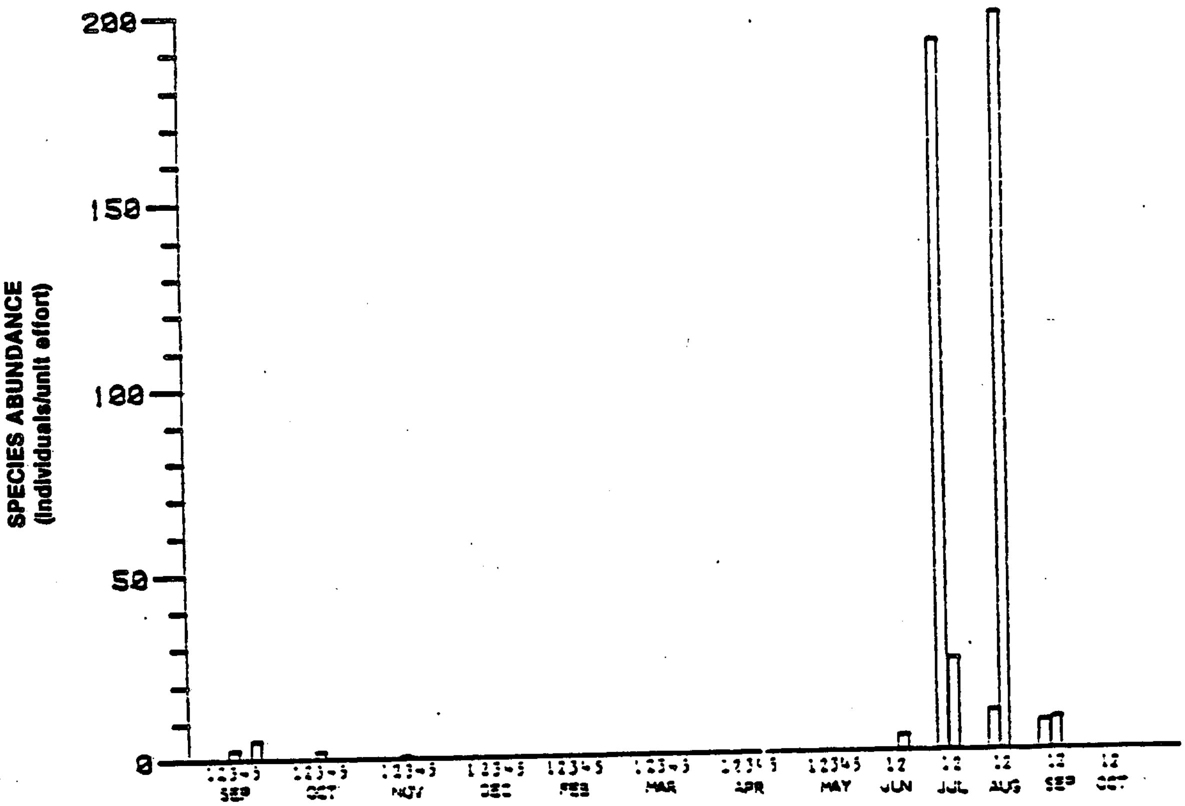
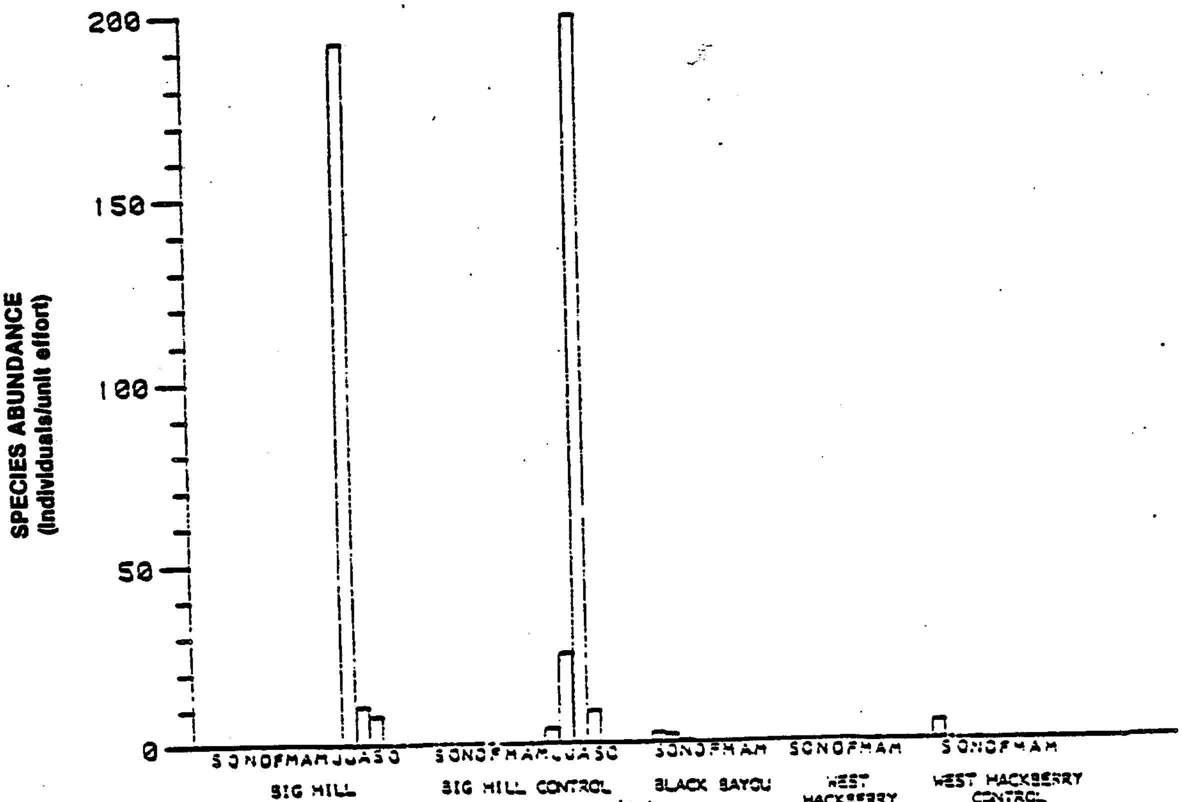


Figure F-80. **Abundance of Xiphopenaeus kroyeri (individuals/unit effort) at the Texoma sites in 1977 and 1978: (a) by cruise, (b) by site. Source: Comiskey et al. (1979).**



(a)



(b)

Figure F-81. **Abundance of Chloroscombrus chrysurus (individuals/unit effort) at the Texoma sites in 1977 and 1978: (a) by cruise, (b) by site. Source: Comiskey et al. (1979).**

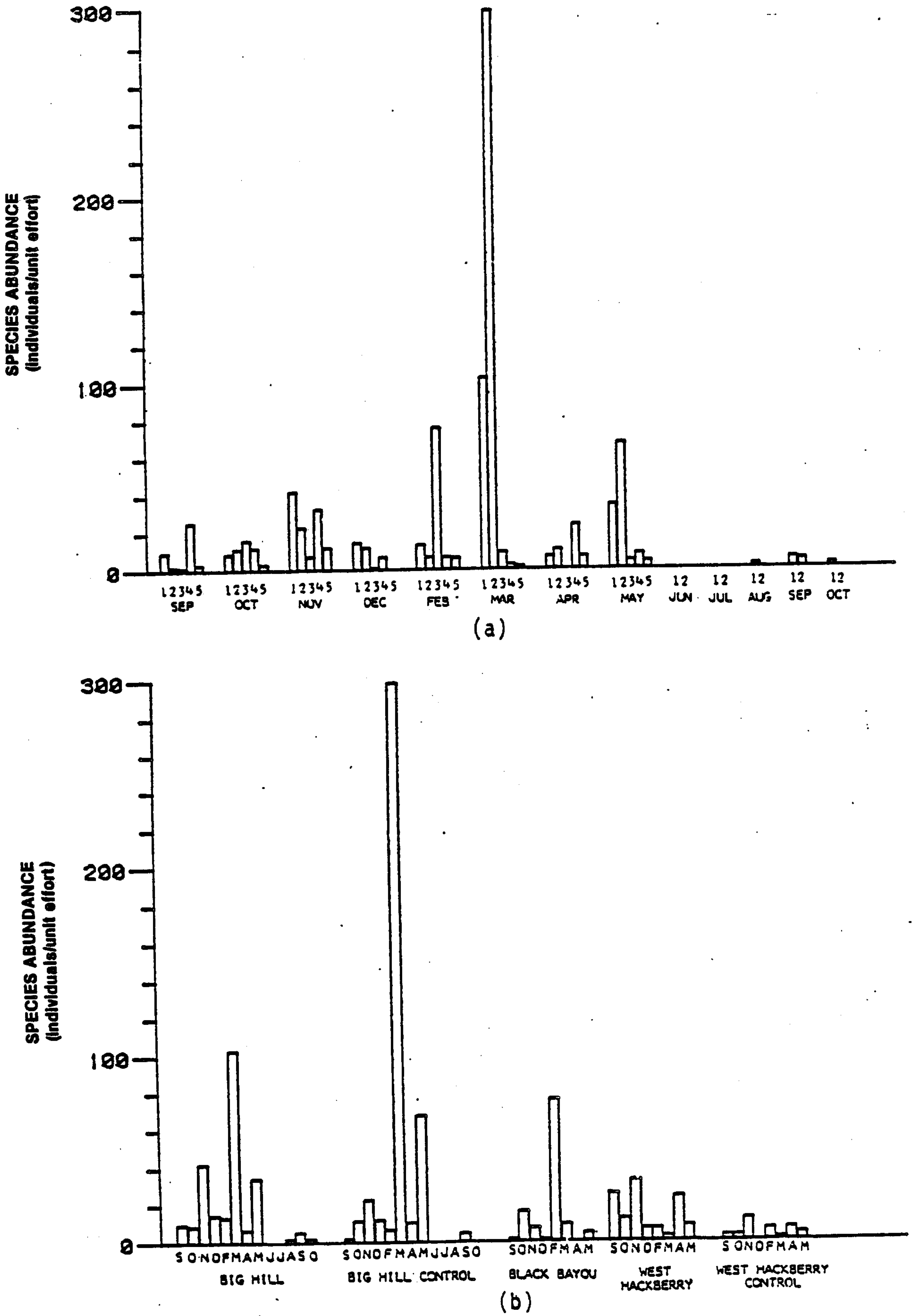
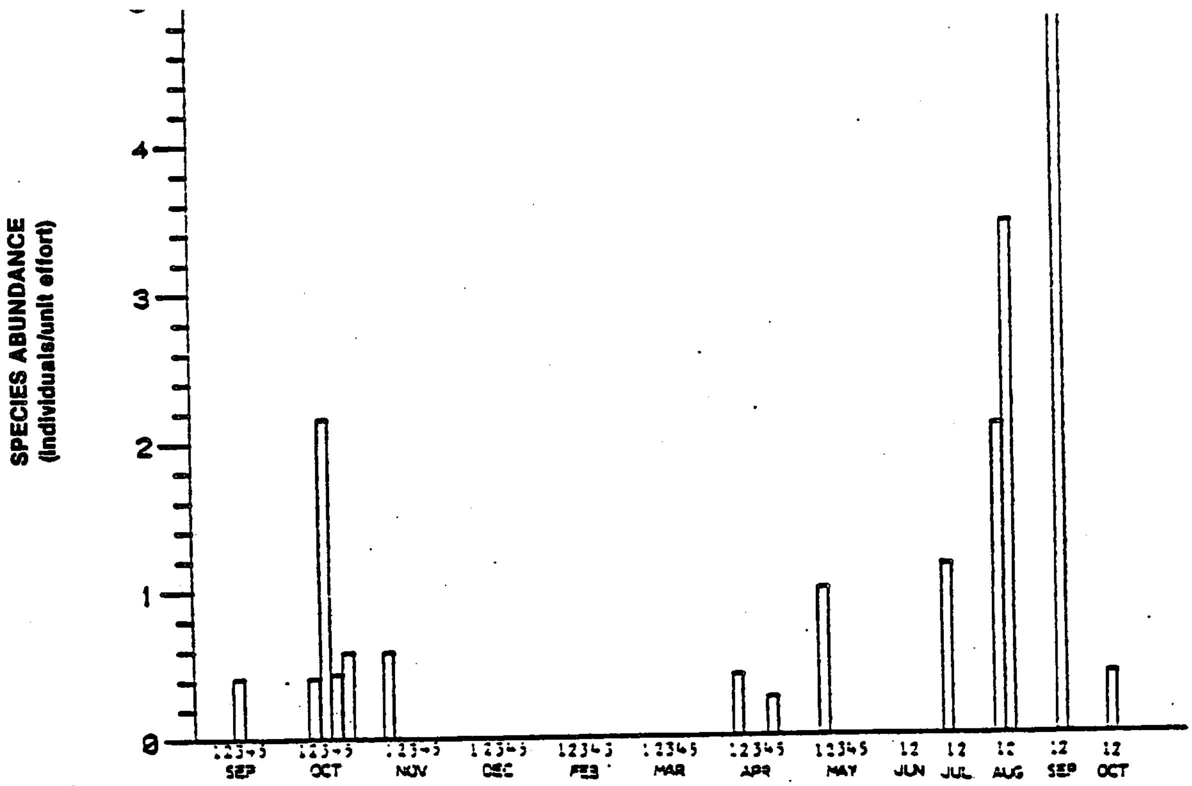
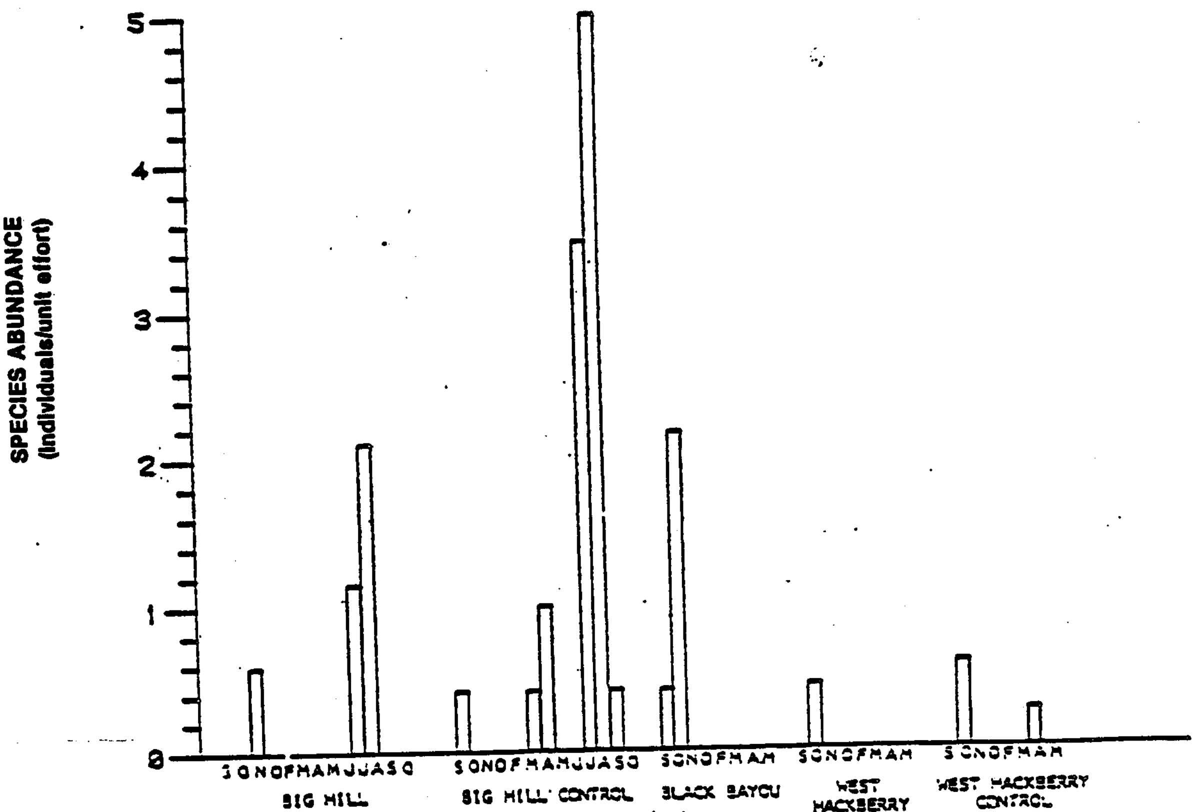


Figure F-82. **Abundance of <u>Penaeus</u> <u>setiferus</u> (individuals/unit effort) at the Texoma sites in 1977 and 1978: (a) by cruise, (b) by site.**



(a)



(b)

Figure F-83. Abundance of Penaeus aztecus (individuals/unit effort) at the Texoma sites in 1977 and 1978: (a) by cruise, (b) by site. Source: Comiskey et al. (1979).

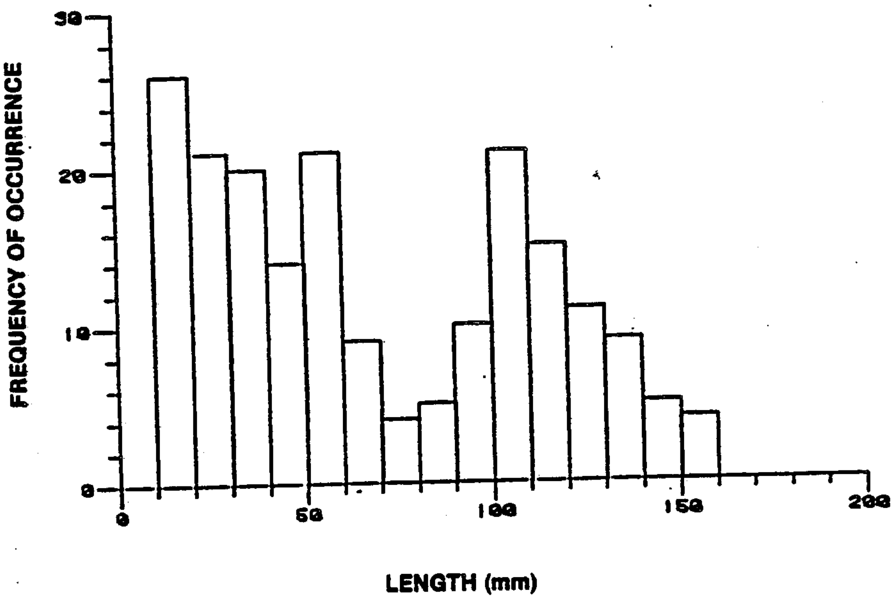
increased abundance in the fall due to recruitment from the estuaries. Large catches of P. setiferus were made in March at the Big Hill cluster of sites. P. aztecus (Fig. F-83) was completely absent from December through March and present in low numbers during spring, disappearing completely in June. Highest numbers were found in August and September. The increase in numbers during late summer (August and September) most probably represents a late recruitment of individuals from the estuaries. A similar situation was reported by Chittenden (1979) for the area off Freeport, Texas, during the same time. Xiphopenaeus kroyeri (see Fig. F-80), present from September through December (3 to 9 individuals/trawl), was absent during the rest of the study, failing to reappear in the fall of 1978. This member of the trawl community showed a great degree of site-specific and temporal variability. It was captured almost exclusively at the Big Hill site in the fall of 1977, suggesting a high degree of correlation with some site-specific environmental variable(s).

An important result evolving from the study was the presence of multiple size classes of white shrimp, ranging from 5 to 160 mm, in the near-shore area most of the year (Figs. F-84 to F-86). The presence of late postlarvae and juveniles in these waters during winter tends to verify that shrimp may overwinter in the near-shore Gulf or at times may use it as a nursery area. Mortality rates in the northwest Gulf are extremely high, approaching annual levels of 95 to 99 percent (Chittenden and McEachran, 1976). Few spawning-size individuals (>140 mm) were collected at the 3.5-mile site.

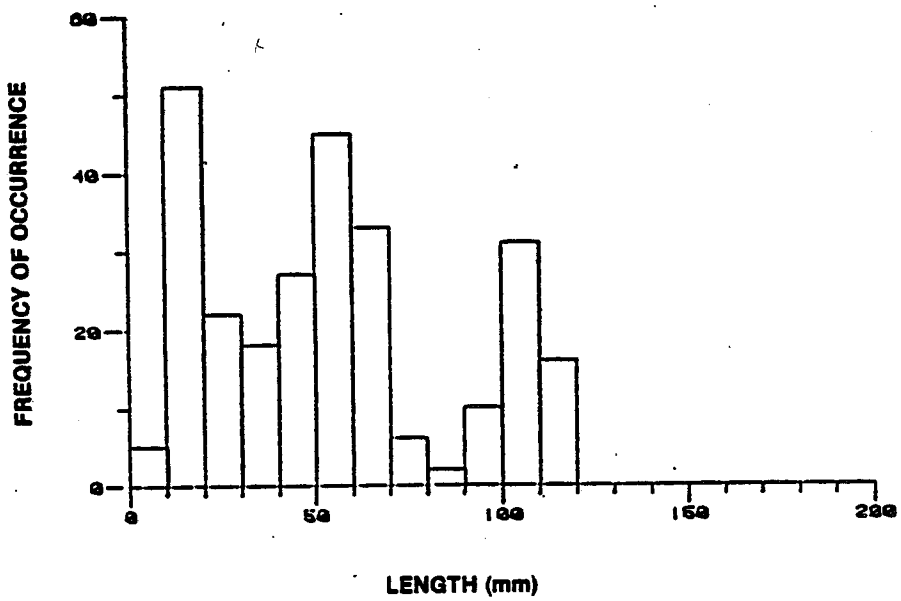
Demersal Community Transition

Although no site-specific data have been collected out to a 12.5-mile site, literature review reveals that the region probably represents the outer range of the white shrimp grounds and the transition zone into the brown shrimp grounds, a trend similar to that for Bryan Mound and Weeks Island sites (Chittenden, 1979; Landry and Armstrong, 1980).

Moving offshore to deeper, more stable environments, two factors exert pressure on nekton community composition. Distance from estuarine nursery grounds places a practical limit on the outer range of spawning grounds for most estuarine-dependent taxa. Second, young of most taxa are generally recruited at more shallow depths than those at which they spawn (Metzbower et al., 1980). Thus, juveniles of the more stable offshore brown shrimp grounds environment are often recruited within the outer range of the white shrimp grounds. Beyond these generalities, the occurrence of an individual, school, or shoal is often directly influenced by environmental variables such as temperature, salinity, nutrients, turbidity, and dissolved oxygen. Common members of the brown shrimp community are presented in Table F-38. Brown shrimp, long-spine porgy, lizardfish, and searobins are often abundant in the transitional region during late summer and fall (Chittenden, 1979; Comiskey et al., 1980; Landry and Armstrong, 1980).

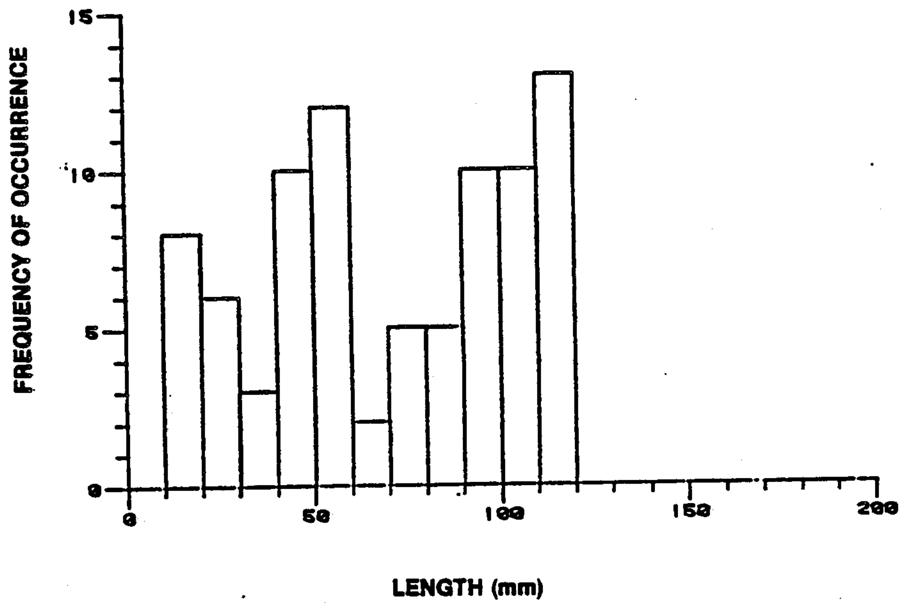


(a)

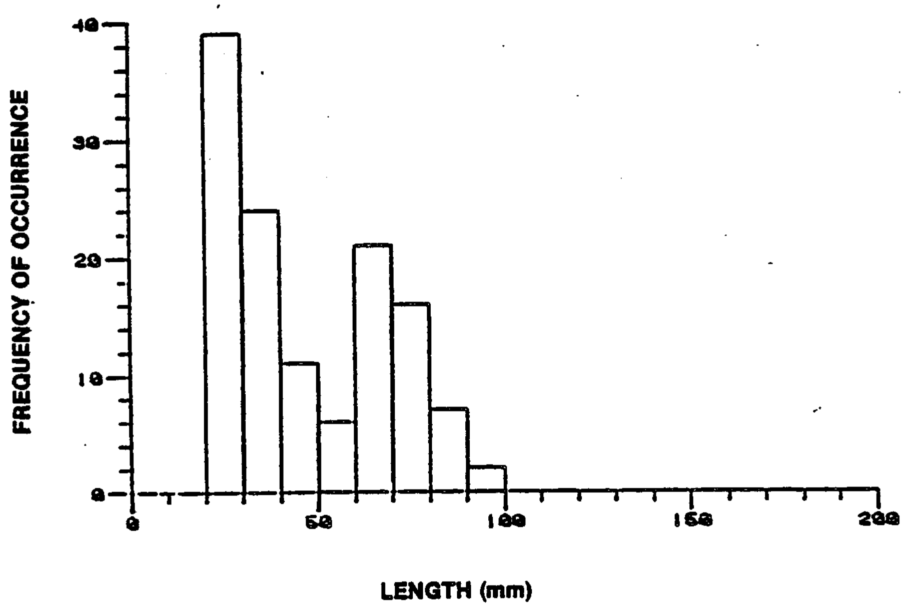


(b)

Figure F-84. Length frequency histograms for Penaeus setiferus collected across the Texoma sites: (a) October 1977, (b) November 1977.



(a)



(b)

Figure F-85. Length frequency histograms for Penaeus setiferus collected across the Texoma sites: (a) December 1977, (b) February 1978.

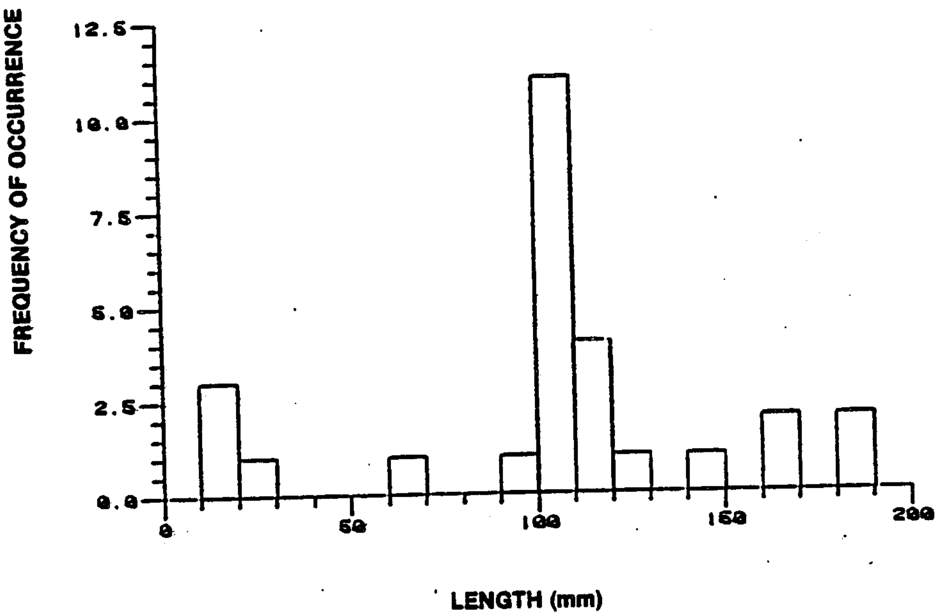


Figure F-86. Length frequency histogram for Penaeus setiferus collected in August 1978 at the Big Hill sites.

Table F-38. Common members of the brown shrimp grounds nekton community

Brown shrimp	*Penaeus aztecus*
Gulf crab	*Callinectes similis*
Longspine porgy	*Stenotomus caprinus*
Shoal flounder	*Syacium gunteri*
Blackfin searobin	*Prionotus rubio*
Blackear bass	*Serranus atrobranchus*
Pancake batfish	*Halieutichthys aculeatus*
Rock sea bass	*Centropristis philadelphica*
Mexican flounder	*Cyclopsetta chittendeni*
Mexican searobin	*Prionotus paralatus*
Inshore lizardfish	*Synodus foetens*
Large scale lizardfish	*Saurida brasiliensis*
Rough scad	*Trachurus lathami*

Historical Benthic Studies in the Big Hill Area

Studies by Keith and Hulings (1965) and Harper (1970) provide data on the sediments and benthic megafauna of near-shore areas similar to the Big Hill 3.5-mile site, and transect investigations by Hulings (1955) and Kennedy (1959) provide benthic megafaunal and sediment data for the same general area encompassing both Big Hill sites (Figs. F-87 to F-90). Although neither the Hulings nor Kennedy studies included sediment analysis, sediment data from the Magnolia Petroleum Company Field Lab were used and are adequate for nonquantitative comparisons. In general, the near-shore sediments out to approximately 30-ft isobath tend to be Beaumont clay and clay mud, changing to an intermediate zone of patchy sediments that range from clay mud to sand. Sandy-shelly sediments generally predominate in the areas surrounding Heald and Sabine Banks. The 3.5-mile diffuser site is located in approximately 30 ft of water in the Beaumont clay and clay mud sediments. The 12.5-mile site is situated on mixed, patchy sediments in approximately 40 ft of water.

Keith and Hulings (1965) conducted a study in the sublittoral zone between Sabine Pass and Bolivar Point (Fig. F-87); they avoided a large Beaumont clay outcropping, but sampled sandy and muddy bottom habitats. Results indicated two distinct benthic faunas inhabiting sand and mud substrates, respectively. The polychaetes Paraonis sp., Streblospio benedicti, Haploscoloplos fragilis, and Spio setosa along with the amphipod Haustorius sp. were diagnostic of sand substrates, while the polychaete Neanthes succinea and the amphipods Corophium cylindricum and Ampithoe sp. were collected in mud sediments. The sand and mud sediments were highly unstable, and benthic organisms inhabiting mud substrates suffered heavy mortality as the effect of hurricane turbulence.

The Harper (1970) study was conducted in water depths of 3 to 11 m off Galveston, Texas (Fig. F-88). The study also found certain species characteristic of sandy, mixed, and muddy bottoms, respectively, and noted generally unstable sediment in the near-shore area (Table F-39).

The transect investigated by Hulings (1955) extended 22 miles from shore just east of the Big Hill diffuser sites (Fig. F-89). Beach and near-shore stations were characterized by Beaumont clay, clay mud, and sandy mud sediments. This dredge study was concerned primarily with characterization of molluscs and did not include polychaetes or crustaceans. The bivalve Petricola pholadiformis and tubes of the polychaete worm, Diopatra cuprea, were common in the beach and intertidal dredge collections. Hulings' data indicate that the sediments in the vicinity of the 3.5-mile site (stations 11 to 14) are predominantly clay mud, with little or no live molluscan fauna collected (Table F-40). Hulings states: "The clay mud substratum is a veritable desert as far as the molluscan fauna is concerned."

At stations in the vicinity of the offshore site (stations 16 to 18, Fig. F-89), Hulings found patchy sediments (with sand, sandy mud, clay mud, and shell debris), all occurring in the general area. Sandy, shelly sediments are more predominant in the Heald and Sabine Bank areas, which are located offshore of the 12.5-mile diffuser site.

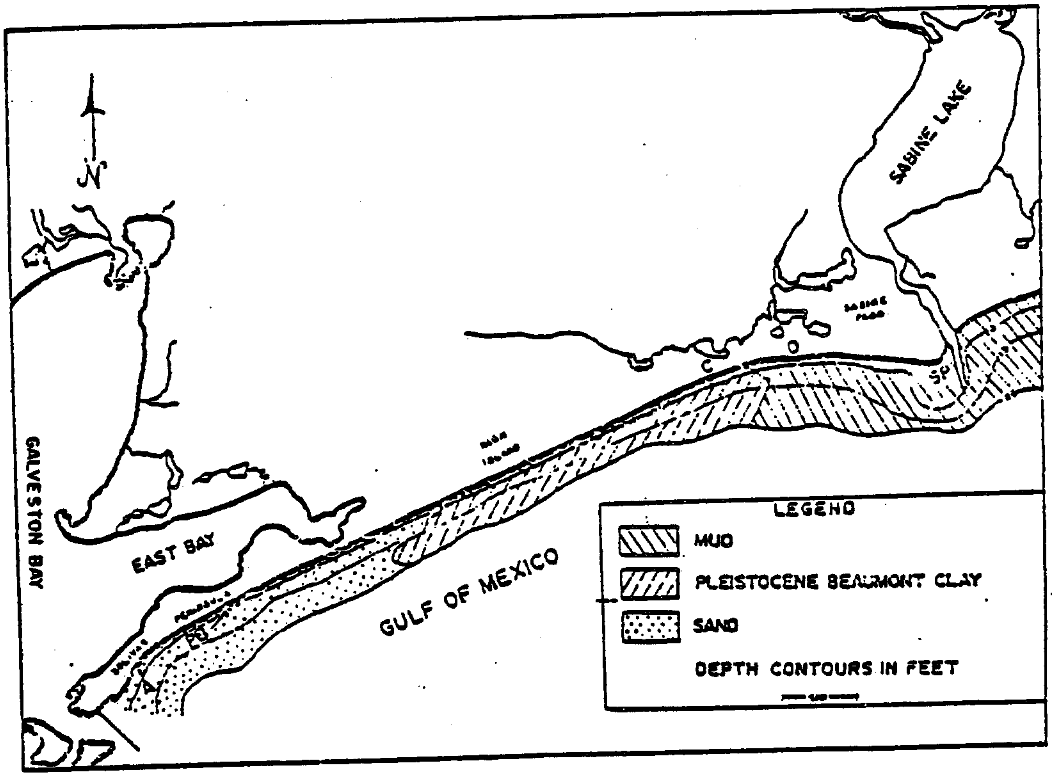


Figure F-87. Locations of stations and distribution of sediments for the Keith and Hulings (1965) study. Source: Keith and Hulings (1965).

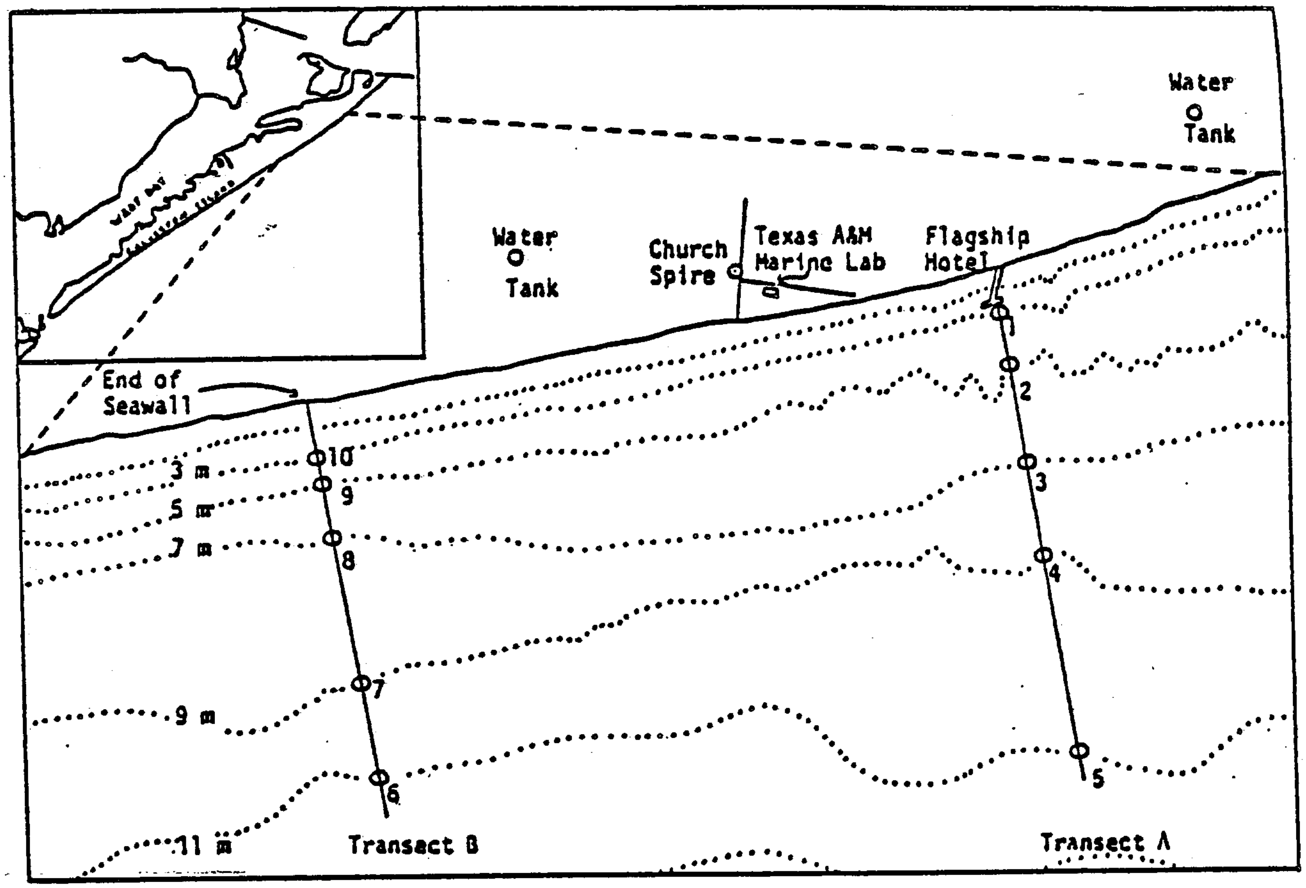


Figure F-88. Map showing Harper's (1970) study area. The transect locations, desired station positions (stations are numbered), and the reference points on Galveston Island used to determine the vessel's position are shown. The inset map depicts the entire Galveston Island. Dashed lines delimit the area shown on the larger chart. Source: Harper (1970).

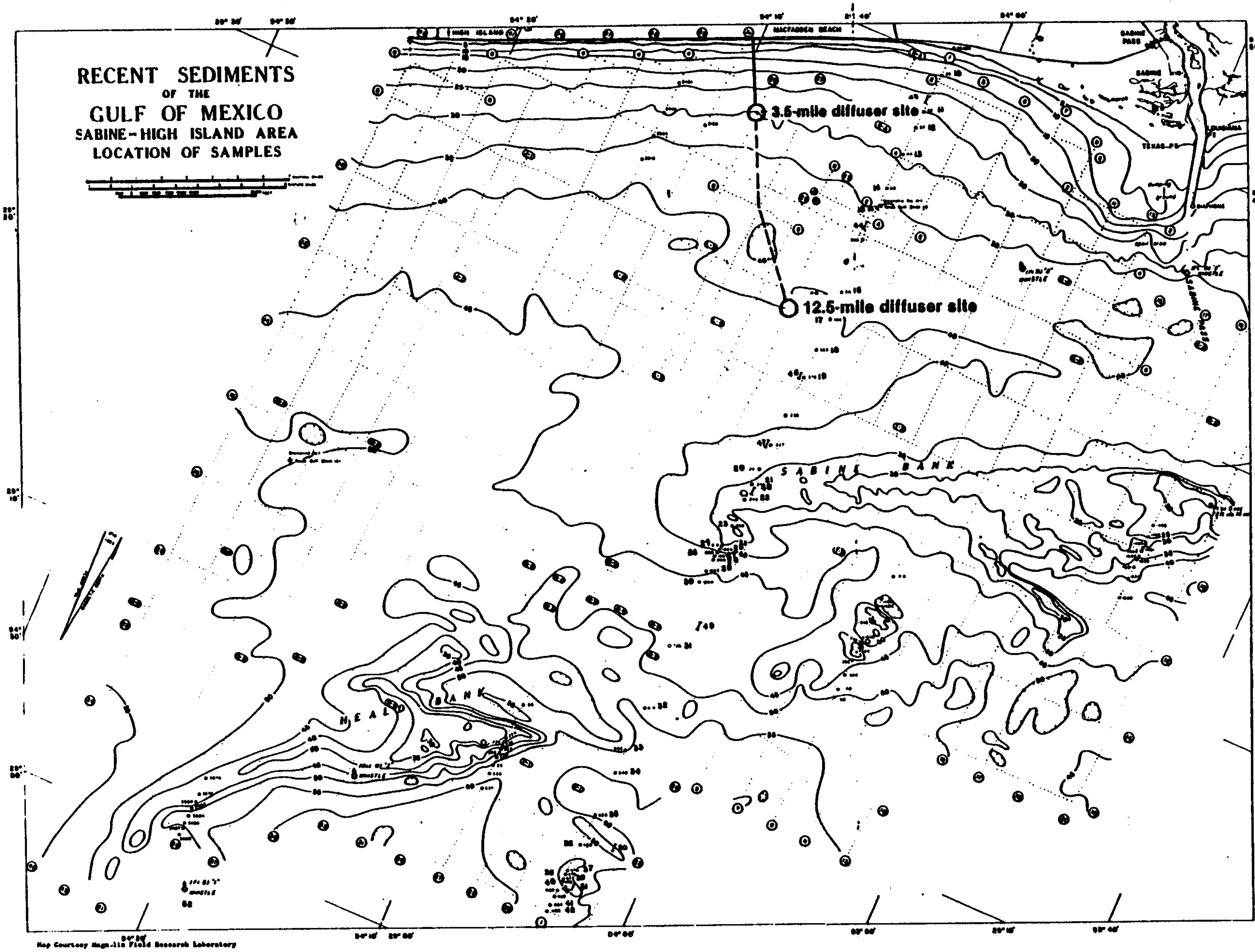


Figure F-89. Stations sampled during the Hulings (1955) study. Source: Hulings (1955).

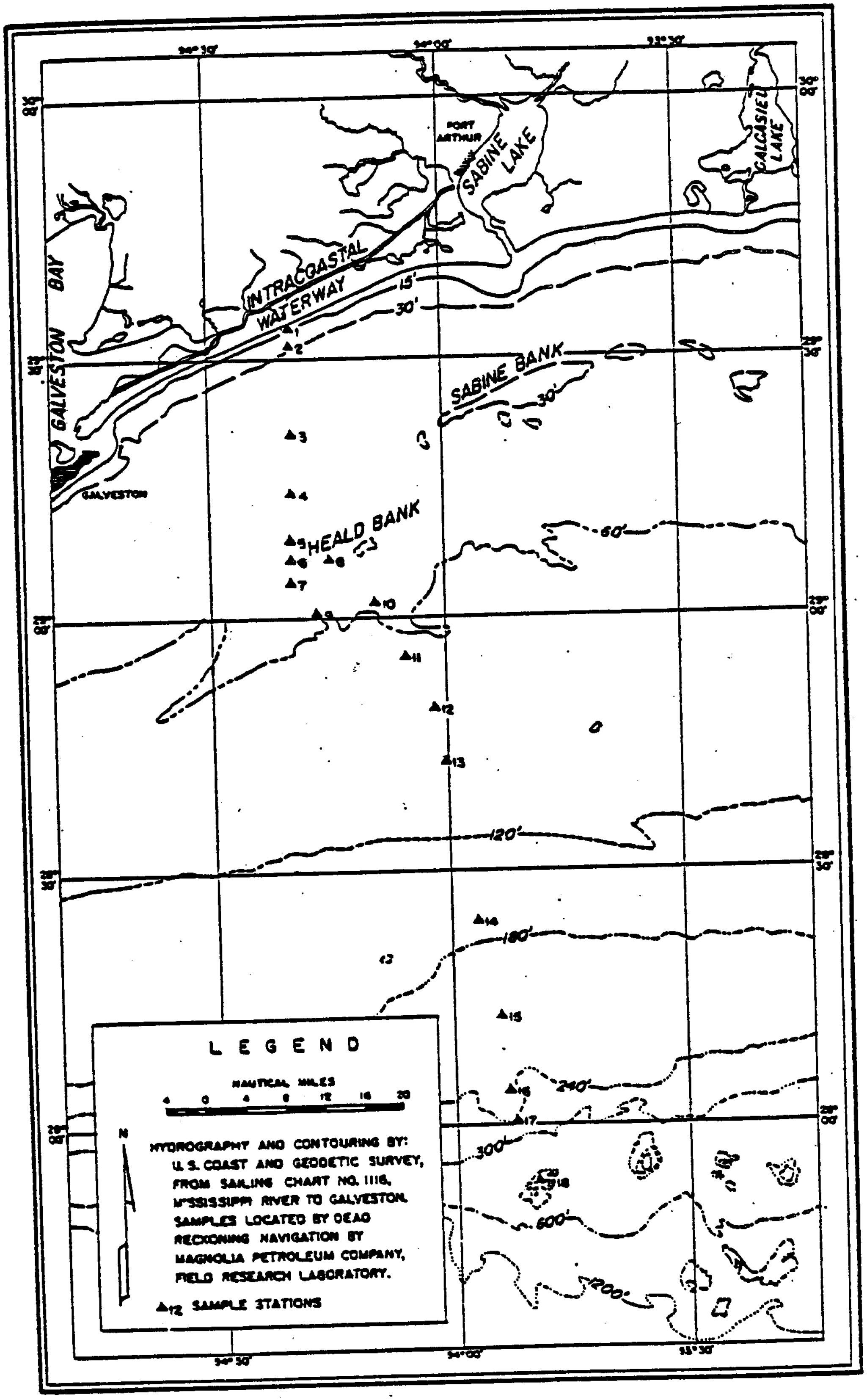


Figure F-90. **Location of stations sampled by Kennedy (1959). Source: Kennedy (1959).**

Table F-39. Animal communities in the Galveston area in relation to substrate type.

Sandy bottom	Mixed bottom	Muddy bottom
First order	First order	First order
Onuphis eremita oculata (P)	*Terebra protexta* (G)	*Diopatra cuprea* (P)
Owenia fusiformis (P)		*Nuculana concentrica* (B)
Mulinia lateralis (B)	Second order	
Tellina iris (B)	*Abra aequalis* (B)	Second order
Olivella mutica (G)	*Corbula caribaea* (B)	*Sternapsis scutata* (P)
Pyramidella crenulata (G)	*Acteon punctostriatus* (G)	*Spiochaetopterus oculatus* (P)
Isocheles wurdemanni (young) (C)		*Lunarca ovalis* (B)
Ancinus depressus (C)		*Volvulella texasiana* (G)
		Micropholis atra (E)
Second order		*Hemipholis elongata* (E)
Terebra dislocata (G)		
Mellita quinquiesperforata (E)		
Pagurus longicarpus (C)		
Libinia dubia (young) (C)		

Legend

B - Bivalvia
C - Crustacea
E - Echinodermata
G - Gastropoda
P - Polychaeta

Source: Harper (1970).

Table F-40. Distribution of mollusk species according to sediment types

CLAY MUD

Spot Sample			Dredge Sample		
Sta. No.	Shells	Live	Sta. No.	Shells	Live
11	0	0	43	40	0
12	0	0			
13	0	0			
14	0	0			
15	0	0			
17	0	0			

SANDY MUD

10	8	0	44	425	1
18	0	0	46	26	2
19	0	0			

MUDDY SAND

31	0	0	47	995	6
33	0	0	49	1,907	68

SAND

16	0	0	50	335	4
20	40	0			
21	78	1			
24	81	0			
29	0	0			
30	122	1			
32	15	2			
36	40	0			
38	141	3			
41	28	0			

Table F-40 (continued)

SAND AND SHELLS OR SHELL DEBRIS

Spot Sample			Dredge Sample		
Sta. No.	Shells	Live	Sta. No.	Shells	Live
22	896	7	45	5,992	8
23	894	7	48	10,898	320
25	394	20	51	3,939	150
26	147	1			
27	500	0			
28	91	1			
37	75	1			
39	62	3			
40	632	11			
42	670	3			

Source: Hulings (1955).

Stations located in mixed and shelly sediments contained a richer molluscan fauna, with shelly substrates providing attachment sites for molluscan epifauna.

Kennedy's (1959) study was conducted in an area approximately 12 nautical miles west of the 12.5-mile site and consisted of a series of 18 dredge stations along a transect extending from near-shore (15-ft depth) to the edge of the Continental Shelf between Sabine Lake and Galveston Bay (Fig. F-90). Stations sampled by Kennedy in the same general depth zone as the 3.5-mile site also revealed outcrops of the faunistically depauperate Beaumont clay. The bivalve Mulinia lateralis and the gastropod Nassarius acutus were prominent species. In the vicinity of the offshore site, Kennedy found patchy sediments including sandy mud, muddy sand, and shelly sand. Characteristic species in this zone included the bivalves Corbula swiftiana and Anadara transversa along with the gastropods Terebra protexta and Natica pusilla. Overall, Kennedy found that the stations from 10 to 60 ft contained more living representatives than the deeper stations, with near-shore stations situated on Beaumont clay substrate being the most depauperate.

In summary, the studies by Keith and Hulings (1965) and Harper (1970) indicate that (1) different substrates support characteristic benthic faunal assemblages; (2) sandy, mixed, and muddy near-shore sediments are highly unstable; and (3) the effects of hurricane turbulence frequently result in mass mortality of near-shore benthic organisms. The Hulings (1955) and Kennedy (1959) studies indicate that the Beaumont clay and clay substrates common in the 3.5-mile site area are faunistically depauperate compared with the mixed, sandy, or shelly substrates located in the vicinity of the 12.5-mile site. Hard clay sediments inhibit the burrowing activities of annelid and molluscan fauna, resulting in lowered populations and a generally less favorable benthic habitat.

APPENDIX F

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APPENDIX G

SHRIMP AND MENHADEN ECOLOGY

APPENDIX G.1
SHRIMP ECOLOGY

Introduction

The life cycle of commercially important penaeid shrimp has been the subject of numerous investigations. According to Kutkuhn (1966a) spawning occurs in the nearshore Gulf, producing large numbers of microscopic, semibuoyant, demersal eggs, which, within hours, hatch into small, planktonic nauplii. Development proceeds rapidly through the protozoal and mysis stages, with the larval shrimp being transported landward toward to mouths of estuaries. The amount of time elapsing between hatching offshore and entry of the one-half inch postlarval shrimp into brackish waters inshore is usually three to five weeks. Once in the estuary, the postlarvae quickly transform into juveniles. Over the subsequent two to four months, they grow rapidly and reach commercial size shortly before their return to the sea, where the life cycle is completed (Kutkuhn 1966a). The management plan for the shrimp fishery of the Gulf of Mexico (Gulf of Mexico Fishery Management Council 1980) and an earlier regional management plan (Christmas and Etzold 1977) are other sources of information on the shrimp fishery, including discussions on life history, biology and population dynamics.

Reproduction

In penaeid shrimp, the female reproductive system consists of two partially fused ovaries, which contain six to eight lateral projections in the cephalothorax and a posterior dorsolateral lobe, extending the length of the abdomen. Five stages of ovarian development are now generally recognized:

1. Underdeveloped - ova small and translucent, ovaries slender and flaccid.
2. Developing - ovaries opaque, yellowish with scattered melanophores, granular in appearance.
3. Nearly ripe - ovaries larger, yellowish brown in *P. aztecus*, yellowish orange in *P. setiferus*.
4. Ripe - ovaries golden brown in *P. aztecus*, drab olive brown in *P. setiferus*.
5. Spent - ovaries greatly reduced in size, flaccid, muddy green in *P. setiferus*; becoming yellow and resembling developing and nearly ripe stages may represent multiple spawn.

Mature individuals appear capable of spawning 500,000 to a million eggs; however, the number actually released may depend on various factors, including multiple spawning.

Female white shrimp are believed to reach sexual maturity at about 135 mm (Moffett, 1970; Lindner and Bailey, 1968). In males, the joining of the petasmal endopods occurs within a size range of 105 to 127 mm. Burkenroad (1934) stated that males possess spermatophores of maximum size and development at a length of 155 mm. Effective sperm, however, is present in specimens as small as 118 mm.

Copulation in P. setiferus is thought to take place primarily between hard-shelled individuals in offshore waters but ripe females have occasionally been collected inside bays and estuaries (Lindner and Anderson, 1956). During copulation, the male spermatophore is anchored to the thelycum of the female by various attachment mechanisms, including an adhesive produced by the male and modifications of the exoskeleton in the form of bristles and plates in the female (Lindner and Bailey, 1968).

Female brown shrimp mature at about 115 to 135 mm (Moffett, 1970; Renfro and Brusher, 1964; Burkenroad, 1934). Males with joined petasmal endopods are usually found between lengths of 85 and 101 mm (Lindner and Bailey, 1968) and are considered capable of spawning at least by the time they reach 135 mm (Moffett, 1970). The thelycum of P. aztecus differs from that of P. setiferus in that it is considered closed. Copulation appears to occur with soft-shelled females without regard to ovarian developmental stage.

Early Life History Stages

The eggs of Penaeus spp. are demersal and sink in still water; however, their specific gravity is close to that of seawater, allowing them to be easily moved by the currents. Egg development may be related to temperature, and hatching occurs within 12 to 14 h. Both taxa pass through five naupliar, three protozoal, two mysid, and two postlarval stages. These early life history stages are usually considered planktonic. However, their distribution in the water column may depend in part on such factors as time, temperature, turbidity, salinity, proximity to tidal passes, and stage of development.

The early developmental stages within genera of the family Penaeidae are so morphologically similar that, at any given stage, the various species cannot be readily distinguished (Cook and Murphy, 1971). Descriptions of the early life history stages of brown and white shrimp can be found in Cook and Murphy (1971) and Pearson (1939). Examination of Table G.1-1 reveals the high degree of similarity between sizes of the two species.

Field surveys disagree as to whether postlarval shrimp exhibit diel rhythms. Much evidence shows maximum numbers of postlarvae in the surface at night (Tabb et al., 1962; Baxter and Furr, 1964; Copeland and Truitt, 1966; and Williams and Deubler, 1968). Temple and Fischer (1965) found vertical migration of penaeid postlarvae during times of stratification, with upward migration at night and a return to lower depths at dawn. When water was isothermal, no vertical differences were seen. Williams and Deubler (1968) also showed that bright light at night drastically reduced catch. Also, higher catches were made during the new moon than full moon. Jones et al. (1970) found no significant

Table G.1-1. Approximate sizes of the various larval stages of brown and white shrimp

Larval Stage	White Shrimp		Brown Shrimp	
Egg	Diameter 0.28 mm		Diameter 0.26 mm	
	Range (mm)		Range (mm)	
	Length	Width	Length	Width
Nauplius				
1	0.30-0.34	0.16-0.20	0.32-0.38	0.18-0.21
2	0.32-0.34	0.16-0.18	0.36-0.41	0.20-0.21
3	0.36-0.40	0.14-0.16	0.36-0.43	0.20-0.23
4	0.38-0.44	0.16-0.18	0.41-0.47	0.22-0.22
5	0.46-0.56	0.16-0.20	0.43-0.58	0.18-0.22
Protozoea				
1	0.80-1.14		0.89-1.21	0.40-0.49
2	1.30-1.70		1.28-2.01	0.72-0.87
3	2.20-2.60		2.40-2.59	0.93-1.40
Mysis				
1	3.20-3.80		3.20-3.50	1.10-1.30
2	4.00-4.40		3.30-4.20	1.20-1.40
3			3.90-4.70	1.30-1.50

Source: Cook and Murphy (1971) and Pearson (1939).

difference between the numbers of postlarvae caught at the surface during the day and those caught during the night. However, Temple and Fischer (1965) found partial vertical separation of immature stages in the water column when a well-defined discontinuity layer was present and the water was exceptionally clear. Postlarval stages occurred more frequently near the surface. Fontaine et al. (1972) found postlarvae occurring in greatest numbers near the surface. On the other hand, St. Amant et al. (1966), Berry and Baxter (1969), and Caillouet et al. (1968) found no difference in postlarval brown shrimp distribution with depth.

Seasonality of Life History Stages

The monthly percentage of female white shrimp in different stages of ovarian development is shown in Figure G.1-1 for the Louisiana offshore fishery (Lindner and Anderson, 1956). By September and October, spawning appears to be complete and is represented by the decline in ripe ovaries and the increase in the occurrence of spent individuals. Considerable evidence exists that P. setiferus may spawn more than once during the season. The percentage of spent females remains low throughout the summer, and evidence of subsequent redevelopment of ovaries has been reported by Lindner and Bailey (1968).

Catches of postlarvae appear in waves (Figure G.1-2), suggesting periodic differences in spawning pulses or in survivorship of larval stages. These fluctuations could result from fluctuations in environmental conditions such as currents, oxygen deficits, and predation if prolonged continuous spawning does occur. Gaidry and White (1973) stated that sampling for white shrimp postlarvae indicated that most enter Louisiana estuarine waters from June to September, with the first presence of juveniles occurring in June and July and recruitment continuing through September.

The presence of ripe and spent shrimp indicates that the spring spawners occur in depths between 9 and 17 fathoms (Table G.1-2) around June; a second group of spawners appears in depths of less than 9 fathoms and subsequently moves to deeper waters as the members continue to mature through August and September. Members of the spring-spawned group, although not mature, are found in shallow depths in August and move off shore in September.

Larger white shrimp move to offshore waters (after estuarine growth) from July through September. Few shrimp are found in shallow waters from December through February, with the approaching winter prematurely moving juvenile white shrimp from the shallow nursery areas into the larger lakes (e.g., Calcasieu Lake) or staging areas and finally into the Gulf, where they remain for the winter, with many reentering the estuaries in early spring. The largest inshore populations of white shrimp occur in April, May, August, and September. The population of the inshore deep lakes and bays from July to December depends mainly on recruitment of shrimp from the nurseries, and the spring inshore population depends on recruitment from the offshore overwintering stocks. The highest density of white shrimp in offshore waters occurs from November through January.

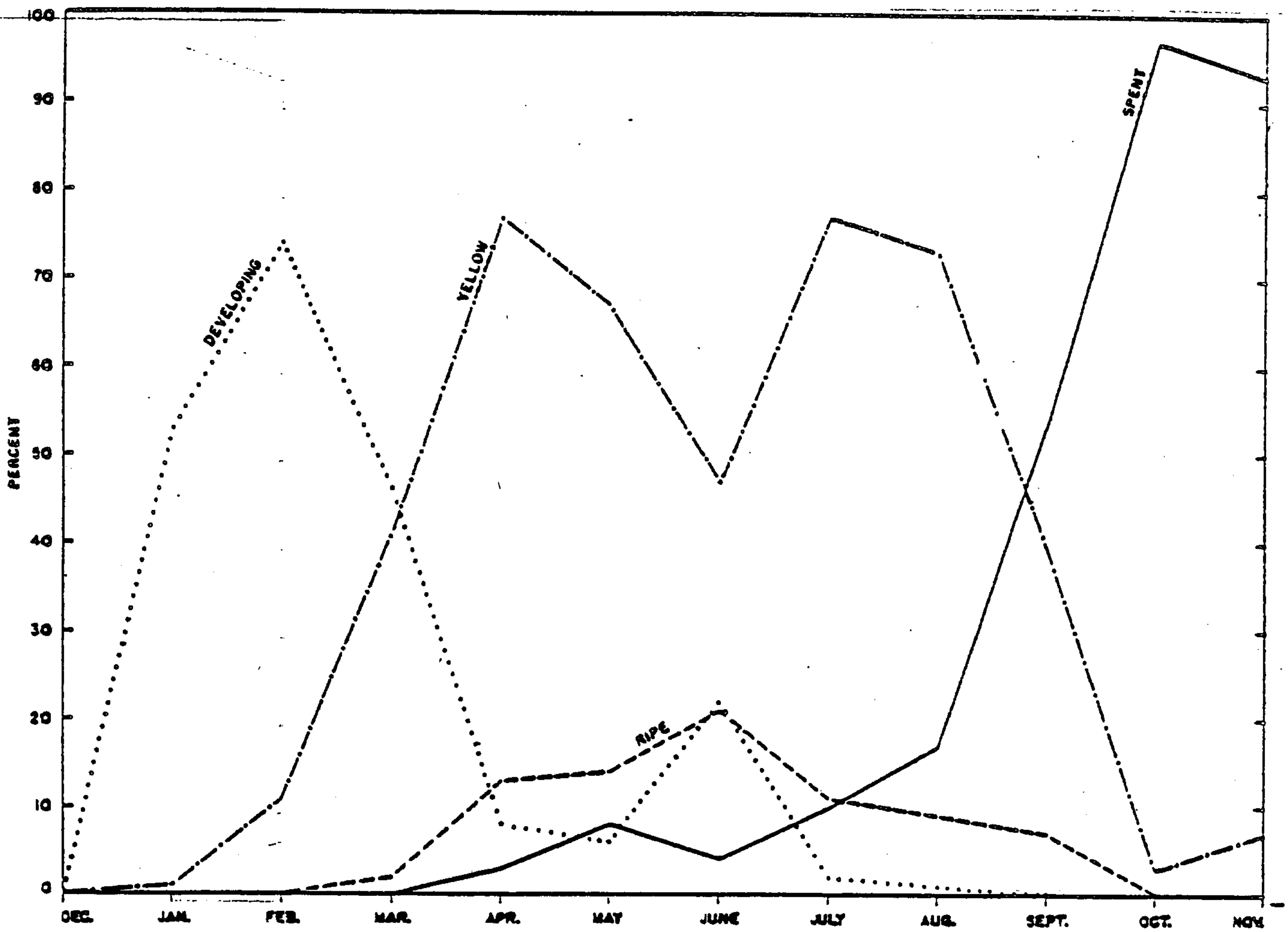

Figure G.1-1. Monthly percentage of female shrimp, according to stage of ovarian development, appearing on the spawning grounds in the Louisiana offshore fishery. The data are from the period December 1941 to November 1942. After August 1942 this figure includes only shrimp approximately 1 year old or more. Source: Lindner and Anderson (1956).

Table G.1-2. **Distribution by stages of ovarian development and by depths, of female shrimp in Louisiana offshore fishery, December 1941 to November 1942**

Month, and stage of ovarian development	Number taken at depth of— 0–4½ fathoms	5–8½ fathoms	9–12½ fathoms	13–16½ fathoms	17 fathoms and deeper	All depths	Total
1941							
December:							
Undeveloped	230	633	22	....	....	935	
Developing	....	....	....	....	....	0	
Yellow	....	....	....	....	....	0	958
Ripe	....	....	....	....	....	0	
Spent	1	22	....	....	....	23	
1942							
January:							
Undeveloped	....	979	131	22	....	1,132	
Developing	....	997	351	15	....	1,363	
Yellow	....	13	2	....	....	15	2,560
Ripe	....	....	....	....	....	0	
Spent	....	....	....	....	....	0	
February:							
Undeveloped	....	19	71	19	42	151	
Developing	....	16	410	264	58	748	
Yellow	....	....	50	49	13	112	1,011
Ripe	....	....	....	....	....	0	
Spent	....	....	....	....	....	0	
March:							
Undeveloped	....	....	62	190	35	287	
Developing	....	....	230	461	471	1,162	
Yellow	....	....	304	260	476	1,040	2,531
Ripe	....	....	....	10	32	42	
Spent	....	....	....	....	....	0	
April:							
Undeveloped	....	....	....	....	....	0	
Developing	....	....	3	33	65	101	
Yellow	....	....	39	442	533	1,014	1,322
Ripe	....	....	4	49	112	165	
Spent	....	....	7	7	28	42	
May:							
Undeveloped	40	....	....	....	....	40	
Developing	22	....	10	18	6	56	
Yellow	14	....	167	333	80	594	882
Ripe	....	....	39	85	2	126	
Spent	....	....	17	43	6	66	
June:							
Undeveloped	25	....	....	....	....	25	
Developing	74	5	....	....	....	79	
Yellow	45	95	31	....	....	171	365
Ripe	....	66	11	....	....	77	
Spent	....	8	5	....	....	13	
July:							
Undeveloped	1	....	....	1	....	2	
Developing	1	32	4	1	....	38	
Yellow	23	655	360	174	....	1,212	1,581
Ripe	1	113	21	41	....	176	
Spent	22	70	50	11	....	153	
August:							
Undeveloped	259	....	2	....	....	261	
Developing	....	....	5	2	....	7	
Yellow	....	94	453	266	....	813	1,370
Ripe	....	9	59	31	....	99	
Spent	1	6	106	77	....	190	
September:							
Undeveloped	385	223	600	....	....	1,208	
Developing	....	....	....	....	....	0	
Yellow	....	12	172	....	....	184	1,681
Ripe	....	1	32	....	....	33	
Spent	12	19	225	....	....	256	

[1] It is obvious that in June 1942 our sampling did not cover the entire spawning population.

Source: Lindner and Anderson (1956).

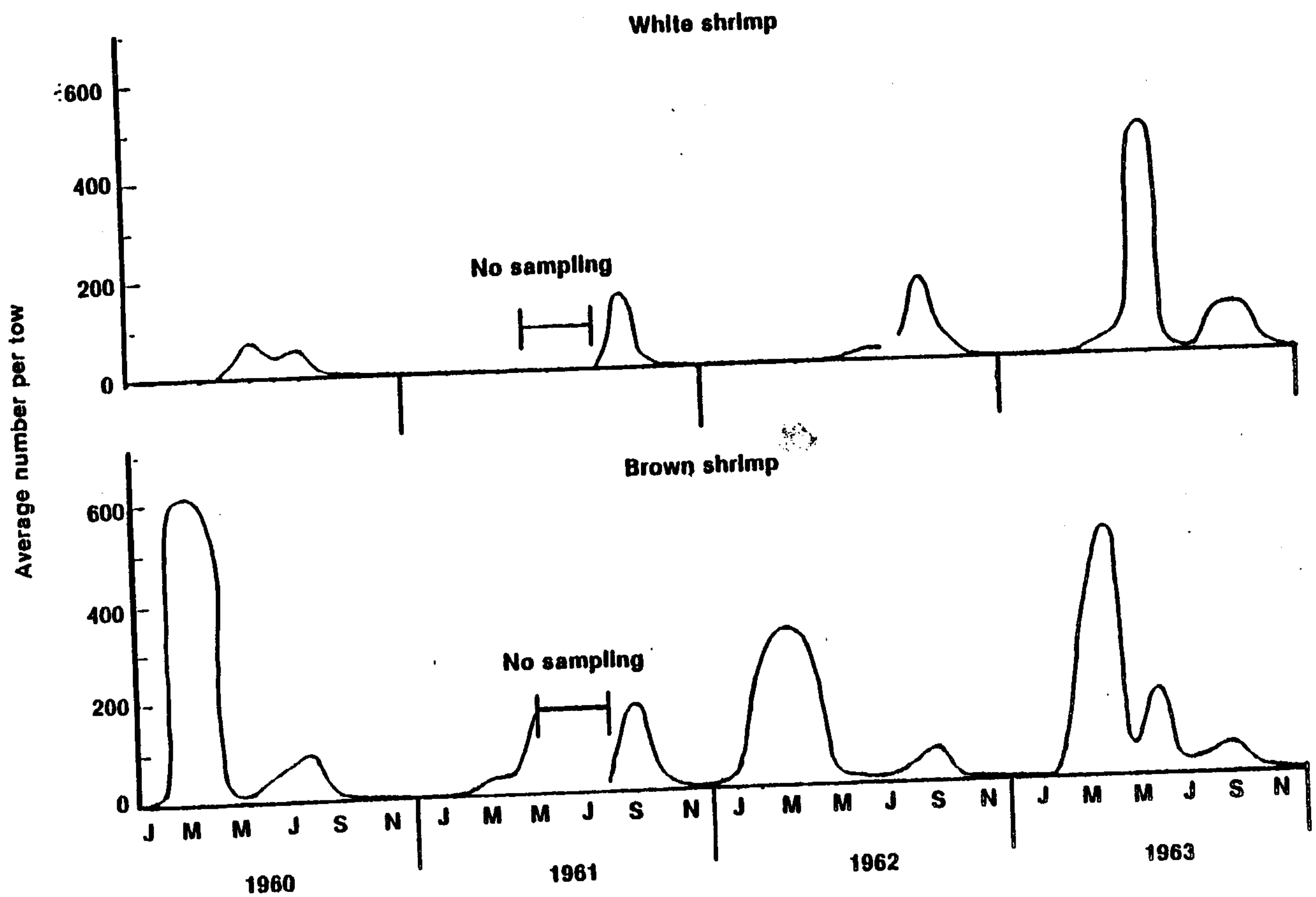

Figure G.1-2. Seasonal abundance of postlarval brown and white shrimp at Galveston Entrance, 1960-63.

from Baxter and Renfro (1967)

Based on of the juvenile abundance in estuaries, Gunter (1950) proposed a brown shrimp spawning peak in February and March. However, Moffett (1970) reports that brown shrimp spawn off Texas between 25 and 30 fathoms throughout the year and spawning occurs between 10 and 25 fathoms from March to December. Renfro and Brusher (1965) report two peaks, September to November and April to June. Temple and Fisher (1965) suggest an August to November peak, supporting the concept of an important fall spawning time based on the collection of planktonic stages. Gaidry and White (1973) and White and Boudreaux (1977) report February and March peak recruitments of brown shrimp in Louisiana. Temple and Fischer (1965) propose an overwintering of postlarval brown shrimp in the nearshore Gulf; their work is supported by the work of Aldrich et al. (1968), which describes postlarval brown shrimp burrowing at low temperatures. The results from the NMFS shrimp spawning site survey for the Bryan Mound brine disposal site off Freeport Texas (Gallaway and Reitsema 1981) tended to support the theory of an important fall spawning season for brown shrimp, and an overwintering of postlarvae in the Gulf of Mexico.

Baxter and Renfro (1967) state that brown shrimp were the only postlarval penaeids that entered Galveston Bay during the first four months of the year. By June, advanced postlarvae and early juvenile white shrimp became abundant, and both brown and white shrimp were present throughout the summer. During times when postlarvae of both species were present, the mean length of the white shrimp was always less than that of the brown shrimp, indicating that the white shrimp postlarvae enter the bay at a much smaller size, probably because of the proximity of their spawning sites to the estuaries.

Gaidry and White (1973) describe a typical year for brown shrimp in Louisiana. A steady increase in estuarine juvenile density occurs from late March through mid-May, when a period of peak density occurs. After this time the population abruptly declines because of (1) Opening of the spring shrimping season (usually May 15-31) and (2) Natural egression of larger juvenile shrimp from smaller estuaries when they reach a length of 65 to 75 mm. Gaidry and White (1973) stated that their data showed a delay in the first appearance of newly recruited juveniles brown shrimp proceeding westward along the Louisiana coast, implying a westward movement of juvenile brown shrimp from the "staging areas" of areas III, IV, and V (Figure G.1-3) where the Louisiana brown shrimp population appeared to be centered. Bay systems in areas III and IV (e.g., Barataria, Caminada, Timbalier, and Terrebonne bays) serve as important staging areas in the early life history of the juvenile brown shrimp. Apparently, shortly after leaving the estuaries, the shrimp reentered certain systems that mimic coastal bays. In the case of western Louisiana, this was Calcasieu Lake. Gaidry and White (1973) showed definitive evidence of an emigration of young adult brown shrimp from Rockefeller Wildlife Refuge and subsequent entry of the same size shrimp into Calcasieu Lake. The movement was consistent for all years of the study. They noted that the size class distribution in Calcasieu Lake showed a distinct lack of recruitment of smaller shrimp, indicating that the larger shrimp comprising the bulk of the population are not produced in the Calcasieu Lake system. Lakes such as the Calcasieu Lake serve as staging areas before the offshore emigration of this group. Sabine Lake

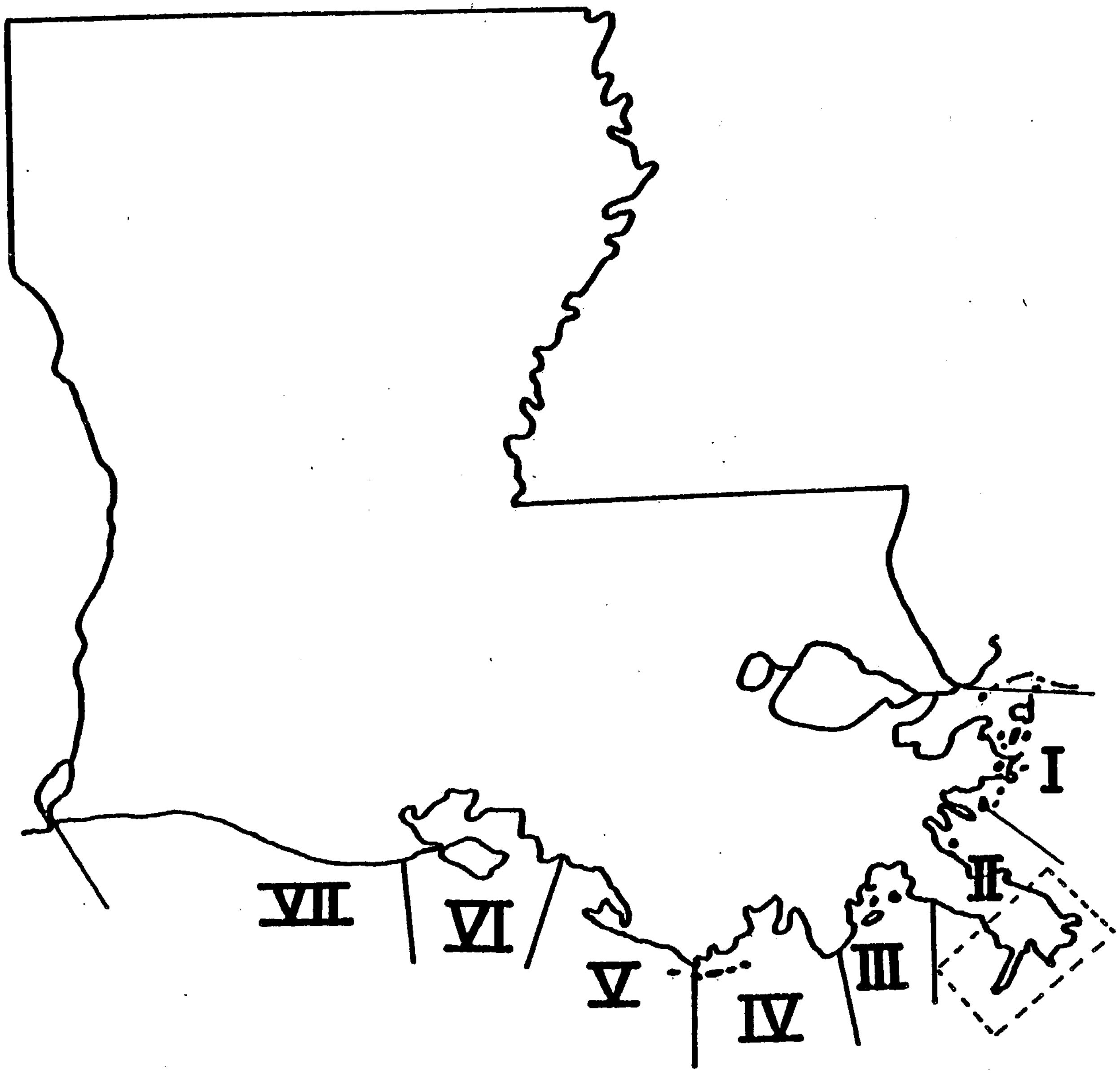

Figure G.1-3. Louisiana Wildlife and Fisheries Commission study areas.

has historically produced no appreciable quantities of brown shrimp and no longer supports a commercial fishery for white shrimp.

Food Habits

Larval stages of brown and white shrimp feed primarily on algae and zooplankton (Pearson, 1939; Ewald, 1965). Postlarvae are capable of deposit feeding. Juvenile and adult white shrimp are considered omnivores, ingesting decaying organic matter, plants, and animals. As young (25 to 44 mm), they indiscriminately ingest the top layer of sediment containing detritus and microorganisms (Jones, 1973). After migrating to deeper waters, they become more active predators, feeding on polychaetes, amphipods, nematodes, and chironomid larvae as well as detritus and algae (Jones, 1973; Darnell, 1958). In laboratory conditions, brown shrimp were able to use 42.2 percent of the total organic carbon ingested during feeding. Within the body, the food was apportioned as follows: 20.5 percent for growth, 3.9 percent shed as exoskeleton, 34.6 percent lost through respiration, 24.24 percent egested, and 14.7 percent unaccountable (Ibrahim, 1973). Assimilation efficiencies calculated by Condry et al. (1972) for diets of diatoms, detritus, and trout chow were 87, 85, and 80 percent, respectively, suggesting the true omnivorous feeding habits of shrimp. Assimilation of an organic moiety is a function of the activity and concentration of the digestive enzymes of the shrimp and the form of the moiety available. Proteins and lipids are, in general, assimilated more efficiently than carbohydrates. The role of lipids and proteins in ova maturation (vitellogenesis) has become the concern of much recent work (Middleditch et al., 1979; Middleditch et al., 1980; as referenced by Gallaway and Reitsema 1981). Lipids and lipoproteins are believed to be assimilated from the environment (food) and transformed through the organism and deposited as yolk material during maturation. This concept is currently under investigation by the National Marine Fisheries Service in their shrimp spawning site surveys being conducted for the Department of Energy.

Salinity Relationships

Most members of the demersal nekton community at the 30-ft contour are highly dependent on the estuaries for juvenile growth and survival (Gunter, 1945, 1950; Pearse and Gunter, 1957). Cody et al. (1978) estimate that 98 percent of the commercial catch of Texas by weight was composed of estuarine-dependent species; similar statistics are found for Louisiana.

Estuarine-related species are almost invariably euryhaline, able to survive and grow over a wide range of salinities. Thus, from the point of view of the ability of the community to tolerate variable salinity concentrations, this inshore assemblage should be the most resilient. They generally have a greater tolerance to both lower and higher salinities than the members of the true marine fauna from which they were derived. For example, most members of the hypersaline realm are derived from the estuarine realm (Day, 1951; Hedgpeth, 1957; Emery, 1957). Simmons (1957) presents a list of fishes taken in the Laguna Madre (at hypersaline conditions of 60 to 75 parts per thousand [ppt]), and all ten are found on Gunter's (1956) list of euryhaline fishes of the United States. The estuarine fauna is generally depauperate compared with the marine fauna.

Pearse and Gunter (1957) state that, in the early (larval) stages, shrimp apparently require oceanic water, but the older larvae and postlarvae must reach estuarine water to survive. Kaiser and Aldrich (1976) concluded from their laboratory studies that postlarvae of both brown and white shrimp sought salinities lower than those generally found in the open Gulf of Mexico and that the postlarvae apparently orient to work bays by using natural salinity gradients. However, laboratory studies (Zein-Eldin, 1963) have shown that postlarval brown shrimp can both survive and grow over a salinity range of 2 to 40 ppt. Johnson and Fielding (1956) raised white shrimp at salinities of 18.5 to 36.0 ppt. Zein-Elden and Griffith (1969) reported that extremes tolerated by 80 percent of the brown shrimp postlarvae were salinities >40 ppt and <5 ppt. Similar values for white shrimp postlarvae were 40 to 45 ppt and 4 ppt. Zein-Eldin and Aldrich (1965) and Zein-Eldin and Griffith (1969) have, however, shown that low salinity in concert with low temperatures, is detrimental to both white and brown postlarval shrimp, probably because of osmoregulation stress (Williams, 1960). White shrimp are more tolerant of high temperature, whereas brown shrimp are more tolerant of low temperature. Zein-Eldin and Aldrich (1965) concluded, on the basis of their own work and that of others (Williams, 1960; McFarland and Lee, 1963), that brown shrimp postlarvae are better osmoregulators than are juveniles or adults.

In their laboratory studies, Kaiser and Aldrich (1976) found a marked seasonal difference in salinity preferences exhibited by brown shrimp postlarvae. During early spring, the median salinity chosen by brown shrimp postlarvae was 30 ppt, 9 ppt greater than that found for brown shrimp tested in summer. No significant difference was seen in salinity preference of white shrimp postlarvae tested in summer and fall, except at the low salinity end. In the summer, brown and white shrimp postlarvae did not exhibit a markedly different preference for salinity, with an average salinity difference of only 3.2 ppt. This suggests that there is less difference in salinity preference between the two species at the postlarval stage than has been suggested for subsequent stages in the life cycle. Kaiser and Aldrich (1976) found that the salinity ranges preferred by 90 percent of the P. aztecus tested were 15.0 to 34.2 ppt, 16.8 to 37.3 ppt, and 16.2 to 37.7 ppt for the summer, fall, and spring, respectively. Similar values for P. setiferus for the summer and fall were 13.4 to 32.32 ppt and 5.8 to 35.5 ppt, respectively. They reported that there was no evidence to suggest that brown shrimp postlarvae are adapted to specific salinities, and conclude that temperature is apparently more important than salinity to postlarval growth and survival. These results, therefore, indicate that penaeid postlarvae are very euryhaline and more responsive to temperature than to salinity.

Bioassay results using Bryan Mound brine (NOAA, 1978) indicated that P. setiferus eggs showed similar hatching success from 31 to 36 ppt brine, at with a dramatic decrease beyond 38 ppt (to zero hatchability). Postlarval stages showed some effects over 96-h periods of exposure when concentrations exceeded 36 ppt, but for most durations of exposure, 40 ppt seemed to be the general level were first deleterious effects were observed. Similar results were seen for the range of temperature tested (28 to 33°C). Nauplii appeared to be more resistant than postlarvae to increased salinities. These results clearly indicate that, for short periods of exposure, concentrations 3 ppt above ambient (24 to 33 ppt) would fall within the tolerance range of all those stages.

Field studies, mainly estuarine, generally corroborate the euryhaline nature of all stages of the life cycle of the penaeid shrimp. Investigations by Truesdale (1970) and Conte (1971) suggest that salinity itself does not influence spatial distribution of postlarval white and brown shrimp in the estuary. Truesdale (1970) concluded that salinity per se had no effect on postlarval distribution and abundance in a low-salinity portion of Trinity Bay near the Trinity River except during periods of high river discharge. When salinity decreased to 0 ppt over much of the area, postlarvae disappeared. Conte (1971) found no relationship between salinity and the distribution of postlarval brown shrimp on two shallow marsh embayments near West Bay of the Galveston Bay System. Hoese (1960), Zein-Eldin (1963), and Parker (1970) have all discounted the role of salinity in shrimp distribution. Extensive field investigations have shown both brown and white shrimp to be present in both hypo- and hypersaline waters (Simmons, 1957; Joyce, 1965). Brown shrimp have been collected in salinity extremes of 0.1 (Williams and Deubler, 1968) to 69.0 ppt (Simmons, 1957), and white shrimp have been collected in extremes of 0.2 (Gunter and Hall, 1963) to 48.0 ppt (Lindner and Cook, 1970). Lindner and Anderson (1956), who found that the size of young shrimp correlated more with locality than with salinity, concluded that salinity over broad ranges was not important although it might be an important stimulus to migration. Hoese (1960) found P. setiferus juveniles on an outer beach at the same time that populations of the same size class were in the adjacent low-salinity estuary. He concluded that juvenile P. setiferus and P. aztecus can populate areas of relatively high salinity if other environmental factors are ideal. Parker (1970) found that salinity apparently did not influence the distribution of juvenile brown shrimp in Galveston Bay (in spring, 0.9 to 36.5 ppt). McFarland and Lee (1963) found that juvenile brown shrimp can osmoregulate over a wide range of salinities, but there was some indication that the optimum range was 23 to 43 ppt.

While the results presented above indicate that the salinity tolerances of penaeid shrimp are large, the results presented below indicate that very low salinities may be detrimental to the success of the year class for at least brown shrimp, apparently by limiting the amount of estuary area that can serve as a nursery area.

These tolerance data, along with outputs of the MIT Transient Plume Model, indicate that, in all but the very smallest area (the 10-ppt-above-ambient salinity plume covering several acres), salinity averages should be in the tolerance range of all stages of all species of commercially important penaeid shrimp in the discharge area.

Factors Affecting Success of Year Classes

One of the important aspects of the penaeid life cycle is the transport of the developing larvae to the estuaries. Current patterns on the Continental Shelf probably govern, to a large degree, the eventual occurrence of postlarvae at the entrances to nursery areas, especially for the brown shrimp which spawns further offshore. Aldrich (1966) has shown that in addition to passive transport, postlarvae are capable of extended swimming. He estimated that swimming alone could transport postlarvae 3 miles per day.

The data relating postlarval recruitment to wind-generated currents (Ekman transport) are not conclusive. Williams and Deubler (1968), working on the Atlantic Coast, found that ten years of collection data did not show a link between wind-generated onshore currents and larvae collected at flood tide in tidal passes. Wind direction at time of catch had no effect on sampling success. There was also no relationship between the magnitude of current and the number of postlarvae collected. In fact, King (1971) showed a positive correlation between offshore winds and the number of postlarval brown shrimp caught on flood tides in a Texas tidal inlet.

Kutkuhn et al. (1969) found that larvae approached the Galveston Bay entrance from opposite directions in different seasons. In spring, most larvae and postlarvae (brown shrimp) approached from the east, whereas in summer larvae and postlarvae (white shrimp) approached from the south and west. This coincides with the net longshore current flow in the northwest Gulf, which is from east to west in all seasons except summer, when a reversed in direction of longshore transport occurs (see Appendix U of Texoma FEIS). Berry and Baxter (1967) did find that strong tides carry large numbers of postlarvae into the Galveston Bay estuaries. This same phenomenon has been seen by Pearson (1939), Tabb et al. (1962), St. Amant et al. (1966), Caillouet et al. (1968), and Fontaine et al. (1972). Because of this dependence on water currents to deliver the postlarvae to the estuary, normal tidal changes, storms, wind-induced current movement, or excessive runoff could affect the number of postlarvae entering the estuaries. King (1971), who collected only on flood tides, found that the rate of brown shrimp postlarvae immigration was positively related to tidal amplitude.

Berry and Baxter (1967) reported that the relative sizes of the shrimp stocks developing in Galveston Bay were better reflected by bait shrimp landings than by postlarval abundance. This indicates that conditions in the estuary during arrival of the postlarvae or early in the juvenile growth period greatly influence the subsequent abundance of commercial shrimp. Distributions of counts of postlarvae collected in March and April of 1960-1966 show that the means of the distributions were fairly similar in all years except 1961. During those same years, commercial catch varied significantly. Gaidry and White (1973) point out that postlarval data alone has proven inconsistent in Louisiana's efforts to correlate these data to production. Louisiana has relied heavily on juvenile indices for predicting offshore catch.

Barrett and Gillespie (1973), in findings similar to those of Berry and Baxter (1967) in Texas, found that a good shrimp year in Louisiana reflects good catches both inshore and offshore, whereas a bad year is bad both inshore and offshore. Barrett and Ralph (1976) found that years of above- and below-average brown shrimp catch inshore and offshore were similar, and a similar trend was seen for white shrimp catch although good years and bad years were not the same for the two species. They found that a smaller percentage of the May through July brown shrimp catch consisted of large individuals during good years, presumably because of better recruitment during good years.

Because neither postlarval abundance offshore or numbers of postlarvae entering the estuary are not well reflected in subsequent offshore shrimp production, postlarval abundance does not appear to be the critical aspect of the life cycle. The success or failure of a shrimp year class will depend to a much greater degree on factors that occur after the postlarvae enter the estuary. St. Amant et al. (1963) showed populations of postlarval brown shrimp to be extremely responsive to certain unstable hydrologic conditions that often exist during and shortly after their arrival in the estuary. Postlarval density (offshore) alone was a poor indicator of impending production levels in Louisiana.

Because of the apparent close correlation between recruitment (juvenile) stocks and subsequent offshore catches, a greater degree of effort has more recently gone into identifying those factors that are responsible for the success of juvenile shrimp inside the estuaries. Of these, temperature and salinity have received the most attention. However, the amount of marsh-water interface is obviously also important (Turner 1977). While in the estuary, juvenile penaeid shrimp feed mainly at the interface of the mash and open water. The small juveniles feed on detritus, while the larger bay shrimp become more predaceous bottom feeders as they move to the deeper parties of the bay (GMFMC, 1980).

Barrett and Gillespie (1973) have related brown shrimp production to various hydrological influences and have shown capabilities for predicting production on the basis of certain hydrological conditions. Barrett and Ralph (1976) relate brown shrimp catch to river discharge, rainfall, salinity, water temperature, and available nursery area. Gaidry and White (1973) found that hydrologic conditions prevailing shortly after the arrival of postlarval shrimp can be directly correlated with brown shrimp production. White (1975), noting that past studies have shown juvenile (brown shrimp) numbers to be quite indicative of future production, states that juvenile abundance is directly related to the hydrologic conditions that occur during and after postlarval recruitment. The low-production year of 1964 was characterized by low temperatures shortly after peak larval recruitment, along with low salinities. The crucial period for brown shrimp growth occurs in Louisiana between April 26 and May 20. Barrett (1975) states that unseasonably low temperatures in Louisiana coastal waters, especially in the early weeks after spawning, are critical factors in the survival of metamorphosing postlarvae arriving in estuarine nursery areas. He suggests that the number of hours below 20°C after April 8 is important in determining brown shrimp production for the year.

St. Amant et al. (1963) and Ford and St. Amant (1970) found increasing numbers of juveniles and maximum postlarvae densities in Louisiana estuaries when water temperatures were maintained at 15 to 20°C. However, salinities were also shown to be important, since denser populations and larger postlarvae were found in salinities above 15 ppt. Barret and Ralph (1976) state that the combined effect of salinity and temperature on juvenile populations (in the estuaries) has been well established as one of the most significant controlling factors determining the growth and abundance of brown shrimp. Barrett and Gillespie (1973) reported that, after April, salinity became the dominant factor influencing brown shrimp distribution.

White (1975) reports that, in Louisiana in 1973, when floods were prevalent in early spring, high discharge from the Calcasieu River and nearby local drainages caused recruitment of juvenile brown shrimp to be low. Otherwise, where local flooding was not present, juvenile abundance was not significantly reduced as a result of flooding of the Mississippi River. Barrett (1975) states that upper to lower bay salinities of 15 and 20 ppt, respectively, were ideal for brown shrimp production and that weekly salinity averages, during years when brown shrimp production in May exceeded 1 million pounds, were above 18.3 ppt. During those years when production was less than 1 million pounds, weekly salinities were below 18.3 ppt. Thus, the annual brown shrimp catch is related to the number of acres of surface estuarine water in coastal Louisiana above 10 ppt in the spring.

Barrett and Ralph (1976) conclude that good brown shrimp catches occur when salinities are above average as a result of low spring rainfall and low river discharge coupled with mild spring water temperatures. Good white shrimp production occurs during low summer discharge (Barrett and Gillespie, 1973). In both cases for Louisiana, higher-than-average estuarine salinities increase both white and brown shrimp production. As seen by the drought of the early 1950s, however, when salinities get excessively high, white shrimp production does decline, probably because of the coincidence of these estuarine phases with highest salinities (midsummer).

In forecasting the shrimp harvest based on the historic record and early season environmental data, Barrett and Ralph (1976) state that, if river discharges and rainfall remain relatively low throughout the summer, white shrimp production should also be well above the average for the year. In 1976 mild water temperatures and low river discharge in the spring indicated that the brown shrimp harvest would be good.

Vulnerability and Resiliency of the Fishery

Kutkuhn (1966b) states that central and western Louisiana and northeastern and central Texas inshore of 20 fathoms is the world's most heavily fished area. Because of this, densities of shrimp, both offshore and in the estuaries, are kept below carrying capacity. This should be especially true for white shrimp, which are heavily exploited in the estuaries (Chin, 1960).

According to Gaidry and White (1973), most experts in the field would agree that the tremendous reproductive capacity of penaeid shrimp renders little chance that the species are in danger of being depleted by overfishing. A limited number of spawners can produce a maximum population if environmental conditions are optimum (St. Amant et al., 1966). Jones and Dragovich (1977), in discussing the U.S. shrimp fishery off the northeast coast of South America, state that ". . .there is no evidence that the abundance of shrimp recruits is dependent on the abundance of the parent stock in the fishery." Berry and Baxter (1967) concluded that, of the many factors influencing the size of brown shrimp populations, only those that affect broad areas of the Gulf have a major effect on abundance. This implies that losses resulting from site-specific activities will be compensated for by inputs from adjacent areas. Kutkuhn (1963) and Gunter (1956) have emphasized that the greatest concern to future shrimp supplies are the long-range effects of man-induced environmental changes in the estuaries.

The penaeid fishery and also the "industrial" finfish industry (Chittenden and McEachran, 1976) operate mostly on single-year classes, and year-to-year fluctuations in populations are to be expected because of the short life cycles of the species. Fluctuations in the annual yield of shrimp result partly from variations in spawning success and in survival of the young in the inshore nursery grounds, which are generally subject to more extreme variations in environmental conditions than the offshore habitat of the adult shrimp.

Because of the great fecundity of the female shrimp, the abundance of shrimp in any one year is not closely related to the size of the parent stock, and a loss of a moderately sized spawning area will negligibly affect subsequent postlarval recruitment. Because the shrimp populations are kept below maximum density, shrimp density can increase in some areas if adjacent areas are negatively affected. This indicates that females could simply avoid the area of the plume and spawn elsewhere, with no loss at all to the fishery.

Historical Trends

In the historical record, there has been a notable change in Louisiana fish catch statistics regarding the two major species, brown and white shrimp. Lindner and Anderson (1956) state that white shrimp made up 95 percent of the total catch off the Louisiana coast at one time. A large decline in white shrimp harvest occurred after 1952, coincident with an increase in brown shrimp production. Viosca (1958) noted that reduction of the number of white shrimp was coincident with increasing salinities during the summer of 1952 to the spring of 1957, a prolonged period of dryness. The question of extended droughts and their relation to the annual productivity of commercial shrimp resources is discussed in the works of Hildebrand and Gunter (1953), Parker (1955), and Viosca (1958). Because young white shrimp display a greater propensity for less brackish water than do other species, it was assumed that higher estuarine salinities accompanying the drought caused environmental stress and reduced habitat carrying capacity, resulting in a lower annual biomass and yield for white shrimp. Such an assumption appears sound. McFarland and Lee (1963) found that white shrimp were better adapted to low salinities than were brown shrimp, with the latter better adapted to high salinities. This may explain why the greatest production of white shrimp has always been from the Louisiana coast, with brown shrimp production being greater in the more saline Texas estuaries. Gaidry and White (1973) reported that, for study area VII (which includes the West Hackberry area), the above-average occurrence of brown shrimp for 1970-1972 resulted from abnormally high salinity levels during this period.

APPENDIX G.1

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APPENDIX G.2
MENHADEN ECOLOGY

Distribution of Menhaden Species

Seven species of menhaden from the western hemisphere have been described. Two species, the American menhaden, *Brevoortia tyrannus* (Latrobe), and the Gulf menhaden, *Brevoortia patronus* Goode, dominate the Atlantic and Gulf of Mexico commercial menhaden fisheries, respectively. Gunter (1941) estimated that, on the basis of total biomass, the Gulf menhaden was the second most abundant fish in the Gulf of Mexico (the bay anchovy, *Anchoa mitchilli* is the most abundant).

Christmas and Gunter (1960) reported that *B. patronus* ranges around the northern Gulf from Brazos Santiago, Texas, to Tampa Bay, Florida, occurring as far off shore as 25 miles, but seldom at depths greater than 20 fathoms. Schaaf et al. (1975) reported that one population of *B. patronus*, ranging from southern Florida to Yucatan, supports a fishery from Florida to Texas. Reintjes and Pacheco (1966) define the principal region of abundance of the Gulf menhaden as Apalachicola Bay, Florida, to Galveston Bay, Texas.

Two other species, *B. smithii* Hildebrand and *B. gunteri* Hildebrand, are also caught off southern U.S. coasts. *B. gunteri* the fine-scale menhaden, is occasionally taken in commercially important quantities (Gunter 1967). The fine-scale menhaden ranges from Chandeleur Sound, Louisiana (east of the Mississippi River outfall) to Campeche, Mexico, whereas *B. smithii*, the yellowfin menhaden, is found in the eastern Gulf and the South Atlantic (Chandeleur Sound around the Florida peninsula to Cape Lookout, North Carolina). *B. smithii* has also been reported from Grand Bahama Island (Levi 1973). Springer and Woodburn (1960) found that Tampa Bay, Florida, is inhabited by both *B. patronus* and *B. smithii*, with the former being somewhat more abundant. Sykes and Finucane (1965) also found both species in Tampa Bay, but their study showed, *B. smithii* to be numerically more important. Tabb and Manning (1961) reported only one species, *B. smithii*, from Florida Bay in the southern portion of the state, supporting the relatively greater abundance of *B. smithii* in the bay waters of south Florida. Although Suttkus (1958) felt that the fine-scale menhaden did not range east of Grand Isle, Louisiana (Hildebrand 1948) it now appears that the ranges of the three species of menhaden inhabiting the Gulf of Mexico overlap in the Chandeleur Sound-Mississippi Sound region off Louisiana (Turner 1971).

A number of bibliographies of menhaden have been produced including Christmas and Collins, 1958; Gunter and Christmas, 1960; Reintjes, Christmas and Collins, 1960; and Reintjes and Keney, 1975. The reader is directed to these publications as well as Christmas and Etzold (1977) for a comprehensive bibliography of the genus *Brevoortia*.

Feeding Behavior

The adult menhaden has a typical shadlike appearance, with a laterally compressed and deep body, quite unlike the long, slender larvae and juveniles of less than 25 mm in length. Reintjes and Pacheco (1966) state that the larval Gulf menhaden are particulate-feeding carnivores (especially microcrustaceans), and juveniles are nonselective filter feeding omnivores (primarily algae and macrocrustaceans). The adult form is assumed by the time the menhaden reaches 50 mm in length. The relatively large head bears no teeth, for the adult menhaden is also a filter-feeder. Food particles are strained from the water column by highly developed gill rakers, which are long and slender and have interlocking lateral filaments. The menhaden swim about in schools with their mouths gaping open, feeding on plankton (Reintjes and June 1961) and plant detritus (Darnell 1958). Gunter (1938) described his observations of large schools of menhaden feeding on the surface in Caminada Bay "... where they wheeled, turned, and swerved from side to side in perfect unison, all the while with mouths agape and lower jaws thrust forward ..."

Menhaden are assumed to form an important component in the estuarine food web, one of the few estuarine fishes (along with the mullet and anchovy) that is a filter-feeding omnivore. However, it is not well represented in stomach contents of carnivorous fishes collected in scientific studies (Miles 1950, Knapp 1950, Simmons and Breuer 1967). Apparently, although menhaden are fed on voraciously at times, they are not a preferred food of most predatory fish.

Life History

The menhaden life cycle typifies that of the estuarine-dependent euryhaline organisms that dominate the commercial fisheries of the Gulf coast. Gunter (1936, 1938) and Gunter and Shell (1958) found B. patronus common in shallow Louisiana estuaries, and Simmons (1957) and Reid (1955, 1956), found similar trends in Texas bays. All information indicates that estuaries are vital to the survival of menhaden, with the quantity and quality of estuaries limiting the size of the menhaden resource. Gunter (1967) estimated that estuarine-dependent species of finfish and shellfish made up about 97.5 percent of the total commercial fisheries catch in the Gulf.

Gunter (1967) provides an excellent summary of the "marine-estuarine" life history. "...The eggs are spawned at sea and the larvae somehow make their way into the low salinity waters of the estuaries. The young animals develop in the estuaries and then return to or towards the sea. This is an extremely important phenomenon and constitutes a general law regarding most of the large motile estuarine organisms of the south Atlantic and Gulf coasts of the United States..."

According to Reintjes (1970), the Gulf menhaden spawn in oceanic waters, with most of the spawning occurring from December to March within the 50-fathom depth contour. Based on the results from the RV Dolphin surveys along the mid-Atlantic coast, Kendall and Reintjes (1975) found that Atlantic menhaden larvae were more abundant in the upper 15 m of the water column. Nelson et al. (1977) state that the passive drift phase of the transport of Atlantic menhaden larvae ends when they reach 10 to 12 mm. Fore and Baxter (1972) found a significant avoidance problem in their daytime sampling of larval menhaden at Galveston Jetty.

Larvae are 10 to 25 mm in length when they arrive at the passes, having been transported by ocean currents for up to 3 to 5 weeks. After the postlarvae transform into juveniles, they move into the upper reaches of the estuary and then, through the summer, gradually move back toward the mouth of the estuary as they grow. Suttkus (1956) reported that, by the time they reached juvenile size (30 mm), menhaden were spread throughout the estuary. However, even though they were spread over the entire estuary, within each area the schooling tendency persisted. By September young-of-the-year menhaden are generally moving in and out of the passes and by October, with the passage of the first "norther," many leave the estuary for the open Gulf. This offshore exodus coincides with the migration of the remaining stock of 1-year and older menhaden in the Gulf to deeper waters, which brings the offshore commercial fishing season to an end. Relatively few of these young-ofthe-year menhaden which make up the 1-year-old age class for the next commercial season, are caught by purse seiners.

Reintjes (1970) summarized three broad factors on which the success of the year class is based:

1. Spawning success, survival in the open Gulf, and movement into the estuaries.

2. Capacity and suitability of the estuaries for menhaden growth and survival.

3. Fishing pressure, and especially its effects on relative year class strengths and the number of menhaden that survive to sexual maturity.

Reintjes (1970) emphasized the importance of the estuarine environment to the menhaden resource.

Christmas and Waller (1975) state that adult menhaden return to rich nursery areas in the spring and emigration from bays and sounds is not complete in the fall, with some menhaden usually found in the bays throughout the year, especially during milder winters. Gunter (1967), in discussing the generalized life cycle of estuarine-dependent species in the Gulf, states that many fish that migrate to the open Gulf in fall and are not common in the bays in the winter, return to inshore waters in the spring. Kroger and Pristas (1974) attributed the low recovery of tagged 1-year-old menhaden in offshore catches to the fact that many never left the estuaries, which was demonstrated by the numbers of menhaden captured in estuarine surveys conducted concurrently with the offshore study.

Few studies in the open Gulf have adequately characterized the temporal and spatial distribution of the adult populations of menhaden, especially in the northwest Gulf. Most scientific studies have used demersal trawling. Demersal trawls do not satisfactorily sample menhaden, which show strong schooling tendencies and generally are not demersal. Because demersal studies are the only nekton studies that have been conducted extensively, the findings from these studies are included in this discussion.

Hildebrand (1954) collected a few Gulf menhaden at stations as deep as 18 fathoms in trawl samples off Texas. Roithmayr and Waller (1963) found menhaden populations in the northern Gulf in winter in waters from 4 to 48 fathoms. Christmas and Gunter (1960) report that USFWS personnel aboard the MV Oregon made isolated catches of Gulf menhaden in waters of depths greater than 50 fathoms. Turner (1969) reported the results of gill nettings in the eastern Gulf, in which all adult menhaden were collected within the 10-fathom contour. Gill nets fished at eight locations in deeper water (32 fathoms) did not catch menhaden.

Probably the most comprehensive study of movement of juvenile Gulf menhaden and their distribution in the Gulf as 1-year-old fish were those conducted by the National Marine Fisheries Services (NMFS), beginning in 1970 (Kroger and Pristas 1974). Thousands of juvenile menhaden (average length of 72 mm fork length) were released in 11 estuaries from Brownsville, Texas, to Pensacola, Florida, from September 15 to November 20, 1970. Tags were recovered in menhaden reduction plants. In most cases, 1-year-old menhaden migrated to offshore fishing areas near the estuaries in which they were raised. The apparent lack of distinct east-west movement indicated that recruitment of 1-year-old menhaden to each of the three commercial fishing areas (northeast Gulf, northwest Gulf, and Delta region) depends on the number of juveniles produced in the estuaries adjacent to each fishing area. Juvenile menhaden produced in estuaries west of the Mississippi River Delta did not show up as 1-year-old fish in catches made east of the Delta. These results indicate that menhaden move only a short distance from the summer grounds during the winter.

Spatial and Temporal Patterns in Menhaden Spawning

Christmas and Waller (1975) reviewed much of the existing literature with reference to spatial and temporal patterns in menhaden spawning. They point out that actual spawning of menhaden in the Gulf of Mexico has not been observed. The temporal and spatial patterns in spawning have been inferred from size distributions of adults and juveniles, gonadal condition of adults and distribution of the planktonic egg and larval stages.

Miller (1965) collected three specimens of B. patronus in the Gulf of Mexico off Aransas Pass, Texas, at 3 and 6 fathoms in demersal trawls. He concluded that the 55-mm specimen collected in February supported the contention of Suttkus (1956) that Gulf menhaden spawn as early as October in Louisiana. On the basis of data collected off the east coast of Louisiana from 1951 to 1958, Suttkus and Sundararaj (1961) found that B. patronus showed enlargement of the gonads in preparation for spawning during late fall, with spawning essentially being completed during February and/or March. Histological condition of the ovaries showed agreement with the spawning trends indicated by ovary weight. The authors found about 20,000 and 35,000 large eggs in the ovaries of age group I and II fishes, respectively. Nelson et al. (1977) report the average fecundity of Atlantic menhaden as 113,000 eggs per female. Turner (1969) found menhaden with ripening gonads from December through February in the eastern Gulf and by March most menhaden were spent or recovering.

Eggs of menhaden appear to be present in the northern Gulf from October to March (Fore 1970; Christmas, Waller, and Perry 1974). Turner (1969) states that, as of the time of his study, eggs of Gulf menhaden had not been described. During the winters of 1964-65, 1965-66, and 1966-67, monthly cruises were conducted by NMFS (Pascagoula, Mississippi) to determine the distribution of clupeids in the eastern Gulf of Mexico (Cape Sable, Florida to Chandeleur Island, Louisiana). Gill nets were placed near menhaden schools, and plankton tows were taken concurrently. Peak spawning off Florida occurred in January and February; eggs and larvae where also collected in December, indicating that spawning had occurred as early as November. Larvae were most abundant in March. A very strong trend was found regarding the offshore occurrence of menhaden eggs and larvae in this study; all planktonic stages were collected within the 10-fathom contour, and most of these were collected within the 5-fathom contour. In Mississippi Sound and adjacent waters, menhaden eggs and larvae were taken in greatest numbers during December and January, with indications of spawning in November. The overall conclusion of the study was that menhaden spawn close to shore during fall and winter in the northeast Gulf of Mexico.

Studies conducted in the western Gulf (Turner 1969; Christmas, Waller and Perry 1974) found menhaden spawning restricted to near-coast waters (within 15 nautical miles of the coast). However, Fore (1970), who studied much of the northern Gulf of Mexico, found that, west of the Delta, the menhaden spawning grounds were further from shore, within a range of 4 to 40 fathoms. He collected relatively few samples close to shore. Given the patchiness of the distribution of menhaden eggs and larvae, Fore could have missed the patches of eggs and larvae. Kendall and Reintjes (1975), who reported on the results of Atlantic menhaden egg and larvae collections on the RV Dolphin cruises off the mid-Atlantic coast, found egg and larval distribution to be very patchy, reflecting the schooling habit of the spawners. Because development is rapid, larvae as well as eggs remain clumped in distribution.

Christmas and Waller (1975) reported that menhaden eggs have been collected from Gulf waters that have depths ranging from 1.8 to 109.7 m, with an average depth to bottom of 21.8 m. Generally, the samples collected closer to shore had more developed larval stages. Most (71 percent) of the samples with eggs were collected within 10 fathoms, but only 18 percent were collected inside 5 fathoms.

Fore (1970) found that maximum concentrations of menhaden eggs occurred around the Mississippi Delta. On the basis of egg and larvae distribution patterns in the northern Gulf, Christmas and Waller (1975) also found that the area of the Mississippi Delta had very high concentrations of these planktonic stages, suggesting that menhaden spawning might be heaviest in this area. Gillespie (1971), who discussed the results of the Louisiana (coastwide) Cooperative Estuarine Inventory, found maximum concentrations of fish eggs and *B. patronus* larvae in the Breton Sound area, just east of the Mississippi Delta.

Christmas, Waller, and Perry (1974) found larvae present in samples from the Gulf off Mississippi from January through March. Of a total of 1439 plankton samples from a number of sources Gulf-wide, Christmas and

Waller (1975) found menhaden eggs in only 77 samples. The temporal distribution of eggs in these 77 samples indicated a long (6-month) period of menhaden spawning. They also found a distinct peak in larvae presence in March, with no larvae found in October or April.

In the Atlantic, the results from the RV Dolphin cruises and the MV Theodore N. Gill cruises showed that Atlantic menhaden larvae were distributed from near shore to the edge of the continental shelf. There was a trend for larger larvae inshore. The situation on the Atlantic coast is differs appreciably from that in the Gulf because of longshore migration of menhaden stocks in response to changing temperatures. In New England, spawning occurs well inshore in summer, with spawners moving progressively into deeper water as they migrate south along the Atlantic coast. Massmann et al. (1962) found menhaden larvae as small as 7 mm, 79 km off Chesapeake Bay, and the results of the Theodore N. Gill cruises showed that larval menhaden were taken as far off shore as 220 km off Cape Fear, North Carolina. Because menhaden spawn further off shore in the South Atlantic, very few small larvae (<12 mm) have been taken in the estuaries of the region.

Very few studies have been conducted on transport of larval Gulf menhaden through estuarine passes. NMFS studied this transport by sampling every 2 h over a 96-h period between April 1 and 5, 1963, in conjunction with a study on the distribution of shrimp larvae near Galveston Inlet (Fore and Baxter 1972). The results showed that highest catches were made at night and on ebb tides. The diurnal effect was attributed to net avoidance during the day, indicating that larval (or small juvenile) menhaden have considerable motility. The authors noted that the transport pattern for menhaden larvae was strikingly similar to that for postlarval brown shrimp, *Penaeus aztecus*.

Nelson et al. (1977) used wind drift data (Ekman transport) computed from mean monthly atmospheric pressure distributions to help predict Atlantic menhaden catches. In general they found that stronger westward transport (offshore to onshore) occurred between November and February in the middle Atlantic region, the period of peak menhaden spawning, and suggested that this might provide a mechanism by which menhaden larvae could be transported long distances to the estuaries. They used a Ricker spawner-recruit curve with the potential number of eggs that could be produced by the spawning stock as the independent variable to account for density-dependent variations. The potential number of eggs depends on the age distribution of the spawners and their size. The parameters of the model were estimated from a linear regression of ln (R/S) on S, where R equals recruitment and S equals the spawning stock. The authors then attempted to explain deviations from this curve that might be caused by density-independent factors, such as environmental variables. They calculated a survival index as the ratio of observed recruits (number of age 1 individuals in the population, as estimated from the catch of age 1 individuals and estimated exploitation rates) to the number of recruits calculated from the Ricker spawner-recruit model. They felt this ratio, which is density-independent, should reflect the environmental effects that influence survival of menhaden before recruitment to the fishery. They found that 62 percent of the variance in the survival index was explained by zonal Ekman transport. They then developed a multiple regression model to predict survival index from several environmental variables and found that 84 percent of the variation in survival index was explained by the model. Nelson et al. (1977) attributed the lower correlations between survival index and Ekman transport in the middle Atlantic (as compared with the south Atlantic) to the increasing importance of long-distance oceanic transport as spawning activities move progressively southward (and off shore) in the Atlantic. If Gulf menhaden spawn close to shore, Ekman transport may not be important (as in the New England and mid-Atlantic Bight Areas on the Atlantic Coast). However, if significant spawning occurs in deeper waters in the northwest Gulf, long-range Ekman transport may be important.

<u>Presence of Larval and Juvenile Menhaden in Estuaries</u>

Springer and Woodburn (1960) found young Gulf menhaden (average length of 23.5 mm total length) most abundant in Tampa Bay, Florida, in March. Tagatz and Wilkins (1973) found that small menhaden (<30 mm SL) began entering Pensacola Bay, Florida, in December, with the influx continuing through April. This indicated that spawning was occurring from October to late March.

Hoese (1965) suggested that menhaden spawning occurred in the Port Aransas area of Texas in fall and winter. Simmons (1957) reported the presence of larval menhaden in the Laguna Madre from March through May. Arnold et al. (1960) report that monthly plankton tows in the East Lagoon of Galveston Bay revealed the presence of larvae from November through May.

The results of Christmas and Waller (1973) and Perry et al. (1974) showed that small menhaden are found in Mississippi estuaries from November through May. Results from the Louisiana Cooperative Estuarine Inventory (Perret 1971) showed the presence of larval menhaden (20 to 30 mm total length) from September through May, with the highest abundance occurring during February and May. Dunham (1972) reported that larval menhaden were found in plankton samples collected from September and November through April in Louisiana inshore waters. Herke (1971), Fore and Baxter (1972), and Arnoldi (1974) found that, in the Chenier Plain region, peak immigration of larval menhaden into the estuaries occurred in the December to March period.

Gosselink et al. (1979) report the initial results of the NMFS juvenile monitoring program. Apparently, the estuaries in the Chenier Plain region (southwest Louisiana and southeast Texas coast from Vermilion Bay to Galveston Bay) are very heavily used by juvenile menhaden. Gosselink et al. (1979) attribute this to the downcoast proximity of the Chenier Plain region to the area of major spawning (Mississippi Delta). Perry (1976) estimated a standing stock of menhaden in the Rockefeller Wildlife Refuge of 64.2 kg/ha.

The evidence at hand indicates that there may be two major spawning populations of menhaden in the northern Gulf, located east and west of the Mississippi Delta. Results of Kroger and Pristas (1974) indicated that adults remained close to the estuaries in which they were raised.

Each spawning population is centered close to the Mississippi Delta, but spawning occurs to some degree all along the coast. Many eggs and larvae are transported longshore by the prevailing currents (westward in northwest Gulf and eastward in the northeast Gulf).

Many studies have shown that menhaden are present in the coastal estuaries during most of the year. Gunter (1938), who trawled for bottom fish in Barataria Bay and the adjacent waters of the Gulf of Mexico, found that, except for February 1932, B. patronus was present in samples collected from the bay in all months from October 1931 through February 1934. B. patronus was found in trawl samples collected from the adjacent Gulf of Mexico during all months sampled from October 1931 to January 1934 except for September 1932. He noted that major peaks occurred in the catch of B. patronus in Barataria Bay, Louisiana, in January 1932 and January and February 1934. A smaller peak also occurred in December 1932 and January 1933. Gunter concluded that there was ample evidence to establish that peak abundance for B. patronus occurred in winter in the open bays, and these mainly small individuals were probably spawned the previous summer and fall. He felt that these winter-caught specimens had possibly moved into the open bay from the nursery areas, making them somewhat more susceptible to collection with the trawls. This would represent a clear case in which menhaden did not return to the open Gulf in the fall and winter. He noted that mainly larger individuals were collected in the Gulf, although some small individuals were taken along the beach.

Dunham (1972) presented length frequency histograms for menhaden collected in otter trawls in Barataria Bay. Young menhaden less than 40 mm were generally found in the late winter to early summer, but were also present in November and December 1971 and in January 1972. Perrett et al. (1971) found large-scale menhaden to be most abundant in Louisiana estuaries in May and least abundant in January, although the species was collected during all months of the year. B. patronus was the most abundant organism taken in seine samples in Louisiana estuaries during the Cooperative Estuarine Inventory being found in all Louisiana estuaries studied. They were most abundant in the western portion of Chandeleur Sound and Lake Borgne, close to the Mississippi River Delta.

Suttkus (1956) found that young-of-the-year Gulf menhaden in Lake Pontchartrain reached about 90 mm by late summer and were about 140 mm at the end of the first year. These fish had entered the lake in December as larvae and postlarvae and moved out in the fall. Presumably, spawning had begun in October.

Perrett and Caillouet (1974) sampled Vermilion Bay, Louisiana, with otter trawls from June 1964 through September 1965. Specimens of B. patronus that were collected ranged in size from 32 to 172 mm (total length). Because otter trawls are not particularly effective in collecting menhaden, numbers of B. patronus captured were variable, although the species was captured during every month. During the first year (June 1964 to May 1965), no seasonal trend in catch was evident, but in the summer of 1965, much higher catches were made.

Parker (1965) found that *B. patronus* was abundant in Galveston Bay and could be found year-around throughout the bay system. McFarland (1963), who seined the surf area off Mustang Island, Texas, during 1960 and 1961, found *B. patronus* to be present from May through August of 1960, but absent during the December 1960 to July 1961 period. Simmons and Breuer (1977) reported that small menhaden entered the upper Laguna Madre in late January 1960 and that they had grown to a modal length of 48 mm by mid-June. They also noted that two other year classes (1 and 2) were also in the Laguna Madre at this time, with model lengths of 135 and 210 to 225 mm respectively. This tendency for reinvasion of the estuaries by 1- and 2-year-old fish appears to be a recurring trend.

Sykes and Finucane (1965) found *B. patronus* and *B. smithii* in Tampa Bay, Florida, mainly in the spring and summer. In Old Tampa Bay, which was relatively unimpacted, typical sizes for *B. patronus* were 24 to 74 mm in spring and 58 to 115 mm in summer. One individual, 105 mm in length, was found in the fall sampling in Old Tampa Bay.

These results indicate that, depending on the particular year, menhaden can occur in significant numbers in estuaries and bays of the northern Gulf of Mexico during any month. Although the major period of growth of menhaden is obviously in the spring and summer, the long periods of spawning by the adults and estuarine residency of young-of-the-year menhaden, combined with tendencies of these young-of-the-year menhaden to remain in the estuaries during milder winters and the adults to reinvade the estuaries in spring, explain the presence of menhaden in the estuaries year-round.

Salinity Relationships

As is typical of the estuarine-dependent fauna of the northwest Gulf of Mexico, menhaden are euryhaline at all stages of their life cycle. The Gulf menhaden is perhaps one of the most euryhaline organisms in the Gulf of Mexico. They also appear to be quite tolerant of varying temperatures, although severe winters (water temperatures less than 4°C) have been known to cause mass mortality of menhaden present in inshore waters.

Turner (1969) found eggs and larvae of Gulf menhaden in samples collected at surface water temperatures, varying from 11°C (February) to 23°C (March). In Mississippi Sound, salinities varied from 25 to 32 ppt during the time that menhaden eggs and larvae were collected. Christmas and Waller (1975) found that, for samples from across the northern Gulf, eggs were found at temperatures ranging from 12.4 to 25.7°C (average 18.7°C) and at salinities ranging from 6.0 to 36.6 ppt (average 30.4 ppt). Of the samples with menhaden eggs 88% had salinities greater than 25 ppt.

Lewis (1966) found that at 0 ppt larvae of *B. tyrannus* survived less than one day at temperatures between 2 and 6°C. Survival time increased with increases in both salinity and temperature, and the upper and lower limits of salinity tolerance increased with increasing temperature. Salinities between 5 and 35 ppt appeared to minimally affect survival time. Lewis and Hettler (1968) found that acclimation history and rate of change of test conditions were important factors in survival of young Atlantic menhaden in their experiments. At salinities of 5 ppt, significant mortality occurred at 34°C, and most temperature-salinity combinations of 34.3 to 36.5°C and 31 to 34 ppt caused mortality.

Christmas and Gunter (1960) reported that the young of both B. smithii and B. gunteri enter freshwater. Several studies corroborate the preference of juvenile menhaden for the less saline portions of the estuaries (Gunter and Shell 1958; Baldauf et al. 1970; Arnoldi 1974). Conner and Truesdale (1972) found that the primary nursery habitats for menhaden are the interior marsh lakes and bayous. Gunter and Shell (1958) collected small B. patronus in Grand Lake, Louisiana, in salinities in the freshwater range (0.10 to 0.19 ppt).

Lichtenheld and Hettler (1968), who conducted laboratory studies on young Atlantic menhaden, hypothesized that there may be a gradual seasonal change in salinity preference as young-of-the-year menhaden grow and move down the estuaries, eventually into the sea. They suggest that this movement may be in response to increasing temperatures in the low-salinity nursery areas, forcing the juveniles to seek higher-salinity waters, which they are better able to tolerate at higher temperatures.

The range of water salinities and temperature for the samples with B. patronus collected from Louisiana estuaries (Perrett et. al., 1971) were fresh-water to 30.0 ppt and 5 to 34.9°C. The greatest number of individuals were taken in a salinity range of 5.0 to 24.9 ppt and in a temperature range of 20.0 to 34.9°C. The size range of specimens collected was 10 to 210 mm, and the average size was 60 mm.

Dunham (1972) found menhaden to be present at all stations he sampled with otter trawls in Barataria Bay, Louisiana. The range of salinities for collections in which menhaden were found was 1.3 to 29.1 ppt, while the temperature ranged from 5.5 to 30.6 ppt and the size ranged from 25 to 255 mm.

Copeland and Bechtel (1974) summarized the results of previous studies dealing with the temperature and salinity ranges found for B. patronus. Large scale menhaden were collected in salinities ranging from freshwater to 45 ppt. They generally found menhaden to be distributed throughout the estuaries. Catch ratios (an indicator of abundance) increased from February to June and then rapidly declined to almost zero in September. The late winter and spring increase was attributed to an influx of juveniles from the open Gulf. On the basis of a comprehensive summary of relevant data, Copeland and Bechtel (1974) found that catch of juvenile Gulf menhaden in estuaries were distributed as follows:

- o Temperature range, 0 to 40°C; optimum catch, 25 to 35°C.
- o Salinity range, 0 to 26 ppt; optimum catch, 0 to 12 ppt.
- o Season, all months; optimum catch, April to August.

Copeland and Bechtel (1974) summarized the results of their analysis of existing menhaden data in a series of two-way plots, relating catch ratio to various combinations of environmental variables (season, salinity, temperature, and location in the bay). They conclude that there are clear temperature-salinity patterns, with juvenile menhaden found more often in low-salinity water when temperatures are high. Menhaden are abundant in a wider salinity range at higher temperatures and in a wider temperature range at lower salinities. They concluded that location in the estuary was probably more influential than salinity per se in determining estuarine distribution of juvenile menhaden.

The adults appear to be equally euryhaline. This is apparent by their ability to migrate back into the estuaries as year 1 fish. Gunter (1945) found B. gunteri in mesohaline bays and also in the freshwater environs of the Mission River in Texas. Simmons (1957) reported B. gunteri as common in the hypersaline Laguna Madre of Texas at salinities of 20 to 60 ppt, but uncommon above 60 ppt. Simmons (1957) found that B. patronus was commonly taken in salinities of up to 60 ppt in the Laguna Madre. Christmas and Gunter (1960) reported isolated catches of menhaden in waters of about 20 fathoms depth (maximum salinity, 36.2 ppt). Christmas et. al. (1960) found that, of the 87 purse seine sets studied (mainly off Louisiana), more than 2 million pounds of menhaden were caught; 70 percent were caught in waters ranging in salinity from 5 to 24 ppt, with the highest salinity for any catch being 31.6 ppt. They showed that menhaden catches in Louisiana, Mississippi, and Alabama were made in salinities of 6.2 to 31.6 ppt, with 88 percent made between 15 and 29 ppt; the average salinity was 21.4 ppt. Gunter (1956) and Briggs (1958) listed B. patronus as euryhaline.

Historical Trends in The Menhaden Fishery

Menhaden were reportedly landed as early as 1900 in the Gulf of Mexico. Christmas and Waller (1975) report that the first menhaden landings in Texas occurred before 1920 and not until after 1945 in Louisiana. The annual catch remained small until after World War II (Chapoton 1971). From 1946 to 1970, there was a 15-fold increase in menhaden landings (35,000 to 546,000 metric tons). The increase was not continuous; decreases in landings occurred several times in the 1950s and 1960s.

In 1963, when Atlantic menhaden landings began to decline, the fishery for Gulf menhaden became the largest single fishery in the United States. During 1971, of the 2.19 billion pounds of menhaden landed at U.S. ports, 73 percent were landed in the Gulf states.

The number of operating menhaden reduction plants increased from 2 in 1946 to 14 in 1968, and there were 13 plants in 1970. Each plant is supplied by 6 to 10 vessels, and between 70 and 90 vessels make up the Gulf fleet. Thirty-five spotter planes were in use in 1971. Christmas and Waller (1975) report that, in 1971, the wholesale value of Gulf menhaden products was greater than 43 million dollars, and the 80 menhaden vessels fishing the Gulf were valued at 31.2 million dollars. The 13 processing plants in operation at that time were valued at greater than 42 million dollars, and more than 2000 people were employed in menhaden operations along the Gulf.

The average size (tonnage) of the vessels has increased through the years, from 54 tons in 1946 to 245 tons in 1971 (a five-fold increase).

Because a vessel's effective fishing ability is well correlated with tonnage, fishing effort for the menhaden fishery is usually expressed as tonnage-weeks (tonnage times weeks). Other factors that have increased the fishing power of vessels over the years include aluminum purse boats, power blocks, synthetic fiber nets, fish pumps and refrigerated holds. By 1965 most of these innovations and improvements in the Gulf fleet had been made (Reintjes 1969). Schaaf (1975) reports that refrigerated vessels were introduced into the Gulf fishery in 1956 and, by 1964, dominated the fleet. Schaaf (1975) noted that technical development of the Gulf menhaden fishery paralleled that of the Atlantic fishery after World War II, with most innovations being tried first on the Atlantic coast. Today, the Gulf fishery is the more advanced operation, with newer, larger, and more powerful vessels.

Through the 1960s there was a distinct trend for the landings at Louisiana ports to increase and the landings at ports in other Gulf states to decrease. Florida and Mississippi landings decreased from 30 percent of the total Gulf landings in 1961 to 17 percent in 1970. For Texas, the annual landings decreased from 13 percent of the total in 1961 to 4 percent in 1970. The Texas commercial fishery for menhaden, which began in 1950 (Simmons and Breuer 1967), essentially ended with the closing of the menhaden fish plant at Sabine Pass, Texas, in 1972.

According to Fisheries of the United States (NMFS, 1981), the Gulf menhaden catches in 1979 and 1980 were 1.72 and 1.55 billion pounds, respectively. Of the 1.55 billion pounds of menhaden caught in the Gulf in 1980, 1.31 billion pounds were caught within 3 miles of the coast. The 1979 Gulf catch was valued at 73.4 million dollars whereas that for 1980 was valued at 69.1 million dollars. For the 5-year period, 1975 to 1979, the average annual catch of Gulf menhaden was 1.39 billion pounds.

Because of the intense schooling habits of menhaden and their common occurrence in the upper portions of the water column, they are not fished with trawl nets. Purse seining is the most commonly used commercial technique on both the Atlantic and Gulf coasts. A typical menhaden purse seine vessel is 100 to 150 feet in length, carries a crew of 20 to 25 men, and includes two 34- to 36-ft purse boats and one smaller strike boat. The strike boat follows the school until the purse boats can be positioned.

In years past, many hours were spent in a crow's nest searching for schools of menhaden. Today, this has drastically changed with the advent of small, single-engine spotter planes. These aircraft leave port early in the day and guide the menhaden boats to the schools of fish. The spotter plane also aids in setting the purse seine by the purse boats.

The purse seine itself is the preferred technique worldwide for capturing schooling fishes in the open seas. A typical Gulf purse seine is 1400 ft long and 90 ft deep and is supported at the top with floats and weighted at the bottom with a metal ring-weight, through which the purse rope is threaded. The purse rope is used to close the bottom of the fixed net ("pursing" the net). The two purse boats, each with one end of the purse seine, head in opposite directions, encircling the school as they come together on the far side. The purse rope is then drawn tight, and the net with the entrapped menhaden is drawn in. An exceptional set may yield a quarter of a million fish, although sets yielding 50,000 to 100,000 fish are considered good. Each set takes about 2 h, and four to five sets are made each day per boat. Results from a number of studies (Knapp, 1950; Filipich, 1947; Gunter, 1963; and Dunham 1972) have shown that menhaden purse seining is a very selective method of fishing, with about 99 percent of the catch being composed of the target species.

Reintjes (1970), in comparing the Atlantic and Gulf menhaden, noted that B. patronus is a shorter-lived species with a higher reproductive potential and, as such, has a greater capacity to recover quickly from a bad year (induced by overfishing or poor recruitment). The catch in any one year depends strongly on the success of recruitment of 1-year-old fish into the offshore population during the previous fall. The Atlantic menhaden attains a larger size than does the Gulf menhaden. Reintjes (1969) reports individual B. tyrannus as large as 420 mm, whereas Chapoton (1970) reports the largest Gulf menhaden to be 247 mm.

The Gulf menhaden fishery appears to depend on two age classes (1- and 2-year-olds) for quantitatively significant harvests. Young-of-the-year fish are not important in commercial catches because they fail to appear on the offshore grounds until fall, after the offshore commercial season is effectively over. Chapoton (1970) reported that 1-year-old menhaden make up about 50 percent of the annual Gulf coast catch. Gulf menhaden age groups of 3 to 5 years collectively contribute about 10 percent to the annual catch (Reintjes 1970). Christmas and Waller (1975) reported that samples of Gulf landings made by NMFS in 1974 indicated that age 1 menhaden constituted 64 percent of the catch and age 2 fish constituted another 34 percent. They noted that the failure of a single year class could drastically reduce the catch in the following year. The number of recruits has varied significantly from year to year (indicated by the catch of 1-year-old fish). Because the fishery is based on only two year classes, the catch varies tremendously from year to year because of variations in recruitment. For example, in the 1967 to 1969 period, annual catch of 1-year-old fish varied from 28 to 68 percent of the total catch (Chapoton 1971). If two bad recruitment years were to occur back to back, the commercial catch would be seriously affected since the cushion that might be provided by sizable populations of older menhaden does not exist. This is in marked contrast to the situation for the closely related Atlantic menhaden, where each of four or five age classes have contributed significantly to the annual catches in particular years. For example, Nicholson and Higham (1965) found that the 1958 age class of Atlantic menhaden dominated the annual catches for at least 4 years, during which time recruitment was very poor.

Christmas and Etzold (1977) found that the Gulf menhaden fishery was most intense within 3 miles of the coast. Legal closed seasons have been adopted by Mississippi, Alabama, and Louisiana to protect the spawning stock in winter months. Simmons and Breuer (1967), who described the Texas menhaden fishery, concluded that the present unavailability of the spawning menhaden schools in winter (movement offshore) was probably the greatest factor in preventing overexploitation of the fishery.

Fisheries Management

Schaaf (1975) reports that both the Atlantic and Gulf menhaden fisheries are conducive to (similar) management practices because they are: (1) wholly domestic, (2) based on a single species, (3) harvested and processed with the same technology, (4) well studied, and (5) vertically integrated.

Several attempts have been made to provide quantified models of the Gulf menhaden fishery for management purposes. Chapoton (1971) regressed catch per unit effort (CPUE) (in metric tons of menhaden vessel tonnage-week) versus effort (in thousands of vessel tonnage-weeks) to describe the historical trends in menhaden catch for the Gulf and Atlantic fleets. The final equation for the Gulf,

$$\text{CPUE} = 2.1238 - 0.0026\ (\text{Effort})$$

indicates that, as effort increases (in later years of the time series), CPUE decreases. The coefficients of this equation were used to calculate maximum sustainable yield by using the methods of Schaefer (1954), where

$$\text{Catch} = 2.12\ (\text{Effort}) - 0.0026\ (\text{Effort})^2 = 434{,}000 \text{ tons.}$$

This yield could be accomplished by 408,000 vessel tonnage-weeks of effort. According to the model, additional effort would negatively affect the population and would tend to reduce future yields. Chapoton (1971) concluded that the Gulf menhaden fishery had reached its predicted maximum yields. Since landings of Gulf menhaden increased at the rate of 59 percent/year between 1946 and 1970, there was concern that the fishery might be overdeveloped before irrefutable evidence is found that this is taking place. Schaaf (1975) updated this model using 1971 and 1972 data; the 1971 data represented the largest catch of Gulf menhaden (about 700,000 metric tons) recorded to date. New values for maximum sustainable yield (MSY) were 478,000 metric tons with 460,000 vessel tonnage-weeks of effort.

Schaaf et al. (1975) used multiple regression models to predict the catch of Atlantic and Gulf menhaden in a given year using catch and effort data (vessel tonnage-week) in prior years. Data for the Gulf of Mexico were based on 27 years of records (1946 to 1972). Results of the analysis showed 86 percent of the variation in the data for the Gulf fishery was explained by the regression model. The model was used to forecast catch for the 1973 and 1974 calendar years, and the errors of the estimates were only 2 and 1 percent, respectively. Schaaf et al. (1975) note that, over the 27-year period, predicted catch agreed more closely with actual catch in the earlier part of the record. They hypothesized that the increase in effort in later years took larger and larger percentages of the available fish. Because of this, the strength of the year class greatly influenced the catch for the next year. Since year class 1 constitutes about 50 percent of the annual menhaden catch, the variability of the catch increased substantially in the later years. For example, although the menhaden catch was 479,000 tons in 1962, it fluctuated between 316,000 and 728,000 tons from 1964 to 1972. Schaaf et al. (1975) point out that the ecological factors underlying these trends in menhaden catch can only be elucidated through a more detailed examination and knowledge of the biology of menhaden recruitment.

Stone (1976) used several statistical techniques to relate menhaden harvest data for Louisiana for the period 1950 to 1971 with environmental variables that were through to be important to the menhaden life cycle. Effort was expressed as vessel-weeks and was therefore not standardized. Based on monthly data, six variables accounted for 81 percent of the variation in the menhaden catch, with effort, year, and four wind (strength and direction) x temperature variables entering the model; effort was the most important variable. Effort and year together account for 70 percent of the variation in catch. When lagged variables were included in the model for monthly data, the R^2 (amount of variance explained by the model) increased to 86.2 percent. Significant variables in the eight-variable model (in descending order of significance) included effort; minimum air temperature x month lagged 12 months, wind direction at New Orleans x month; wind direction at Baton Rouge x minimum air temperature lagged 12 months; wind direction at New Orleans, mean air temperature, minimum air temperature x month; and maximum water temperature. When effort and yearly effects were removed from the analysis, the R^2 value was only 55 percent.

A best-three-variable model, based on annual data, showed an R^2 of 80.0 percent. The three independent variables included in the model were yearly effects, effort, and the sum of the minimum monthly air temperatures during December, January, and February.

Cross-correlation analysis indicated that menhaden harvest in individual months was related to maximum tidal range during portions of the winter and spring of the same year and the previous 2 years. A similar trend was seen for wind speed.

Schaaf (1975) has proposed a quota system as an initial step toward managing the Gulf menhaden fishery. Because of the high reproductive potential of the Gulf menhaden and the expected resiliency this provides against overfishing, he felt liberal quotas could be set. He summed up our knowledge of the Gulf menhaden resource and fishery, indicating that the most pressing needs are for (1) valid information on the age structure of the population (to allow calculation of mortality ratios); (2) assessment of the adequacy of the measurement of fishing effort (tonnage-weeks); and (3) valid techniques to quantify the strength of recruitment upon which quotas can be established.

<u>Summary</u>

Of the seven species of menhaden described from the western hemisphere, the Gulf menhaden (<u>B. patronus</u>) and the American menhaden (<u>B. tyrannus</u>) dominate the Gulf of Mexico and Atlantic fisheries, respectively. The principle region of abundance for the Gulf menhaden encompasses the northern Gulf from Galveston Bay, Texas, to Appalachicola Bay, Florida, with particulary high populations occurring in the area of the Mississippi River Delta.

The menhaden life cycle is typical of estuarine-dependent euryhaline organisms. Most spawning occurs in oceanic waters during late fall and winter. Larvae are then transported landward toward estuarine passes, with peak numbers generally occuring in March in the nearshore northern Gulf. As the postlarvae transform into juveniles, they move into the upper reaches of the estuaries and then, during the summer, gradually move toward the mouth as they continue to mature. With the approach of cold weather, many menhaden move a short distance offshore, however, substantial numbers remain in the estuaries and bays, especially during mild winters. Evidence indicates that the Mississippi Delta may be the dividing point for two major spawning populations of menhaden in the northern Gulf, with prevailing currents maintaining a partial seperation between the eggs of the eastern and western populations.

Significant commercial menhaden catches in the Gulf of Mexico are dominated by the 1- and 2-year-old age classes, with purse seining the most effective commercial fishing technique. Landings increased from 35,000 to 546,000 metric tons from 1946 to 1970, primarily in response to increased vessel tonnage and technological advancements in equipment. During the 1960s, the landings at Louisiana ports increased while those for other Gulf states decreased. Of the 1.55 billion pounds of menhaden caught in the Gulf during 1980, 1.31 billion pounds were caught within 3 miles of the coast, with the total value for the 1980 catch equalling approximately 69.1 million dollars. Statistical models of menhaden catch in the Gulf of Mexico indicate that the menhaden fishery has reached maximum sustainable yields, with fishing effort, wind direction, and air temperature for December, January, and February among the most important variables for predicting catch.

APPENDIX G.2

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APPENDIX H

BRINE DISPOSAL BY UNDERGROUND INJECTION

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Brine disposal has been addressed in previous Strategic Petroleum Reserve (SPR) Final Environmental Impact Statements (FEISs) in terms of three alternatives: usage by local industry, deep-well injection, and disposal to the Gulf of Mexico (FEA, 1976a). The preferred disposal method would be usage as feedstock by the local petrochemical industry. This method was used initially at Bryan Mound for a limited time and on a limited scale to dispose of existing high-quality brine created by local industry for its own use. At no existing or candidate SPR site, however, is there a local market capable of accepting the required rate or volume of brine. Further, industry cannot use SPR brines from solution mining (leaching) because of the relatively poor quality of raw water used by SPR. It was determined, therefore, at the commencement of Phase I facilities construction that underground injection and discharge into the Gulf of Mexico were the only two viable disposal alternatives.

An early conceptual design (Fenix and Scisson, 1976) indicated the feasibility of underground injection at the required rates and recommended a system of deep wells on 1,000-ft centers and with casings and pumps sized for a nominal flow rate of 1,000 gal/min (34,285 barrels per day [bbl/d]). This design was the basis for detailed assessment of underground injection in earlier SPR FEISs.

The programmatic SPR FEIS (FEA, 1976a) noted that industrial experience with underground injection did not approach the SPR rate and volume requirements and briefly highlighted concerns with the uncertainty of geohydrologic boundaries (faults, abrupt strata thinning, facies changes) and with maintaining proper pressures to avoid fracturing aquicludes, deforming strata, or otherwise interfering with oil and gas production. The most significant hazard considered in this FEIS was encountering old, perhaps unknown, wells that are not sufficiently plugged to prevent contamination of freshwater zones. As old wells are usually relatively shallow, this risk is mitigated by injecting at great depths.

Detailed site-specific descriptions of subsurface aquifers, injection reservoir mechanics analyses, and injection risk and impact assessments were presented in FEISs for Phase I sites with existing leached caverns, Bayou Choctaw, West Hackberry, and Sulphur Mines (FEA, 1976b; FEA, 1977; DOE, 1978a). Predictably, increasing awareness of potential problems was reflected in increasing site-specificity of the geology. The West Hackberry and Sulphur Mines FEISs included discussion of incompatibility of waters, water-sensitive formations, and water quality and biological characteristics (FEA, 1977; DOE, 1978a). Notwithstanding the relatively great amount of historical oil and gas exploration about West Hackberry salt dome, sand beds between -2,000 and -8,000 ft in the West Hackberry vicinity could not be correlated because of "lack of data" (FEA, 1977).

SPR Phase I Underground Injection Experience

A total of 32 deep injection wells have been constructed among four sites for Phase I brine disposal (Table H-1). Well casings and pumps were sized according to the conceptual design to accommodate a nominal 1,000 gal/min (34,285 bbl/d); injection zones were located in Miocene sands, 2,000 to 8,000 ft underground, which are isolated from freshwater aquifers and oil- and gas-bearing strata.

Reservoir calculations indicated sufficient permeability and capacity to accept the required rates and volumes of brine at each site. However, at each site, serious problems developed soon after the injection wells became operational.

As shown in Table H-1, projections of sustainable rates based on Phase I operating experience range from 32 percent of the design rate at Bayou Choctaw to 52 percent of the design rate at Bryan Mound. No significant injection experience has occurred to date at Sulphur Mines. At Bayou Choctaw, fewer than half of the 28 wells envisioned in the site-specific FEIS (FEA, 1976b) have been built.

Phase I brine disposal involves displacement by oil fill of existing high-quality brines that were created by the petrochemical industry as feedstock. They are (1) generally saturated (265 ppt dissolved salt); (2) made from drinking-quality water, which was chemically treated to remove undesirable dissolved solids in the brine; and (3) are relatively free of suspended particulates. In contrast, brines created by SPR leaching made from untreated, low-quality water generally contain significant loads of suspended solids.

Table H-1. Phase I underground injection program: design versus projected sustained rates

Site	Number of wells	Total site sustained injection rate (1000's of bbl/d) Design	Projected[1]
Bryan Mound	6	144	75
West Hackberry	10	300	130
Bayou Choctaw	12	360	115
Sulphur Mines	4	100	80

[1]Projected from Phase I experience; Source: DOE, 1980.

Daily brine disposal reports for each well were initiated in October 1978. However, underground brine injection ceased with the stoppage of oil fill in 1979 and did not begin again until oil fill resumed in September 1980. Records are available for a period of fairly continuous brine injection at West Hackberry from November 1, 1978, through February 14, 1979 (PB-KBB, 1979a). The data recorded during this period are summarized in Table H-2.

Table H-2. Summary of brine disposal well operation data at West Hackberry for the period November 1, 1978, through Feburary 14, 1979

	Total available well-hours	Actual operating well-hours	Brine injection (bbl)	Actual injection rate (bbl/operating hour)
November	7,200	4,422	2,586,528	584
December	7,200	6,320	2,921,787	462
January	7,440	4,715	2,344,411	497
February	3,120	2,451	1,165,110	475
Total	24,960	17,908	9,017,836	
Average	6,240	4,477	2,254,459	504

Source: After Tables 1 and 4, PB-KBB, 1979a.

The total number of well-hours for which brine disposal operations could have been conducted during the period was 24,960. This figure represents the number of "on line" well-hours and therefore does not reflect the time that wells were not operational during acidization or for other reasons. The total number of well-hours during which brine was actually being injected during the period was 17,908, resulting in a 0.72 utilization factor. The total number of barrels of brine disposed, divided by 17,908 well-hours, results in 504 bbl/h per well, which is the average rate of injection while brine was being disposed of. If operation were continuous for a 24-h period, this hourly rate would correspond to 12,096 bbl/d per well. The average calendar day of actual operations is 361 bbl/h per well, or the equivalent of 8,670 bbl/d per well.

Of the 109 days analyzed during the period, the brine disposal rate exceeded 15,000 bbl/d per well for only 16 days and never exceeded

20,000 bbl/d per well (PB-KBB, 1979a). The best performance was observed during November 1978, for which the equivalent 24-h period average was 585 bbl/h per well (14,038 bbl/d per well). Based on this analysis, it does not appear likely that an injection rate of more than 15,000 bbl/d per well could be maintained for the duration of solution mining (about 4 years).

To achieve the injection rates recorded in Table H-2, a total of 33 acidizing operations (one for every 273,267 bbl of brine injected) were performed. These acidizing operations were apparently required to remove accumulated deposits from the formation adjacent to the wells which were reducing injectivity. The cost of each acidization was $13,000, representing a major portion of the total 1978 operating cost of $25,000 per month per well. Although injectivity might be improved on the average well by mechanical filtration of brine before injection, costs for such filtration would be no less than the cost of additional well construction (Lehr, 1978).

Industrial Subsurface Brine Injection Experience

The petroleum industry has extensive experience with subsurface injection wells. In general, such wells have been used for disposal of salt water produced in conjunction with hydrocarbon extraction and to maintain formation pressure to enhance petroleum production from oil reservoirs that are being depleted. According to Lehr (1978), there are over 100,000 oil field brine injection wells, most of which receive less than 1,000 bbl/d. In addition, there are over 450 permitted chemical waste disposal wells, none of which approaches rates intended for the SPR.

Such industrial experience with subsurface injection is admittedly not directly applicable to the SPR brine disposal situation. In a pressure maintenance project, for example, the formation pressure stays nearly constant, and the volume of water injected is balanced by the volume of oil removed from the reservoir. However, available evidence indicates that formation plugging near the well bore does limit injectivity of existing brine disposal wells and illustrates the nature of the difficulties that can be encountered when a fluid is injected into a subsurface aquifer. This formation plugging phenomenon is quite similar in both oil field injection wells and SPR brine disposal wells.

The current maximum reinjection rate has been reported to be about 10,241 bbl/d per well for the Cameron field and about 5,700 bbl/d per well for the east Texas oil field (FEA, 1977). These values are generally comparable to the actual daily injectivity rate experienced by DOE at West Hackberry.

In a paper presented by Jordan, Edmondson, and Jeffries-Harris at the Society of Petroleum Engineers 43rd Annual Fall Meeting in Houston in 1968, injectivity problems associated with development of a water flooding project for Standard Oil of California in Miocene sand reservoirs adjacent to the Bay Marchand salt dome were discussed. Although involving considerably deeper wells than SPR, the basic reservoir characteristics (uniform porosity of about 29 percent and the varied permeabilities between 100 millidarcies and 2 darcies) were similar to the values encountered in SPR. Initial injectivities of about 5,000 bbl/d of seawater per well were experienced. In spite of extensive efforts to treat the brine with chlorination, 10-micron (nominal) filtration, oxygen scavenging, and corrosion inhibitors, rapid reductions in injectivity were experienced.

Another major problem encountered was sand inflow, which developed in the injection wells. This problem had not previously occurred when the same wells were used as conventional production wells. Additional injection wells had to be drilled to maintain the required injection rates. Cores were taken to study the effect of applied plastic sand consolidation. Plastic sand consolidation improved the formation strength, but reduced permeability by 20 to 30 percent. The hydraulic fracture gradient for the Miocene sands was determined to be between 0.65 and 0.76 psi/ft. Because the original injection pressure had been set above this fracture gradient, further operations resulted in vertical fracturing of the formation.

Reduction of injection pressures below the fracture pressure and elimination of alternately injecting and back-flowing the wells brought the sand influx problem under control. However, injectivity losses continued. Flow tests with water from the normal injection treatment facility established the plugging agent to be colloidal-size iron particles. Only after 0.45-micron diatomaceous earth filters were installed, were the injectivity losses controlled enough to permit continued operation of the injection wells.

Disposing of Brine Generated During Solution Mining

Phases II and III would store SPR oil in salt dome caverns created by the solution mining process. The rate of brine disposal required during these phases would be six to ten times that experienced at West Hackberry during Phase I and would continue over a considerably longer period. For example, the brine disposal rate for Phase II at Bryan Mound must average 980,000 bbl/d over a period of about 4 years to create the required storage. The brine disposal rate for the Phase III Big Hill project must average 1.4 million barrels (MMB) of brine per day for almost 4 years.

Implications of SPR Experience with Brine Injection

Theoretical reservoir calculations (disregarding impurities in the brine) indicate that high well injectivities are possible, although practical experience to date indicates otherwise.

Brine disposal well performance during Phase I indicates it is unlikely that an injection rate of more than 15,000 bbl/d per well could be sustained for 4 or more years. Thus, for Big Hill, 112 wells would be required to dispose of 1.4 MMB of brine per day located on 980 acres of land (PB-KBB, 1979a). The estimated cost of this brine disposal system is about $139 million, of which the energy cost alone would be $15.2 million. This figure includes an allowance for brine treatment; however, it is likely that acidizing will still be required. The experience at West Hackberry, where the brine is generally considered to be of the best quality in the SPR system, required acidizing a well after each 273,267 bbl of brine was injected at a cost of $13,000 per treatment. Even with a 300 percent increase in injection volume between acid treatments at Big Hill, acidizing operations would be required every day throughout the entire leaching period at an estimated cost (based on $13,000/treatment) of about $20 million.

In an independent evaluation of SPR experience conducted for the U.S. Environmental Protection Agency, Lehr confirmed the difficulties encountered in Phase I brine disposal and noted that, for the given scale of operations, even a short-term period of successful brine injection may be unattainable because of underground variables that are essentially unknowable (Lehr, 1978).

Conclusions

A battery of complex and lengthy studies is required for any site where subsurface brine disposal is to be used in order to properly design the system. However, the scale of the operation required to support the solution mining process is such that even these studies could not guarantee successful operation of the system, but could establish that disposal by deep-well injection is not feasible.

The large volume of brine which is generated during the solution mining process must be disposed of at a substantially higher rate than experienced by industry or DOE and for a period of several years. Although this may be technically feasible, the cost of such a complex system would be great, and its reliability would be subject to the variability of the salt being dissolved and uncertainties in subsurface strata.

Even if excessive costs and delays inherent in developing underground brine injection could be accommodated by the SPR program, there is no assurance that the subsurface disposal zones would accept the required volume or the required rate for the required period. Therefore, relying completely on underground injection is a great risk to the SPR program. While underground injection is feasible for limited rates and durations and is appropriate for an interim backup system, it is not a practicable alternative for the SPR leaching program of Phases II and III.

APPENDIX H

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APPENDIX I

OIL SPILL RISK

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The oil spill analysis was collected from several sources and based on three types of historical data regarding accidental oil spills:

- o Number of spill incidents during a certain time period.
- o Exposure to spills (e.g., number of tanker ship trips, time duration of pipeline usage).
- o Size distribution for spills of the several types considered.

The quotient of factors from the first two types of data gives the frequency of accidental spills, whereas data of the third type were used to estimate the size of an average spill. Also, the accident frequency data were combined with spill size distributions to estimate the probability of a spill exceeding a given volume. The frequencies of the several types of accidental spills derived from these data are presented in Table I-1. The size distribution of these spills is presented in Fig. I-1 for tank vessel casualties, Fig. I-2 for vessel loading-offloading accidents, and Fig. I-3 for pipeline accidents. The sources of the data used are presented in Table I-2. These data are the same as used in previously published FEISs for the SPR program, but are summarized here for completeness.

The fact that the spill frequencies and size distributions were based on extensive historical data gives credence to their general reliability. This is because many of the methods and vessels that would be used to transport SPR oil are much the same as those used in the recent past. On the other hand, more stringent procedures and methods, which would ensure a lower accidental spill rate relative to the historical rate, would be required.

The figures relating to spill risk, which appear on Tables I-3 and I-4, were developed by using the following formulas in conjunction with Table I-4 and Figs. I-1, I-2, and I-3.

Spill frequency (Table I-1) per trip, mile, or operation	x	Number of trips, miles, or operations	=	Total average number of spills for total number of trips, miles, or operations
Total average number of spills for total number of trips, miles, or operations	x	Average spill size (Fig. I-1, I-2, I-3) for tanker, operation, or pipeline	=	Total average amount of oil spills for total number of trips, miles, or operations

Table I-1. Frequency of accidental oil spills

A) Vessel casualty frequency (polluting casualty only)

Transits in coastal waters (between lightering location and harbor entrance)

Tanker: 3.7 + 10^{-8} spills/mile and 50-mile distance between harbor entrance and lightering permit = 1.9 x 10^{-6} spills/trip

Transits in harbors and ports

Tanker = 4.4 x 10^{-5} spills/trip into port

B) Accidents

Loading-offloading operation

Loading-offloading	=	13.5 x 10^{-3} spills/operation
Other operation	=	6.9 x 10^{-3} spills/port call
Total	=	20.4 x 10^{-3} spills/operation

Lightering operation

Loading-offloading	=	13.5 x 10^{-3} spills/operation
Other operation	=	13.8 x 10^{-3} spills/operation
Total	=	27.3 x 10^{-3} spills/operation

Pipelines

Diameter >12 in. = 6.8 x 10^{-4} spills/mile per year

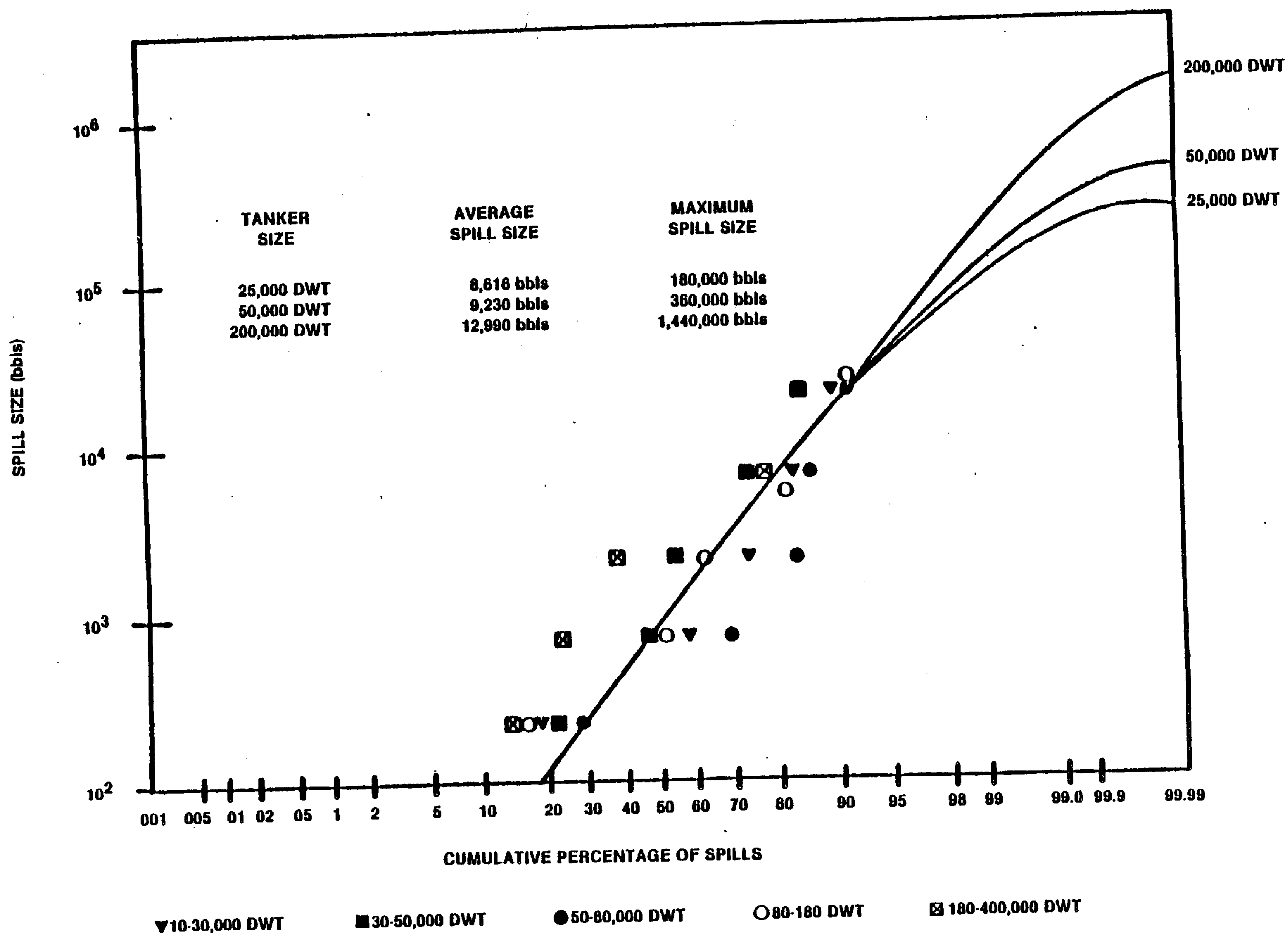

Figure I-1. Distribution of quantity of oil spilled accidentally from tankships during loaded voyages.

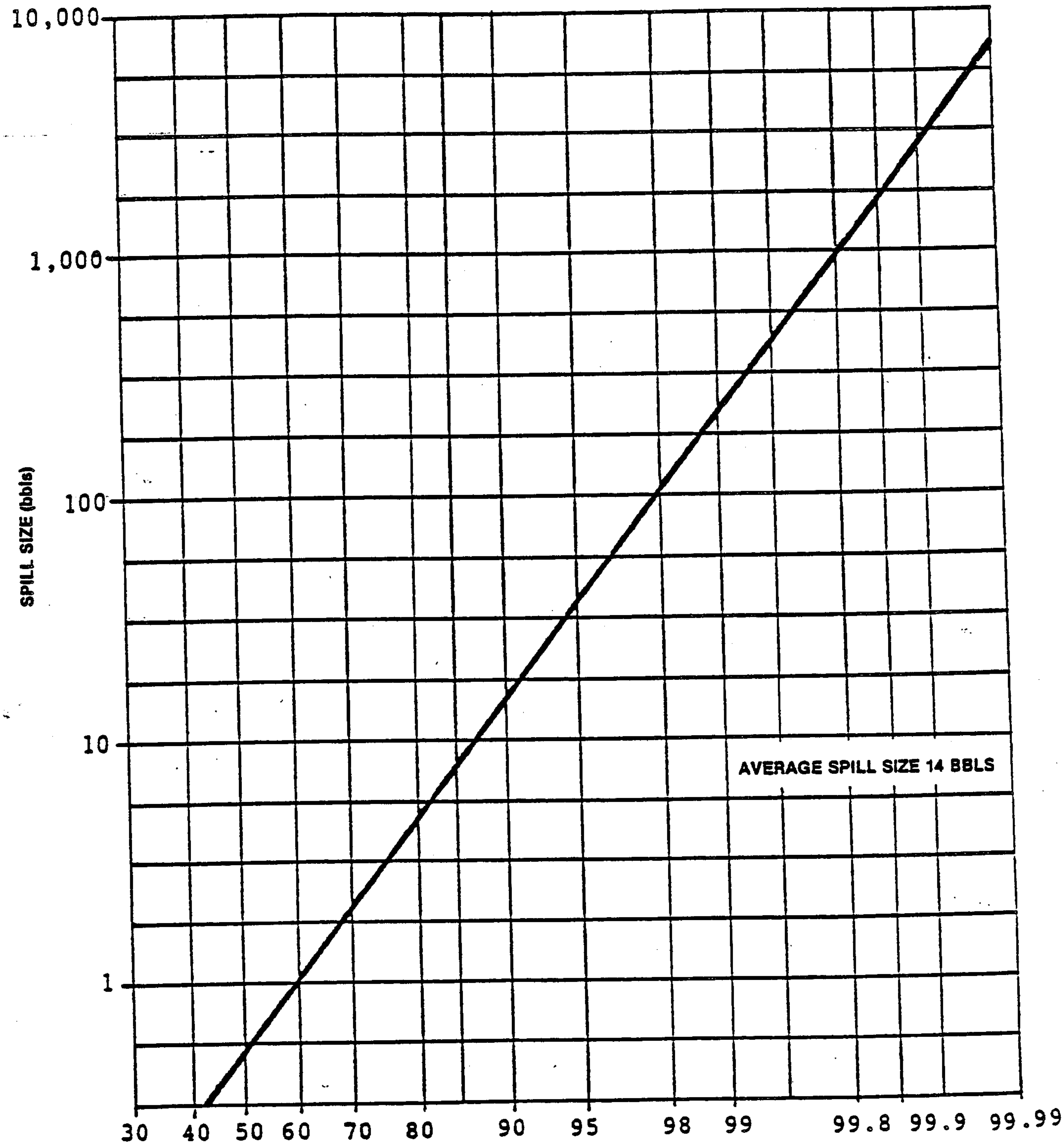

Figure I-2. Distribution of quantity of oil spilled accidentally during loading and offloading tankships and tankbarges.

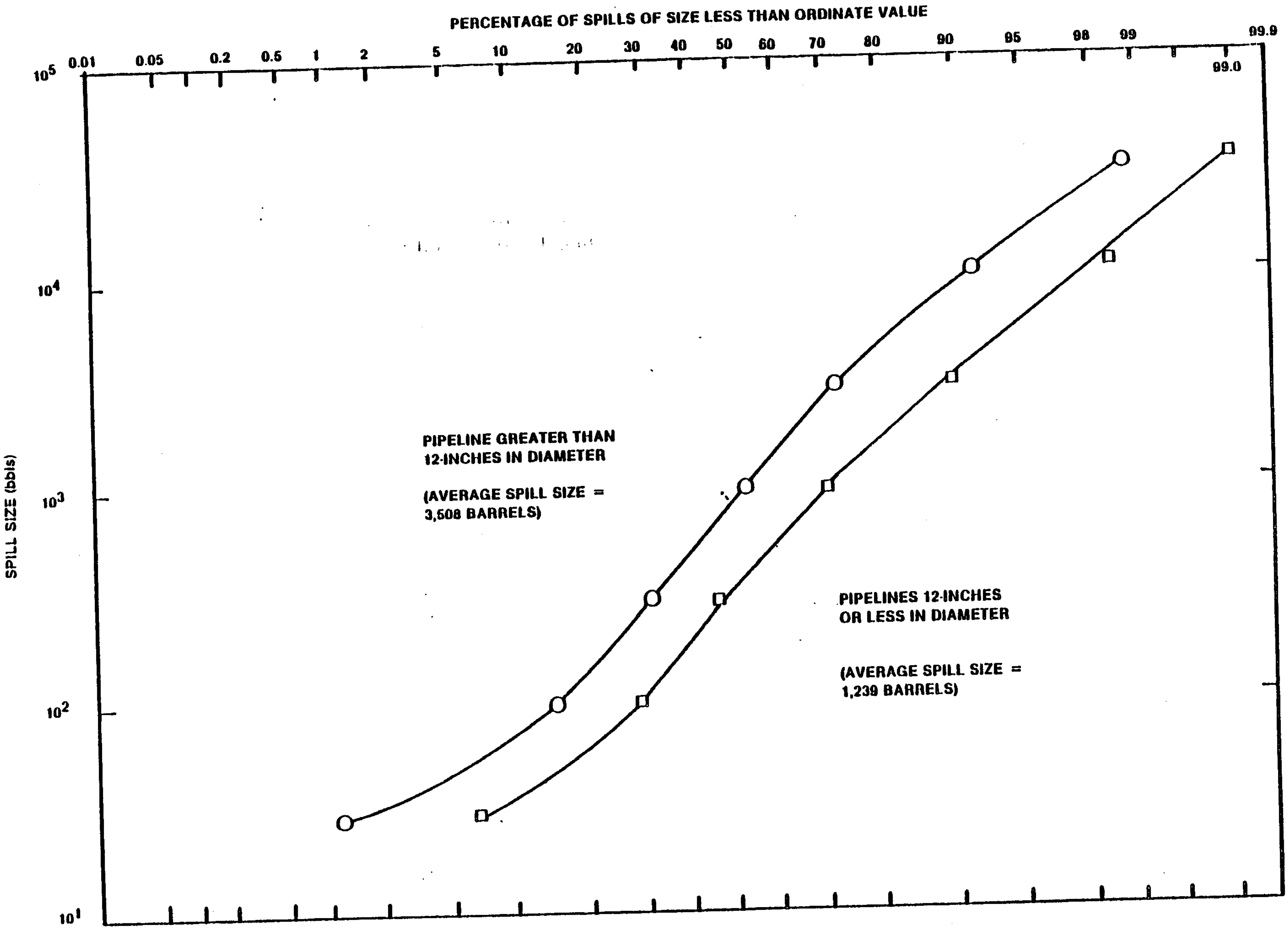

Figure I-3. Size distribution of spills from U. S. terrestrial pipelines transporting liquid.

Table I-2. Sources of data

Vessel casualties	Accidents and spill sizes	Exposure data	Remarks
At sea	U.S.C.G., 1	2	3
Gulf Coast harbors and ports	4	5	3
Rivers	4	5	
<u>Loading-offloading operations</u>			
Lightering	Estimated, 10, 12		Estimated, 10
Fixed, inland berth	PIRS, 6, 12		Estimated, 5
Pipelines	OPS, 8, 11		Bu Mines, 9

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Table I-3. Estimated spill from tanker operations for each scenario

	Average number of spills		Total average spill (bbl)	
Tanker size	60,000 dwt	45,000 dwt	60,000 dwt	45,000 dwt
Bill Hill leach/fill via Sun Terminal				
Lightering	9	11	127	154
Transit to coast	0.00001	0.00002	0.1	0.1
Transit inland waters	0.01	0.02	162	161
Offloading/loading	7	9	98	126
Big Hill withdrawal via Sun Terminal				
Transit inland waters	0.007	0.009	77	75
Offloading/loading	3	4	42	56
Big Hill withdrawal via OTTI or Pelican Island				
Transit inland waters	0.005	0.006	57	56
Offloading/loading	2	3	28	42
Big Hill refill via Sun, OTTI, or Pelican Island				
Lightering	9	11	127	154
Transit to coast	0.00001	0.00002	0.1	0.1
Transit inland waters	0.01	0.02	162	161
Offloading/loading	7	9	98	126
West Hackberry leach/fill via Sun Terminal (30 MMB)				
Lightering	2	3	28	42

Table I-3 (continued)

	Average number of spills		Total average spill (bbl)	
Tanker size	60,000 dwt	45,000 dwt	60,000 dwt	45,000 dwt
West Hackberry refill via Sun Terminal (243 MMB)				
Lightering	16	21	224	294
Transit to coast	0.00001	0.00002	0.1	0.1
Transit inland waters	0.025	0.033	238	300
Offload/load	12	16	168	224
Bryan Mound leach/fill via Seaway Terminal (40 MMB)				
Lightering	3	4	36	56
Transit to coast	0.000004	0.000005	0.03	0.04
Transit inland waters	0.004	0.005	46	46
Offload/load	2	3	28	42
Bryan Mound leach/fill via Seaway Terminal (60 MMB)				
Lightering	4	5	54	71
Transit to coast	0.000005	0.000006	0.06	0.06
Transit inland waters	0.006	0.008	69	69
Offload/load	3	4	42	56
Bryan Mound withdrawal via Seaway Terminal (220 MMB)				
Transit inland waters	0.009	0.012	86	109
Offload/load	4	7	56	98

Table I-3 (continued)

	Average number of spills		Total average spill (bbl)	
Tanker size	60,000 dwt	45,000 dust	60,000 dwt	45,000 dwt
Transit to coast	0.000002	0.000005	0.03	0.04
Transit inland waters	0.003	0.007	34	59
Offloading/loading	1.4	3	20	42
West Hackberry leach/fill via Sun Terminal (10 MMB)				
Lightering	1	1	14	14
Transit to coast	0.0000009	0.000001	0.009	0.009
Transit inland waters	0.001	0.001	12	14
Offloading/loading	0.5	0.6	7	9
West Hackberry withdrawal via Sun Terminal (263 MMB)				
Transiting inland waters	0.014	0.018	133	164
Offloading/loading	6	8	84	112
West Hackberry withdrawal via Sun Terminal (243 MMB)				
Transiting inland waters	0.013	0.017	124	156
Offloading/loading	6	8	84	112
West Hackberry refill via Sun Terminal (263 MMB)				
Lightering	17	22	238	308
Transit to coast	0.00001	0.00002	0.2	0.2
Transit inland waters	0.028	0.036	266	328
Offload/load	13	17	182	238

Table I-3 (continued)

	Average number of spills		Total average spill (bbl)	
Tanker size	60,000 dwt	45,000 dwt	60,000 dwt	45,000 dwt
Bryan Mound withdrawal via Seaway Terminal (240 MMB)				
Transit inland waters	0.010	0.013	95	118
Offload/load	5	6	70	84
Bryan Mound refill via Seaway Terminal (220 MMB)				
Lightering	14	19	196	266
Transit to coast	0.00002	0.00002	0.1	0.1
Transit inland waters	0.023	0.030	219	273
Offload/load	11	14	154	196
Bryan Mound refill via Seaway Terminal (180 MMB)				
Lightering	16	20	224	280
Transit to coast	0.00002	0.00003	0.2	0.2
Transit inland waters	0.025	0.033	238	300
Offload/load	12	15	168	154

Table I-4. Probability for a major oil spill[1]

	Leach/fill		Withdrawal		Refill	
Tanker size (dwt)	45,000	60,000	45,000	60,000	45,000	60,000
Big Hill via Sun Terminal						
Tanker trips	437	333	219	166	437	333
Lightering	0.057	0.044			0.057	0.044
Transit to coast	0.000002	0.000001			0.000002	0.000001
Transit inland waters	0.0019	0.0015	0.0009	0.0007	0.0019	0.0015
Offloading/loading	0.04	0.03	0.02	0.02	0.04	0.03
Big Hill via OTTI						
Tanker trips			153	117	437	333
Lightering					0.057	0.044
Transit to coast					0.000002	0.000001
Transit inland waters			0.0007	0.0005	0.0019	0.0015
Offloading/loading			0.02	0.01	0.04	0.03
West Hackberry via Sun (30 MMB)						
Tanker trips	94	71	411	313	822	626
Lightering	0.013	0.009			0.106	0.082
Transit to coast	0.0000003	0.0000003			0.000003	0.000002
Transit inland waters	0.0005	0.0003	0.0015	0.0009	0.004	0.03
Offloading/loading	0.009	0.007	0.04	0.03	0.08	0.06
West Hackberry via Sun (10 MMB)						
Tanker trips	31	24	289	380	760	576
Lightering	0.004	0.003			0.098	0.076
Transit to coast	0.0000001	0.0000001			0.000003	0.000002
Transit inland waters	0.0001	0.001	0.0015	0.0009	0.003	0.003
Offloading/loading	0.003	0.002	0.03	0.04	0.07	0.06
Bryan Mound via Seaway (40 MMB)						
Tanker trips	125	96	275	210	688	524
Lightering	0.017	0.013			0.089	0.068
Transit to coast	0.0000005	0.0000004			0.000003	0.000002
Transit inland waters	0.0005	0.0004	0.001	0.0009	0.003	0.002
Offloading/loading	0.01	0.010	0.03	0.02	0.07	0.05
Bryan Mound via Seaway (60 MMB)						
Tanker trips	187	143	300	229	750	572
Lightering	0.025	0.019			0.097	0.075
Transit to coast	0.0000007	0.0000005			0.000003	0.000002
Transit inland waters	0.0008	0.0006	0.001	0.001	0.003	0.003
Offloading/loading	0.02	0.01	0.03	0.02	0.07	0.06

[1]Major oil spill is here defined as the maximum credible spill, as described in the Seaway Group FEIS.

Major spills from: tankers ~ 60,000 bbl
operations ~ 500 bbl
pipelines ~ 10,000 bbl

To arrive at the probability of a major spill during ship-to-ship transfers of oil (lightering), transiting, and offloading/loading, the spill frequency was multiplied by the percentage fraction that such a spill would occur. The product was then subtracted from unity. This figure was then raised to the power equal to the total number of trips, miles, or operations and subtracted from unity.

Determination of the probabilities of major pipeline spills was performed in much the same manner. Spill frequency was multiplied by the percentage fraction that such a spill would occur. The product was then subtracted from unity. This figure was raised to the power equal to pipeline usage time (in years) and subtracted from unity. Risk of spills from pipelines are presented in Table I-5.

The risk of oil spills during lightering was estimated by using the spill frequency and the distribution of the size of spills for loading and offloading at conventional docks. This application probably resulted in an overestimation of this risk. The probability of accident during lightering operations is believed to be less than that for loading and offloading operations at conventional docks.

Uncertainties in the frequencies of spills from the various types of accidents may be as high as a factor of 2. These uncertainties arise, in part, from the historical data and, in part, from assumptions that must be made to apply the data.

The uncertainties in the spill size distributions arise primarily in the projection of the fraction of large spills, which are at the extreme end or outside the range of the data. This is especially true of pipeline spills. It is estimated that the fraction of spills projected in the upper 2 percentile in Figs. I-1 through I-3 could be in error by as much as a factor of 2. However, this would cause a corresponding uncertainty of no more than 50 percent in the estimates of the average spill sizes. The uncertainty in the fraction of very large spills arises because of the relative infrequency of large-spill accidents and the relative shortness of the time span of the data base. Also, log normal distributions of spill size, which seem to fit the data, have been used in this analysis. In a recent statistical analysis, a gamma distribution had been preferred for spill size. This distribution projects a small fraction of large spills using the same data. Hence, the log normal distribution appears to be conservative in the sense of overestimating the fraction of large spills.

Spill Prevention and Control Countermeasure (SPCC)

NO

Before any operations occur on the new site (receipt of oil), the conceptual Spill Prevention Control and Countermeasure (SPCC) Plan will be finalized and approved by the appropriate state and Federal agencies. At a minimum, the SPCC plan includes:

- A dike around each of the caverns associated wellheads capable of containing at least 78,000 bbl of fluid (oil, brine, raw water).

Table I-5. Risk of oil spills from pipelines[1]

Pipeline	Leach/fill	Withdrawal	Refill
Big Hill/Sun Terminal			
Spill frequency, total pipeline length (23 miles)	0.06	0.006	0.04
Pipeline oil loss, bbl	175	21	140
Probability of major spill	0.006	0.0006	0.004
West Hackberry/Sun Terminal			
For 10-MMB spill frequency, total pipeline length (41.5 miles)	0.004	0.011	0.043
Pipeline oil loss, bbl	14	38	150
Probability of major spill	0.0005	0.001	0.005
For 30-MMB spill frequency, total pipeline length (41.5 miles)	0.013	0.011	0.043
Pipeline oil loss, bbl	46	38	150
Probability of major spill	0.0014	0.001	0.008
Bryan Mound/Seaway Terminal			
For 40-MMB spill frequency, total pipeline length (4.1 miles)	0.0016	0.001	0.008
Pipeline oil loss, bbl	6	1	28
Probability of major spill	0.0002	0.0001	0.0007
For 60-MMB spill frequency, total pipeline length (4.1 miles)	0.0024	0.001	0.008
Pipeline oil loss, bbl	8	1	28
Probability of major spill	0.0003	0.0001	0.0007
Big Hill/OTTI			
Spill frequency, total pipeline length (58 miles)		0.015	0.105
Pipeline oil loss, bbl		53	368
Probability of major spill		0.002	0.011
Big Hill/Pelican Island			
Spill frequency, total pipeline length (54 miles)		0.014	0.09
Pipeline oil loss, bbl		49	315
Probability of major spill		0.001	0.010
Big Hill/Gulf of Mexico (brine)			
Spill frequency, total pipeline length (12.5 miles)	0.03		0.02
Pipeline brine loss, bbl	105		70
Probability of major spill	0.003		0.002
West Hackberry/Gulf of Mexico (brine)			
Spill frequency, total pipeline lenght (23 miles)	0.008		0.04
Pipeline brine loss, bbl	28		151
Probability of a major spill	0.0008		0.004
Bryan Mound/Gulf of Mexico (brine)			
Spill frequency, total pipeline length (15 miles)	0.009		0.03
Pipeline brine loss, bbl	33		105
Probability of major spill	0.0009		0.003

[1]The maximum credible spill size of 10,000 bbl (Seaway Group FEIS) was utilized for estimation of a major spill.

- Pumps, piping, valves, connections and other equipment required to remove and properly dispose of contained spilled fluids.

- Appropriate methods and equipment to clean up and remove residual spilled fluids.

The SPCC plan is being developed in compliance with all relevant regulations stipulated in 40 CFR 112, "Oil Pollution Prevention." No site operations would commence before development and approval of the SPCC plan. Bryan Mound and West Hackberry are now operating under approved SPCC plans. These plans would be amended to include the expansion facilities as part of the Phase III expansion.

APPENDIX J

LETTERS OF COMMENT RECEIVED ON THE DRAFT SUPPLEMENT ENVIRONMENTAL IMPACT STATEMENT

Appendix J contains 24 letters of comment received from the Agencies and Organizations from who comments were requested (see Table 9-2).

Letters are arranged according to date received and follow the same sequence of presentation as found in Section 9.3.

Advisory Council On Historic Preservation

1522 K Street, NW
Washington, DC 20005

Reply to:

Lake Plaza South, Suite 616
44 Union Boulevard
Lakewood, CO 80228

May 26, 1981

Mr. C. Curtis Johnson
Project Manager
Strategic Petroleum Reserve Project
U.S. Department of Energy
900 Commerce Road East
New Orleans, Louisiana 70123

Dear Mr. Johnson:

Thank you for your request of May 15, 1981, for comments on the environmental statement for the Strategic Petroleum Reserve Seaway and Texoma Groups of Salt Domes, Cameron Parish, Louisiana and Brazoria and Jefferson Counties, Texas. Pursuant to Section 102(2)(c) of the National Environmental Policy Act of 1969 and the Council's regulations, "Protection of Historic and Cultural Properties" (36 CFR Part 800), we have determined that your draft environmental statement mentions properties of cultural and/or historical significance; however, we need more information in order to evaluate the effects of the undertaking on these resources. Please furnish additional data indicating compliance with Section 106 of the National Historic Preservation Act of 1966 (16 U.S.C. Sec. 470f, as amended, 90 Stat. 1320).

(1) The environmental statement must demonstrate that either of the following conditions exists:

1. No properties included in or that may be eligible for inclusion in the National Register of Historic Places are located within the area of environmental impact, and the undertaking will not affect any such property. In making this determination, the Council requires:

   - evidence that you have consulted the latest edition of the National Register (Federal Register, March 18, 1980, and its monthly supplements);

- evidence of an effort to ensure the identification of properties eligible for inclusion in the National Register, including evidence of contact with the State Historic Preservation Officer whose comments should be included in the final environmental statement. The State Historic Preservation Officer for Louisiana is Mr. Robert B. DeBlieux and the Texas State Historic Preservation Officer is Mr. Truett Latimer.

2. Properties included in or that may be eligible for inclusion in the National Register of Historic Places are located within the area of environmental impact, and the undertaking will or will not affect any such property. In cases where there will be an effect, the final environmental impact statement should contain evidence of compliance with Section 106 of the National Historic Preservation Act through the Council's regulations, "Protection of Historic and Cultural Properties" (36 CFR Part 800).

Should you have any questions, please call Charles M. Niquette at (303) 234-4946.

Sincerely,

Louis S. Wall
Chief, Western Division
of Project Review

UNITED STATES DEPARTMENT OF AGRICULTURE
FARMERS HOME ADMINISTRATION
101 S. Main St.
Temple, TX 76501

Mr. C. Curtis Johnson, Project Manager
U. S. Department of Energy
900 Commerce Road East
New Orleans, LA 70123

June 2, 1981

Dear Mr. Johnson:

We have made a cursory review of the Final Environmental Impact Statement; DOE/EIS-0021, DOE/EIS-0029 dated May 1981.

1 Farmers Home Administration recently made a loan to Oyster Creek Municipal Utility District for a domestic water supply which is approximately 3 miles north of the Bryan Mound SPR site in Brazoria County, Texas. They are obtaining their water from a fresh water formation which is 250-300 feet deep. Since this is their only source of water, extreme care should be taken to prevent salt-water intrusion or cantamination of this formation.

The report states that Brazos River's water or Intercoastal Waterway's water will be used for recovery of the oil. We do not believe that ground water from a fresh water formation should be used. Since the storage will be under pressure, extra precautions should be made to insure that salt-water or oil will not escape into a fresh water formation.

Sincerely,

for: JOHN O. BARNES
Acting State Director

pc: Environmental & Technology Staff
FmHA, Washington, D. C.

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS UNITED STATES AIR FORCE
WASHINGTON, D.C. 20330

3 JUN 1981

Mr. C. Curtis Johnson
Project Manager
Strategic Petroleum Reserve Project
Management Office
United States Department of Energy
900 Commerce Road East
New Orleans, Louisiana 70123

Dear Mr. Johnson

We appreciate the opportunity to review the Department of Energy's Draft Supplement to the Final Environmental Impact Statements for the Strategic Petroleum Reserve Seaway and Texoma Groups of Salt Domes.

(1) There is no apparent environmental interaction between this proposal and any Air Force activities in the project area, and we have no specific comments on this environmental document.

Sincerely

ROBERT L. KLINGENSMITH, Col, USAF
Chief, Environmental Division
Directorate of Engineering & Services

TEXAS HISTORICAL COMMISSION

TRUETT LATIMER
EXECUTIVE DIRECTOR

P.O. BOX 12276
AUSTIN TEXAS 78711

June 8, 1981

Mr. Paul T. Wrotenbery
Governor's Budget and Planning
Office
14th and San Jacinto
Sam Houston Bldg., 7th Floor
Austin, Texas 78711

Re: Draft Supplement to FEIS
Strategic Petroleum Reserve,
Phase III Development - Texoma
and Seaway Group Salt Domes
Dept. of Energy

Dear Mr. Wrotenbery:

(1) We have received the above referenced document for review. In reviewing our files and the document we note we do not have all the pertinent archeological data to make a proper assessment of the work accomplished for this undertaking. The report by Thomas, et al (1977) is needed, We would appreciate receiving all the archeological data generated by this undertaking. Also, the document does not indicate which properties, if any, are eligible for inclusion to the National Register of Historic Places. Statements regarding the National Register of Historic Places must be contained in the document.

Please forward the information we require to make a proper assessment of this undertaking pursuant to Section 106 of the National Historic Preservation Act of 1966. Thank you for your attention to this matter.

Sincerely,

Truett Latimer
State Historic Preservation Officer

by

LaVerne Herrington

LaVerne Herrington, Ph.D.
Director
Resource Conservation

PEP/LH/lft

cc: Dept. of Energy

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
819 TAYLOR ST., ROOM 8A00
FORT WORTH, TEXAS 76102

June 11, 1981

REGION 6

REFER TO:
HEP-06

Mr. C. Curtis Johnson, Project Manager
Strategic Petroleum Reserve Project
Management Office
U. S. Department of Energy
900 Commerce Road East
New Orleans, Louisiana 70123

Dear Mr. Johnson:

The draft Environmental Impact Statement for the "Strategic Petroleum Reserve Project, Cameron Parish, Louisiana; Brazoria and Jefferson Counties, Texas" has been reviewed by our Division Offices in Louisiana and Texas, and this office. (1) We believe the proposed project would not significantly affect any projects or programs under this agency's jurisdiction. Therefore, we have no comments on the draft EIS.

Sincerely yours,

Roger Borg
Associate Regional Administrator
for Planning and Program Development

DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT
FORT WORTH REGIONAL OFFICE
221 WEST LANCASTER AVENUE
P.O. BOX 2905
FORT WORTH, TEXAS 76113

REGION VI

IN REPLY REFER TO:

June 12, 1981

Mr. C. Curtis Johnson, Project Manager
Strategic Petroleum Reserve Project Management Office
U. S. Department of Energy
900 Commerce Road East
New Orleans, Louisiana 70123

Dear Mr. Johnson:

(1) The draft Supplement to the Final Environmental Impact Statement for the Strategic Petroleum Reserve Seaway and Texoma Groups of Salt Domes has been reviewed in the Department of Housing and Urban Development's Dallas Area Office, New Orleans Area Office and Fort Worth Regional Office and it has been determined that the Department will not have comments on the Supplement.

Sincerely,

Victor J. Hancock
Environmental Clearance Officer

AREA OFFICES
DALLAS, TEXAS • LITTLE ROCK, ARKANSAS • NEW ORLEANS, LOUISIANA • OKLAHOMA CITY, OKLAHOMA • SAN ANTONIO, TEXAS

United States Department of Agriculture

Soil Conservation Service

3737 Government Street
Alexandria, LA 71301

June 12, 1981

Mr. C. Curtis Johnson
Project Manager
Strategic Petroleum Reserve Project Management Office
U. S. Dept. of Energy
900 Commerce Road East
New Orleans, LA 70123

Dear Mr. Johnson:

Re: Draft Supplement to Final EIS
Strategic Petroleum Reserve Phase III Development
Texoma and Seaway Group Salt Domes
(West Hackberry and Bryan Mound Expansion, Big Hill)

As requested, we have reviewed the referenced draft supplement to the Final Environmental Impact Statement. The impacts at the West Hackberry expansion site, Cameron Parish, will result in the commitment of up to 34 acres of pastureland and residential land to storage facilities.

Enclosed for your use is a copy of the General Soil Map of Cameron Parish, LA. From the information presented in the draft supplement, this West Hackberry site is located on soils of the Crowley-Morey-Mowata association. These soils are classified as prime farmland.

Prime farmlands are those whose value derives from their general advantage as cropland due to soil and water conditions. The land does not have to be presently in row crops to be classified as prime farmland. Prime farmland can be cropland, pastureland, forestland, or other land, but not urban builtup land.

(1) Conversion of prime farmland to other uses at this 34-acre site should be addressed by the impact statement.

We appreciate the opportunity to provide these comments on this draft supplement.

Sincerely,

Alton Mangum
State Conservationist

Enclosure

cc: Norman Berg, Chief, SCS, Washington
Edward E. Thomas, Assistant Chief, SE, SCS, Washington, D.C.
Billy M. Johnson, Director, STSC, SCS, Fort Worth
Director, Environmental Services, SCS, Washington, D.C.

The Soil Conservation Service is an agency of the Department of Agriculture

SCS-AS-1
10-79

GULF OF MEXICO FISHERY MANAGEMENT COUNCIL
Lincoln Center, Suite 881 • 5401 W. Kennedy Blvd.
Tampa, Florida 33609 • Phone 813/228-2815

June 15, 1981

Mr. C. Curtis Johnson
SPR Management Office
U.S. Department of Energy
900 Commerce Road East
New Orleans, LA 70123

Dear Mr. Johnson:

Reference is made to the Draft Supplement to Final Environmental Impact Statements; DOE/EIS - 0021, DOE/EIS - 0029. Phase III development of the SPR project involves creation of the Big Hill site and expansion of the Bryan Mound and West Hackberry sites. The Gulf Council has commented previously on the creation of the West Hackberry site. The staff of the Council has reviewed the draft supplement and offers the following comments.

(1) Our principal comments concern the effect of the brine discharge on penaeid shrimp populations and the shrimp fishery in the affected areas. In particular, the generalities (8-11) on page 3-20 appear misleading in their implications. While there is little spawner-recruit relationship, long or short-term destruction of shrimp habitat (estuarine or spawning areas) should be minimized. The draft supplement should at least acknowledge this habitat alteration. Generalities 9 and 10, which appear to justify such alteration, are quite contradictory in relating the overcapacity of the environment (#9) to the oversupply of postlarvae (#10). Furthermore, a review of the references in Appendix G (Berry and Baxter, 1969; Truesdale, 1970) do not substantiate generality #8 that all stages of the penaeid life cycle can tolerate wide ranges of salinty, which is the key issue of the brine discharge.

(2) The section on environmental impacts on penaeid shrimp (Section 4.2.5.2, page 4-25) again uses the faulty generalizations cited above to conclude that actual catches will not decrease, but made up from adjacent areas. The same "heavy commercial exploitation of shrimp stocks" cited on the bottom of page 4-25 may well invalidate this conclusion. The shift in fishing effort from the affected discharge areas to adjacent areas with existing "heavy exploitation" will either divide up the limited resources or result in proportionately less increase in catch for the same increase in effort.

Mr. C. Curtis Johnson
June 15, 1981
Page Two

(3) The section on socioeconomic impacts on penaeid shrimp (Section 4.2.8, page 4-33) describes the potential costs in terms of lost revenue to the shrimp industry under various cases. This section should be very helpful to decisionmakers; however, a question arises as to the purpose of this section. Since all other entities will be compensated for direct impacts of the SPR project, does this section develop a basis for compensation to affected fishermen?

Thank you for the opportunity to review this document. We hope these comments will be useful in revising the document.

Sincerely,

Wayne E. Swingle
Executive Director

WES:VJB:jak

cc: Bobby O'Barr
Nick Mavar
John Green
D. R. Ekberg
Staff

UNITED STATES DEPARTMENT OF COMMERCE
Maritime Administration
Washington, D.C. 20230

June 15, 1981

MEMORANDUM FOR: Bruce R. Barrett
Acting Chief, Environmental and Technical Evaluation Division
Department of Commerce

Subject: U.S. Department of Energy-Draft Supplement to the Final Environmental Impact Statement (FEIS)-Strategic Petroleum Reserve, Phase III Development (CN 8105.16)

In accordance with your memorandum of May 13, 1981, the Maritime Administration has reviewed the draft supplement and submits the following comments for your consideration.

Oil Spill Risk, Section 4.3.1, pg. 4-33

Discussion:

This section presents an analysis of the risks that are associated with the transport of SPR crude oil through Gulf Coastal areas of the United States. The analysis used U.S. Coast Guard regulations and international conventions which were pending when the Texoma Group FEIS was completed.

(1) Comment:

This discussion should be updated to reflect present U.S. Coast Guard regulations and Intergovernmental Maritime Consultative Organization conventions.

Related Risks, Section 4.3.1.3, pg 4-47

Discussion:

This section discusses risks related to the crude oil distribution system including fire and explosions. It is stated that explosions in vessel cargo tanks are rare, provided the tank vents are equipped with flame arrestors and precautions are taken to reduce the presence of ignition sources.

(2) Comment:

U.S. Coast Guard regulations (46 CFR Part 32) require that a U.S. or Foreign Flag crude tanker between 20,000 and 70,000 deadweight tons have an inert gas system after May 31, 1983. Crude tankers greater than 70,000 deadweight tons are required to have an inert gas system after May 31, 1981. An inert gas system will prevent an explosion from occuring. The discussion should be revised.

Kenneth W. Forbes

Kenneth W. Forbes
Chief, Division of Environmental Activities
Office of Shipbuilding Costs

WALLACE MENHADEN PRODUCTS, INC.
SUITE 805, AAA BUILDING
3445 N. CAUSEWAY BOULEVARD
METAIRIE, LA 70002

TELEPHONE 504-838-8211

June 18, 1981

Mr. C. Curtis Johnson, Project Manager
Strategic Petroleum Reserve Project Management Office
U. S. Department of Energy
900 Commerce Road East
New Orleans, Louisiana 70123

Attention: Dr. Joyce Teerling

Re: Draft Supplement to Final Environmental Impact Statements; DOE/EIS-0021, DOE/EIS-0029

Dear Mr. Johnson:

(1) Cameron, Louisiana is consistently the top ranking port in U. S. fishery landings, due in large part to the menhaden fleet operating there. A significant tonnage of these menhaden is taken in the area of the West Hackberry brine diffuser site and in the area of the proposed Big Hill site. The EIS relating to the West Hackberry project gave little more than a cursory acknowledgement of the existence of menhaden in this area. Regrettably, the Phase III Development Draft Supplement (DOE/EIS-0075) has replicated the efforts of the above mentioned EIS in that it almost ignores this substantial fishery, and where it is recognized, unsupported generalizations are made.

For example, p. 3-20 #8 states that "All literature reviewed indicated that all stages of the ... life cycle ... for the Gulf menhaden, *Brevoortia patronus*, can tolerate wide ranges of salinity." A more careful review of the literature would indicate that different life stages are collected in Gulf waters, at differing times, in different areas, in different salinities. Eggs may be hatched in a very narrow range and immediate survival might be critically related to salinity. P. 4-18 states that "impacts (of the brine plume at Bryan Mound) should be restricted to the bottom communities." A recent study by Randall and Hann indicates, however, that the plume on occasion was as high as 25 feet. At the proposed Big Hill site, this could place the plume near the surface which could have a large impact on the fishery, if indeed those eggs, or larvae, cannot tolerate the change in salinity.

(2) Task 5, p. 5-4 will evaluate the effects of brine on Red Drumm eggs, larvae, and post larvae. Certainly the economics of the menhaden warrant a similar evaluation.

(3) Another concern, previously voiced many times, is that the effects of multiple sites along the shoreline may have an impact on a species which passes through all those areas. Adult shrimp and menhaden may be able to circumnavigate individual areas of

altered salinities, but the menhaden spawned off lower Texas, in following their natural migration pattern, must now pass through Bryan Mound, Big Hill, and the almost immediately adjacent site, West Hackberry. This could significantly alter or reduce the range of the fish. I cannot find that this possible impact is even addressed.

These examples clearly indicate the casual position taken by the drafters of the EIS regarding the menhaden.

Sincerely yours,

WALLACE MENHADEN PRODUCTS, INC.

W. Borden Wallace

W. Borden Wallace
President

WBW/ds

OFFICE OF THE GOVERNOR

WILLIAM P. CLEMENTS, JR.
GOVERNOR

June 18, 1981

Mr. Robert J. Stern, Director
NEPA Affairs Division
Office of Environmental Compliance
and Overview
U. S. Department of Energy
Washington, D.C. 20585

Dear Mr. Stern:

(1) The Draft Supplement to the Final Environmental Impact Statement pertaining to Texoma and Seaway Group Salt Domes (Phase III Development) prepared by the U. S. Department of Energy (DOE), has been reviewed by the Budget and Planning Office and interested state agencies. Copies of the review comments are enclosed for your information and use. The State Environmental Impact Statement Identifier Number assigned to the project is 1-05-50-011.

The following specific comments are noted for your consideration. The Texas Department of Water Resources provided a further explanation regarding the DOE permit to appropriate state water for Bryan Mound Salt Dome Project. This agency also recommended that certain additional data and explanation about water requirements and permitting actions be included in the final supplement to the environmental impact statement.

The Budget and Planning Office appreciates the opportunity to review this project. If we can be of any further assistance during the environmental review process, please do not hesitate to call.

Sincerely,

Leon Willhite

Leon Willhite, Manager
Intergovernmental Section
Budget and Planning Office

jc
Enclosures

SAM HOUSTON BUILDING • P. O. BOX 12428, CAPITOL STATION • AUSTIN, TEXAS 78711

Texas Department of Health

Robert Bernstein, M.D., F.A.C.P.
Commissioner

1100 West 49th Street
Austin, Texas 78756
(512) 458-7111

Robert A. MacLean, M.D.
Deputy Commissioner

June 2, 1981

RECEIVED
JUN 5 1981
Budget/Planning

Mr. Paul T. Wrotenbery, Director
Governor's Budget and Planning Office
P. O. Box 13561, Capitol Station
Austin, Texas 78711

ATTENTION: Intergovernmental Section

SUBJECT: Bryan Mound and Big Hill Salt Domes
Brazoria and Jefferson Counties
Strategic Petroleum Reserve
Phase III Development
Draft Supplement to Final
Environmental Impact Statement
EIS No. 1-05-50-011

Dear Mr. Wrotenbery:

The subject Draft Supplement to the Final Environmental Impact Statement has been reviewed for its public and environmental health implications as requested by your memorandum of May 13, 1981.

(1) Based on the information contained in the Supplement, and the listed related components, it is believed that no adverse public or environmental health conditions should arise if proper construction and operation techniques are followed.

We appreciate the opportunity to review and comment on the subject Draft Supplement.

Sincerely,

G. R. Herzik, Jr.

G. R. Herzik, Jr., P.E.
Deputy Commissioner for Environmental
and Consumer Health Protection

RLJ/dbs
ccs: Program Budgetary Services, TDH
Public Health Region 10, TDH
Public Health Region 11, TDH
Brazoria County Health Department
Local Health Services, TDH

Suggested Questions to be Considered by Reviewing Agencies:

1. Does the proposed project impact upon and is it consistent with the plans, programs and statutory responsibilities of your agency?

2. What additional specific effects should be assessed?

3. What additional alternatives should be considered?

4. What better or more appropriate measures and standards should be used to evaluate environmental effects?

5. What additional control measures should be applied to reduce adverse environmental effects or to avoid or minimize the irreversible or irretrievable commitment of resources?

6. How serious would the environmental damage from this project be, using the best alternative and control measures?

7. What specific issues require further discussion or resolution?

8. Does your agency concur with the implementation of this project?

As a part of the environmental impact statement review process, the Budget and Planning Office forwards to the originating agency all substantive comments which are formally submitted. If, after analyzing this document, you conclude that substantive comments are unnecessary, you may wish to so indicate by checking the box below and forwarding the form to this office. This type of response will indicate receipt of this document by your agency and that no formal response will be prepared.

(1) [x] No Comment.

Murray C. Moffatt

Name and Title of Reviewing Official
Murray C. Moffatt
Engineer

June 3, 1981 Railroad Commission of Texas (Oil & Gas Div.)
Agency

R.R.C. OF TEXAS
MAY 19 1981
O.G.
AUSTIN, TEXAS

Parker

TEXAS DEPARTMENT OF WATER RESOURCES

1700 N. Congress Avenue
Austin, Texas

May 18, 1981

RECEIVED
MAY 26 1981
Budget/Planning

Mr. Paul T. Wrotenbery, Director
Governor's Budget and Planning Office
P.O. Box 13561
Capitol Station
Austin, Texas 78711

Dear Mr. Wrotenbery:

Re: U.S. Department of Energy (DOE)--Draft Supplement to Final Environmental Statement (DS/FEIS) relative to Strategic Petroleum Reserve (SPR): Phase III Development of Texoma and Seaway Group Salt Domes (West Hackberry and Bryan Mound Expansion, and Big Hill), Cameron Parish, Louisiana and Brazoria and Jefferson Counties, Texas. (DOE/EIS-0021 and DOS/EIS-0029). May 1981. (State Reference: EIS-1-05-50-011).

In response to your May 13 memorandum, and DOE's letter of May 1 (Certified Mail No. P-228165552), the staff of the Texas Department of Water Resources (TDWR) has reviewed the referenced draft report, pertaining to DOE's proposed Phase III plan to increase the SPR crude oil storage capacity to 750 million barrels (MMB) by the addition of 212 MMB, and to increase the average daily drawdown-rate capability by 1.0 MMB per day (MMB/d) from 3.5 MMB to 4.5 MMB/d. To achieve this incremental 212-MMB SPR Phase III will require: (1) construction of storage facilities for 140 MMB in the Big Hill Salt Dome, Jefferson County, Texas; (2) expansion of existing storage caverns in the Bryan Mound Salt Dome, Freeport, Brazoria County, Texas by 40 MMB; (3) expansion of existing storage caverns in the West Hackberry Salt Dome, Hackberry, Cameron Parish, Louisiana by 30 MMB; and, (4) provision for the storage of 2.0 MMB in existing associated pipelines and surface storage tanks.

From the standpoint of our water-related responsibilities under the Texas Water Code, and our interagency review obligations to the State A-95 Clearinghouse for Federal Project Notification and Review under OMB Circular No. A-95, we offer the following review comments:

1. We note the statement made in the DS/FEIS (p. v, third para.) that "DOE has applied to the Texas Department of Water Resources for an amendment to its permit to appropriate 215,000 acre-feet of state water from the Brazos River to provide for increased volume of raw water required for leaching." In the interest of accuracy, consistency, and completeness of record and data, we offer the following relevant information from our files:

P.O. Box 13087 Capitol Station • Austin, Texas 78711 • Area Code 512/475-3187

a. TDWR Permit No. 3681 to appropriate State water, granted to DOE on July 30, 1979, authorized the permitee to directly divert and use: (1) not to exceed 135 acre-feet per year (AF/Y) from the Brazos River for emergency fire protection for the duration of the Bryan Mound Salt Dome Project (BMSD Project); (2) a total of 101,400 AF from the Brazos River, but not exceed 33,800 AF/Y for mining purposes during the leaching phase of the BMSD Project, by four injection wells in order to leach caverns; (3) a total of 103,000 acre-feet from the Brazos River, but not to exceed 33,800 AF/Y for mining purposes during the displacing phase of the BMSD Project.

b. Based on an application (No. 3987A) filed on April 27, 1981, by DOE with the Texas Water Commission of TDWR, a Public Notice of Hearing Before the Texas Water Commission was published on April 29, 1981 announcing that DOE is seeking an amendment to Permit No. 3681, pursuant to Section 11.122, Texas Water Code, and Texas water Development Board (TWDB) Rules 156.04.10.001 - .002, to increase the total amount of State water authorized to be diverted and used from the Brazos River, for the leaching and displacement phases of the BMSD Project from 204,400 AF to 367,000 AF, and to authorize the diversion from the Brazos River of 3.5 AF/Y of water, up to a maximum total of 88 AF, for a potable water supply. The public hearing is to be held in Austin, Texas on June 12, 1981.

(1) We feel that the final report should contain accurate and complete data as furnished above, regarding the present and proposed water rights permits for both leaching and displacement mining purposes at the BMSD Project.

(2) 2. Also, we feel that the final report should contain data and explanation, relative to the following additional permitting requirements and actions:

a. Application to TDWR for permit to appropriate necessary State water from, and to construct the necessary raw water diversion and intake structure at Mile 305 of the Gulf Intracoastal Waterway (GICW), for leaching and displacement mining purposes at the proposed new 140-MMB Big Hill Salt Dome Project (BHSD Project), pursuant to Sections 11.021 and 11.121 of the Texas Water Code. (We believe it would be desirable to discuss the water requirements and permitting actions in the analytical Appendix B of the said supplemental report.)

b. Application to TDWR for permit to discharge leaching and displacement brines and other wastes from the BHSD Project, and the construction of brine pipelines and diffuser, located 3.5 miles offshore in State coastal waters, pursuant to Chapter 26 and Section 16.238 of the Texas Water Code, and Article 4477-7 of Vernon's Annotated Civil Statutes.

c. Application to TDWR for the potential needed amendment of State Permit No. 02271 (corresponding to NPDES Permit No. TX 0074012), regarding the disposal of wastes from the BMSD Project to the Brazos River (Diversion Channel) southwest of the City of Freeport, to the GICW, and to the Brazos River Tidal Segment No. 1201 in the Brazos River Basin.

TDWR appreciated the opportunity of reviewing the referenced draft report. TDWR will continue to work closely with DOE to ensure that a reasonable degree of practical consistency is achieved between the extremely vital SPR Program projects and objectives, and TDWR's own statewide water resources planning and development objectives pursuant to the Texas Water Code and the implementing State regulations. Therefore, please advise if we can be of further assistance in furthering the SPR Program which was mandated by the Energy Security Act.

Sincerely,

Charles E. Nemir

for Harvey Davis
Executive Director

UNITED STATES DEPARTMENT OF COMMERCE
The Assistant Secretary for Policy
Washington, D.C. 20230

JUN 1 9 1981

Mr. C. Curtis Johnson
Project Manager, Strategic Petroleum
Reserve Project Management Office
U.S. Department of Energy
900 Commerce Road East
New Orleans, Louisiana 70123

Dear Mr. Johnson:

(1) This is in reference to your draft supplement to the final environmental impact statement entitled "Strategic Petroleum Reserve Phase III Development Texoma and Seaway Group Salt Domes." The enclosed comments from the National Oceanic and Atmospheric Administration (NOAA) and the Maritime Administration are forwarded for your consideration.

Thank you for giving us an opportunity to provide these comments, which we hope will be of assistance to you. We would appreciate receiving eight copies of the final statement.

Sincerely,

Robert T. Miki
Director of Regulatory Policy

Enclosure Memos from: Robert B. Rollins
National Ocean Survey, NOAA

D. R. Ekberg
National Marine Fisheries Service
NOAA

Kenneth W. Forbes
Office of Shipbuilding Costs
Maritime Administration

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL OCEAN SURVEY
Rockville, Md. 20852

JUN 5 1981 OA/C52x6:JVZ

TO: PP/EC - Joyce M. Wood

FROM: OA/C5 - Robert B. Rollins

SUBJECT: DEIS #8105.16 - Strategic Petroleum Reserve, Texoma and Seaway Group Salt Domes, Cameron Parish, Louisiana, and Brazoria and Jefferson Counties, Texas

The subject statement has been reviewed within the areas of the National Ocean Survey's (NOS) responsibility and expertise, and in terms of the impact of the proposed action on NOS activities and projects.

(1) The National Ocean Survey has no specific comments on the subject Draft Supplement to the Final Environmental Impact Statement. However, the Final Supplement should incorporate the following documents:

Frey, H. R., M. W. Szabados, and L. E. Hickman. NOS Strategic Petroleum Reserve Support Project: Special Report. "Physical Oceanography at the West Hackberry Brine Disposal Site." National Ocean Survey, National Oceanic and Atmospheric Administration, March 1981, 218 pp.

National Ocean Survey. NOS Strategic Petroleum Reserve Support Project: Final Report, Volume Two - "Measurements and Data Quality Assurance." Edited by: H. R. Frey and G. E. Appell. National Ocean Survey, National Oceanic and Atmospheric Administration, March 1981, 184 pp.

Frey, H. R., M. W. Szabados, and L. E. Hickman. NOS Strategic Petroleum Reserve Support Project: Final Report, Volume One - "Oceanography on the Louisiana Inner Continental Shelf." National Ocean Survey, National Oceanic and Atmospheric Administration (in press).

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
Southeast Region
9450 Koger Boulevard
St. Petersburg, FL 33702

June 9, 1981 F/SER61/RR
893-3503

TO: PP/EC - Joyce Wood

FROM: F/SER6 - D. R. Ekberg

SUBJECT: Comments on Draft Supplement to Final Environmental Impact Statement -- Strategic Petroleum Reserve Phase III Development, Texoma and Seaway Group Salt Domes (West Hackberry and Bryan Mound Expansion, Big Hill) Cameron Parish, Louisiana and Brazoria and Jefferson Counties, Texas (DOE) (DEIS #8105.16)

The subject draft environmental impact statement that accompanied your memorandum of May 20, 1981, has been received by the National Marine Fisheries Service for review and comment.

The statement has been reviewed and the following comments are offered for your consideration.

General Comments

This document lacks a detailed analysis of the potential Strategic Petroleum Reserve (SPR) brine discharge impacts to the Gulf menhaden population of the northwestern Gulf of Mexico. NMFS data indicate that in terms of pounds landed the Gulf menhaden has been a vital fishery in the United States in recent years. A significant portion of this fishery is located in the vicinity of the Big Hill and West Hackberry diffusor sites. Furthermore, field sampling efforts (Fore 1970, and Christmas and Waller, 1975) have indicated that the vicinity of the Big Hill and West Hackberry brine disposal sites is a significant menhaden spawning ground. Although menhaden larvae generally occur in the upper portion of the water column, significant vertical extension of the salt plume, shown by study results at Bryan Mound (Randall and Hann 1981), and wind and current induced mixing of the salt plume and near-surface water containing menhaden eggs and larvae could
(1) significantly impact this resource. Based on this information, we believe that the impact statement should contain as detailed discussions of menhaden ecology (Section 3.0) and expected project impacts (Section 4.0) to the menhaden fishery as presented for brown and white shrimp. It should also discuss the relative importance of the proposed Big Hill diffusor location to menhaden spawning activities.

(2) The DEIS contains an inadequate analysis of alternative offshore brine disposal locations. Two potential locations, one each at 3.5 miles offshore (-30-ft. water depth) and 12.5 miles offshore (-40-ft. water depth) were discussed, but justification for selection of these sites, or for elimination of alternative sites at other depths, is lacking or weak. In view of this, we suggest that the discussion of alternative discharge sites be expanded to include at least an alternative location between the white and brown shrimp fishing grounds (water depth of approximately 60 ft. and over) and a location which would be preferred if all known environmental conditions were taken into consideration if that location is different than any of the above.

(3) Most of the discussion of salinity impacts to shrimp in the DEIS covers tolerance and occurrence with little or no coverage of salinity/temperature ranges for optimum growth and survival.

Specific Comments

2.0 DESCRIPTION OF PROPOSED ACTION

2.3 OTHER ALTERNATIVES

2.3.3.1 Alternative Crude Oil Distribution

(4) Page 2-27, paragraph 3. The DOE has apparently misunderstood the design of facilities at Pelican Island, a proposed alternative pipeline terminus. The proposed terminal at Pelican Island, to be built by private interests, would mainly consist of pipelines and surge tanks which would connect Pelican Island to Virginia Point. We believe that the proposed Virginia Point facility, rather than Pelican Island, would have the appropriate storage and distribution facilities necessary for the SPR.

2.3.3.3 Alternative Brine Disposal Site

(5) Page 2-28, paragraph 3. The rationale for selecting only two alternative offshore brine disposal sites should be presented. If the 12.5-mile alternative was selected to coincide with the distance offshore of the brine disposal site at Bryan Mound, there should be environmental justification provided similar to that developed for Bryan Mound (i.e., the Bryan Mound 12.5-mile site was selected to be at a depth intermediate between the major brown and white shrimp grounds). The section also should include a presentation of an alternative site of 10 or more fathoms (between the brown and white shrimp ground communities, as described by

Chittenden and McEachran (1976), and nearly the same depth as the Bryan Mound brine discharge) and the environmentally most desirable offshore brine discharge location, if it is either of these sites.

6 Page 2-29, paragraph 1. Substantiation should be provided for the statement that, "It may be postulated that biotic communities at the 3.5 mile site are better suited to withstand the effects of brine discharge than communities at a 12.5 mile site", or this statement should be deleted.

3.0 AFFECTED ENVIRONMENT

3.2 SITE-SPECIFIC ENVIRONMENT

3.2.1 Big Hill Storage Facility (140 MMB)

3.2.1.5 Species and Habitats

Brine Disposal Sites (3.5 to 12.5 mile alternatives)

7 Pages 3-18, paragraph 6 through 3-20, paragraph 4. The eleven generalizations and comparisons based on Appendices F and G are overly simplistic and often provide misleading information on shrimp and fish ecology. Therefore, we suggest that each of the listed items presented on pages 3-19 and 20 be carefully reviewed and adequate substantiation be provided. In particular need of correction, clarification and/or documentation are items numbered 5 and 7 thru 11, as briefly detailed below.

Item 5.

8 Page 3-19, paragraph 5. Although the statement that euryhaline organisms are tolerant of both high and low salinities is generally correct, the paragraph should point out that certain life stages of euryhaline organisms may have a narrow range of prolonged salinity tolerance, preference, optimal growth, and optimal survival.

Item 7.

9 Page 3-19, paragraph 7. This paragraph should present available information on the chronic or sub-lethal impacts of increased salinities which might be encountered at the diffusors to shrimp, Gulf menhaden, and other important species.

Item 8.

(10) Page 3-20, paragraph 1. The DEIS states that, "all literature reviewed indicated that all stages of the penaeid life cycle and also those for the Gulf menhaden, *Brevoortia patronus*, can tolerate wide ranges of salinity." However, much of the literature on shrimp that DOE cited in Appendix G., Shrimp Ecology, does not indicate that all stages of the penaeid life cycle can tolerate wide ranges of salinity. At least one study that was cited as indicating a wide range of salinity tolerance only surveyed brackish to fresh salinity. In addition, we are unaware of any literature cited in the DEIS that indicates that all stages of the Gulf menhaden life cycle can tolerate wide ranges of salinity. As noted in our General Comments, a review of menhaden ecology should be just as appropriate as shrimp ecology.

The optimum salinities for growth, survival and fecundity as well as apparent preference should be indicated for shrimp and menhaden.

Item 9.

(11) Page 3-20, paragraph 2. The degree of heavy exploitation of each species of fish and shrimp in the Big Hill area should be provided to substantiate, or refute, the first sentence. If data are available which describe the "carrying capacity of the environment" in the vicinity of the Big Hill diffusor site, they should be provided for each species, or the last sentence deleted or modified.

Item 10.

(12) Page 3-20, paragraph 3. The statement that there, "appears to be a general oversupply of penaeid shrimp postlarvae" (emphasis added) is ecologically incorrect. Species such as shrimp which have evolved into having extremely high fecundity have correspondingly high rates of natural mortality. Therefore, the number of shrimp postlarvae is not an unnecessary oversupply but a number sufficient to ensure the survival of a species which has always incurred a large natural mortality of larvae and juveniles and more recently fishing mortality of juveniles and adults. In addressing this issue in the FEIS, we recommend a review of literature dealing with the concept of compensatory reserve (e.g., Goodyear, 1977).

(13) The last sentence of this item should be modified to indicate penaeid populations do not necessarily "rebound quickly" in a year following one of poor production.

Item 11.

(14) Page 3-29, paragraph 4. Concerning the second sentence, studies in Galveston Bay and entrance channel by Baxter (1963) and Berry and Baxter (1969) indicate that the postlarval shrimp catch can be used to project adult production for a particular year - class. It, therefore, appears that it is the abundance of postlarvae entering the estuaries from the Gulf, along with the environmental factors inside the estuaries, that determine the size of the harvestable shrimp crop.

(15) The statement that Sabine Lake is "no longer conducive to shrimp production" should be substantiated. In addition, this section should be expanded to differentiate between harvest and nursery utilization in Sabine Lake when referring to production. We are unaware of any recent data on early life stages in Sabine Lake which would indicate whether it is no longer conducive to production of shrimp harvested in the Gulf.

Threatened and Endangered Species

(16) Page 3-20, paragraph 5. This section should document any endangered species consultation that the DOE has had with the NMFS regarding sea turtles and marine mammals.

3.2.1.8 Socioeconomics

(17) Page 3-23 thru 3-33. This section should document Gulf menhaden economics to the same degree as was documented for shrimp in the subsection Offshore Shrimp Fisheries Economics. Gulf menhaden represent the greatest landings by weight of any Gulf fishery, and the vicinity of the proposed Big Hill diffusor site may serve as an important spawning ground in the region.

3.2.2.2 Water Environment

(18) Page 3-41, paragraph 2. All Galveston Bay oyster reef crossings of the southern pipeline to Pelican Island (or Virginia Point) should be documented.

4.0 ENVIRONMENTAL IMPACTS OF THE PROPOSED AND ALTERNATIVE ACTIONS

4.2 Big Hill (140-MMB CRUDE OIL STORAGE FACILITY)

4.2.1 Land Features

(19) Page 4.3, paragraph 2. To avoid confusion or misunderstanding, the third sentence should state that double-ditching and other available mitigation techniques would be used during pipeline crossings of wetlands.

4.2.2 Water Environment

(20) Page 4-4, paragraph 3. The last sentence should state when the agency consultation would be initiated to develop mitigation measures for waterway crossings.

4.2.5 Species and Habitats

4.2.5.2 Brine Disposal

Brine Discharge Experience at Bryan Mound

(21) Page 4-18, paragraph 3. Although, by extrapolation from other studies, plume thickness has been computed to be less than 3 ft., these data should be compared to Bryan Mound monitoring studies which found the plume to have a vertical extent of up to 25 ft. under less than maximum discharge levels (Randall and Hann, 1981). The implication of such a large vertical extent of the plume should be discussed in terms of impacts to the Gulf fishery at the Big Hill site which has a total depth of only 30 ft.

Brine Plume Projections for Big Hill

(22) Page 4-21, line 3. The DOE's definition of an "unreasonable buildup of brine" should be provided.

Impacts on Penaeid Shrimp

(23) Page 4-25, paragraph 2. Assessment of bioassay results should also consider chronic or sub-lethal effects of salt dome brine on various life stages of penaeid shrimp.

(24) Page 4-25, paragraph 3. The extent to which shrimp larvae could avoid the brine plume (lines 13-15) in an oceanic environment should be discussed and documented.

(25) Page 4-25, paragraph 3. The statement that shrimp stocks and many demersal fish in the northwestern Gulf are below carrying capacity as a result of commercial harvest should be documented.

(26) Page 4-26, after paragraph 1. As noted in our General Comments, a sub-section on impacts on menhaden should be added.

4.3 CRUDE OIL DISTRIBUTION SYSTEM

4.3.2 Pipeline Routes

4.3.2.5 Species and Habitats

(27) Page 4.54, paragraphs 2 and 4. In the event that ship channel crossings are not completed by horizontal directional drilling techniques, these paragraphs should discuss the impacts of storage of large volumes of spoil from the channel crossings and means to mitigate those impacts (e.g., upland disposal, temporary barge storage, etc.).

4.5 IMPACTS TO FLOODPLAINS AND WETLANDS

4.5.2 Phase III Floodplain and Wetland Assessment

Crude Oil, Raw Water and Brine Disposal Pipelines for Big Hill

(28) Page 4-69, paragraph 4. This paragraph should discuss under what conditions double-ditching techniques for wetlands crossings for pipeline installation would be used and details of additional mitigation measures being proposed (e.g., revegetation, avoidance of alterations of marsh hydrology, etc.).

(29) Page 4.70, paragraph 1. This paragraph should document correspondence with Federal and State fish and wildlife agencies for the purpose of determining the need for a wetland revegetation program.

5.0 ENVIRONMENTAL MONITORING

5.4 PHASE III, OFFSHORE MONITORING

(30) Page 5-4 thru 5-5. This section should be expanded to discuss what corrective measures would be taken if the monitoring program documents significant environmental impacts to the Gulf fishery from Big Hill brine discharges.

6.0 SUMMARY OF IMPACTS AND MITIGATION MEASURES

Table 6-1

(31) Page 6-3. Under item B. Water environment, dredging in the Gulf of Mexico, it is stated that the Gulf pipeline trench would be backfilled "if practical". We suggest that the potential impacts to

commercial trawlers and their gear of exposed pipelines be discussed in Section 4.0 and the parameters for determining backfill practicality be presented. To avoid personal injury and vessel and gear destruction, we believe that mandatory backfilling should be an essential mitigation measure. The only time no backfilling would be a viable alternative would be where self burial has already occurred.

9.0 CONSULTATION AND COORDINATION

Table 9.1

(32) Page 9.3. Under the heading U.S. Department of Commerce, the National Marine Fisheries Servive's jurisdiction and responsibility under the Fish and Wildlife Coordination Act should be summarized.

APPENDIX G - SHRIMP ECOLOGY

(33) Although we have not thoroughly reviewed the accuracy of the conclusions drawn from the numerous publications cited in this appendix, inaccuracies in references to Berry and Baxter (1969) and Truesdale (1970) lead us to suggest that each be carefully reviewed. For example, the DEIS references to Truesdale (1970) indicated that this scientist concluded that salinity does not influence shrimp distribution in the estuary, and although unclear in the text, he presumably corroborated the euryhaline nature of shrimp and their tolerance of high and low salinity. In our review of this reference, we found that the mean salinity for all stations sampled by Truesdale from March 1966 thru May 1968 was only 2.3 ppt (the highest individual salinity was only 15.6 ppt; well below oceanic salinities) and that he reported freshwater inflow (a major factor affecting salinity) did influence shrimp distribution. Therefore, this publication did not corroborate shrimp tolerance of high salinity. It did, however, confirm the occurrence of the early life stages of shrimp in low salinity estuarine waters and the influence of high river flows and very low salinities on shrimp distribution during the major nursery season.

Seasonality

(34) Page G-1, paragraph 3. The comment that Sabine Lake no longer produces a fishable stock of brown shrimp is misleading since we are unaware of changes of brown shrimp catches (which were never a significant portion of the total shrimp landings) since closure of Toledo Bend Dam and subsequent inflow alterations.

Spawning and Distribution

(35) Page G-4, paragraph 2, and Page G-5, Figure G-2. The first sentence and the cited figure should be clarified to indicate that the reference is only to white shrimp.

Food Habits

(36) Page G-8, paragraph 4 thru G-10, paragraph 1. Documentation should be provided for the discussion of proteins and lipids (last 3 lines, page 8 and first 3 lines, page 10).

Salinity Relationships

(37) Pages G-10 to G-12. This section should discuss past study findings on optimal salinity as thoroughly as salinity ranges are discussed. For example, according to Gunter et al. (1964), the optimum salinity for postlarval and juvenile white shrimp ranges from 0.5 to 10.0 ppt. However, a report by Zein-Eldin and Griffith (1969) on some more recent laboratory studies, though not indicating a need for water quite as fresh, nevertheless noted that at temperatures of 30°C and above, twice as much tissue was produced by postlarval white shrimp at salinities of 5 and 15 ppt than at salinities of 25 and 35 ppt. Laboratory studies performed at the Gulf Coast Research Laboratory (Lakshmi et al., 1976; Venkataramiah et al., 1974, 1975 and 1977) showed that young brown shrimp fare best in lower salinities. Although the juvenile brown shrimp (70 mm mean length) can survive a wide salinity range, the best growth and survival rates were obtained in salinities of 8.5 to 17.0 ppt. Also, optima for subadult shrimp (95 mm mean length) seem to exist above 10 ppt salinity and preferably between 15 and 25 ppt salinity. In the field, Christmas and Langley (1973) reported that the highest catch of brown shrimp per haul in their Mississippi Sound samples was in the salinity interval 15.0 to 19.9 ppt.

In consideration of data developed on optimal salinity conditions during various shrimp life stages, adverse impacts of salinity alterations expected (e.g., feeding rates, metabolism, disorientation, predator avoidance, etc.) should be discussed.

Factors Affecting Success of Year Class

(38) Page G-13, paragraph 6. Examination of Table 1 presented by Berry and Baxter (1969) indicates that postlarval collections in 1960 and 1962-66 were not very similar.

(39) Page G-14, paragraph 2. This and the following paragraph should discuss and reference studies on the importance of marsh vegetation to shrimp production (e.g., Turner, 1977).

Historical Trends

(40) Page G-16, paragraph 3. This section should be expanded to discuss both historical trends in fishing effort and in the average size of shrimp landed in the northwestern Gulf of Mexico.

CLEARANCE SIGNATURE AND DATE

F/HP:RSmith Yates M. Barber, Jr. for R Smith 6/15/81

Attachment
Literature Cited

cc:
F/HP (3)
F/SER612
GOMFMC

LITERATURE CITED

Baxter, K.N. 1963. Abundance of postlarval shrimp - one index of future fishing success. Proc. Gulf Caribb. Fish. Inst. 15:70-87.

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______________, and R.S. Waller. 1975. Location and time of menhaden spawning in the Gulf of Mexico. Gulf Coast Res. Lab., Ocean Springs, MS. 20 pp.

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DEPARTMENT OF THE ARMY
GALVESTON DISTRICT, CORPS OF ENGINEERS
P.O. BOX 1229
GALVESTON, TEXAS 77553

REPLY TO ATTENTION OF:

SWGED-E

22 JUN 1981

Mr. C. Curtis Johnson
Project Manager
Strategic Petroleum Reserve
Project Management Office
U.S. Department of Energy
900 Commerce Road East
New Orleans, Louisiana 70123

Dear Mr. Johnson:

This is in response to a letter dated 1 May 1981 from Mr. Robert J. Stern, Director, NEPA Affairs Division which provided copies of the Draft Supplement to Final Environmental Impact Statement Strategic Petroleum Reserve, Phase III Development, Texoma and Seaway Group Salt Domes (West Hackberry and Bryan Mound Expansion, Big Hill), Cameron Parish, Louisiana and Brazoria and Jefferson Counties, Texas, for our review and comments in conjunction with the New Orleans District, Corps of Engineers.

Our coordinated comments are as follows:

(1) a. The 100-year flood plain level of 14.0 feet mean sea level for the Big Hill site is still water and does not account for wave runup.

(2) b. Projects are within the purview of Section 10 of the 1899 River and Harbor Act.

(3) c. Projects are within the purview of Section 404 of the Federal Water Pollution Control Act as amended.

(4) d. Project will involve placement of fill material in wetlands at the Big Hill and Bryan Mound sites. It is recommended that Mr. Marcos De La Rosa, Chief, Permit Branch, Galveston District, Corps of Engineers, FTS telephone 527-6378 be contacted regarding Department of Army permits in the Galveston District.

SWGED-E 22 JUN 1991

Mr. C. Curtis Johnson

e. Coordination regarding Department of Army permits should also continue with New Orleans District.

Sincerely,

FOR JAMES M. SIGLER
Colonel, Corps of Engineers
Commanding

Copy furnished:
Mr. Henry Glaviano
New Orleans District,
Corps of Engineers
P.O. Box 60267
New Orleans, LA 70160

United States Department of the Interior

OFFICE OF THE SECRETARY
WASHINGTON, D.C. 20240

ER 81/982

JUN 23 1981

C. Curtis Johnson, Project Manager
Strategic Petroleum Reserve Project
Management Office
U.S. Department of Energy
900 Commerce Road East
New Orleans, Louisiana 70123

Dear Mr. Johnson:

We have reviewed the draft environmental impact statement for the Phase III Development, Texoma and Seaway Salt Domes (West Hackberry and Bryan Mound Expansion, Big Hill) sent to us May 1, 1981. Our major concerns are that adequate provision be made for the disposal of PCB contaminated dredge spoils and that any mineral resource commitments be fully considered.

(1) The disposal of PCB contaminated dredge spoils should be carefully controlled and monitored to reduce the possibility of toxic effects on fish and wildlife. Any dredged material that is contaminated with PCB's should not be returned to the water, even for pipeline backfill. This polluted material should be confined in upland disposal areas, Category 3.

Known mineral resources of the Bryan Mound, West Hackberry, and Big Hill areas include petroleum, natural gas, salt, sulfur, limestone, and sand and gravel. Because of previous storage development at Bryan Mound and West Hackberry and solution mining at the Big Hill site, no significant conflict is anticipated between the proposal
(2) and mineral resources or their development. It is suggested, however, that the investigation include a brief evaluation of in situ mineral resources within the project sites and an analysis of the project's effect upon such resources.

In addition, we have the following specific comments:

(3) Page 4-16, 4.2.5.1 - Project effects, if any, on the stand of live oak trees at the Big Hill site should be clearly stated. These coastal stands are very valuable to migratory birds and should be protected if possible.

4 Page 4-24, 4.2.5.2, #7 - Since the near-shore brine disposal site has lower ambient salinities than the far-shore site, it would be more subject to salinity change from brine disposal. Although the salinity change may not exceed the tolerances of any species in the area, it would change the habitat characteristics of the area, especially for any species using the area because of its lower salinity.

5 Page 4-25, 4.2.5.2 - Physical factors (temperature and salinity) in the Gulf generally do not control shrimp population because these factors are relatively constant. If these factors in the Gulf start to fluctuate, as proposed with brine disposal, they could become controlling factors on shrimp populations as much as estuarine conditions.

6 Page 4-56, 4.4.1 - Although the Fish and Wildlife Service has reached an agreement with DOE regarding wetland creation to replace the wetlands destroyed at Bryan Mound, the best design would still place all well sites in upland areas.

We appreciate the opportunity to review this statement.

Sincerely,

CECIL S. HOFFMANN

Special Assistant to
Assistant SECRETARY

FEDERAL ENERGY REGULATORY COMMISSION
WASHINGTON 20426

IN REPLY REFER TO:

June 23, 1981

Mr. Robert J. Stern
Director, NEPA Affairs Div.
Office of Environmental
Compliance & Overview
U. S. Department of Energy
Washington, D. C. 20585

Dear Mr. Stern:

I am replying to your request of May 1, 1981 to the Federal Energy Regulatory Commission for comments on the Final Environmental Impact Statement for the Strategic Petroleum Reserve Seaway and Texoma Groups of Salt Domes. This Final EIS has been reviewed by appropriate FERC staff components upon whose evaluation this response is based.

This staff concentrates its review of other agencies' environmental impact statements basically on those areas of the electric power, natural gas, and oil pipeline industries for which the Commission has jurisdiction by law, or where staff has special expertise in evaluating environmental impacts in-
(1) voled with the proposed action. It does not appear that there would be any significant impacts in these areas of concern nor serious conflicts with this agency's responsibilities should this action be undertaken.

Thank you for the opportunity to review this statement.

Sincerely,

Jack M. Heinemann
Advisor on Environmental Quality

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION VI
1201 ELM STREET
DALLAS, TEXAS 75270

June 24, 1981

Mr. C. Curtis Johnson
Project Manager
Strategic Petroleum Reserve
U.S. Department of Energy
900 Commerce Road East
New Orleans, Louisiana 70123

Dear Mr. Johnson:

We have completed our review of the Draft Supplement to the Final Environmental Impact Statement (EIS) for the proposed Phase III expansion of the Strategic Petroleum Reserve (SPR), Texoma and Seaway Group Salt Domes. This proposed expansion will provide storage for an additional 212 million barrels (MMB) of crude oil, bringing the existing SPR storage capacity from 538 MMB to a total of 750 MMB. A secondary objective of the proposal is to increase average drawdown capabilities from 3.5 MMB to 4.5 MMB per day. Expansion will be accomplished through developing 4 additional 10 MMB caverns at the existing Bryan Mound SPR site in Brazoria County, Texas, and 3 additional 10 MMB caverns at the West Hackberry site in Cameron Parish, Louisiana. A new site, Big Hill, located in Jefferson County, Texas, will also be developed creating 140 MMB of crude oil storage, the remainder of the SPR Phase III expansion storage capacity.

The following comments are offered for your consideration in preparation of the Final Supplement:

<u>Brine Disposal</u>

(1) 1. Although we do not object to the proposed Phase III expansion plan,
the Department of Energy (DOE) should be advised to substantiate
the claim that impacts on the shrimp fishing will be minimal. Of
concern is the location of brine discharge for Big Hill in the
(2) Gulf of Mexico. DOE should recognize that the brine discharge from
Big Hill will be subject to the Ocean Discharge Criteria (40 CFR,
Part 125, Subpart M) promulgated on October 3, 1980, under Section
403(c) of the Clean Water Act, as amended. Therefore, under these
requirements, EPA will require the result of the completed ongoing
National Marine Fisheries Service shrimp tagging and spawning
studies in the Big Hill study area to make final determination on
the issuance of the Ocean Discharge permit for the proposed diffuser
location. The study concentrates on the aspects of the shrimp life
cycle and spawning sites which may be related to brine disposal impacts.
Results of shrimp tagging and spawning studies implemented in discharge
monitoring for Bryan Mound may also be useful here. The availability of
the completed studies for public review should be identified in the
Final Supplement.

(3) 2. We do not expect any long-term significant impacts resulting from the expansion of Bryan Mound and West Hackberry Salt Domes since existing systems will be utilized for disposal of brine. However, the increases in brine discharges will increase the aerial extent of the brine plume. Therefore, we request that prior to initiating Phase III related brine discharges, the completed comprehensive monitoring plan be submitted to EPA for final review and approval.

Air Quality

1. The Draft Supplement addresses that both Brazoria and Jefferson Counties, Texas, are designated as non-attainment areas for ozone. In addition, according to available data near the West Hackberry sites, Cameron Parish, Louisiana, is also not attaining the ozone National Ambient Air Quality Standards (NAAQS). Therefore, the
(4) Final Supplement should recognize that the volatile organic compound (VOC) emissions resulting from the Texoma and Seaway Group Salt Domes would be subject to the Federal offset policy or non-attainment provisions of the applicable State Implementation Plan (SIP). There is no discussion pertaining to these requirements. Such discussion should be provided in the Final Supplement.

2. Section 4.2.3 addresses estimated non-methane hydrocarbon (NMHC) concentrations and identifies in this section, and other sections,
(5) that the 3-hour NMHC standard of 160 ug/m^3 is exceeded. The Final Supplement should recognize that the NMHC standard was used only as a guide in developing SIP's to achieve the ozone standard and since has been revoked. Attention should be focused on the ozone standard, not the NMHC standard.

3. We are in agreement with the air quality analysis presented on page 4-15 stating "as currently proposed, the levels of hydrocarbon emissions at the storage sites and at Sun Terminal will be insufficient to have an important impact on non-local, overall regional levels of photochemical oxidants. Elevated NMHC levels alone would not be sufficient to produce significant levels of photochemical oxidants and it is unlikely that other resources would independently violate the NMHC standard outside terminal boundaries."
(6) However, to further minimize air emissions and their associated impacts, we urge the DOE to provide, whenever possible, lowest achievable emission rate (LAER) technology such as vapor recovery systems. Assurances should be made in the Final Supplement that this effort will be pursued.

Socioeconomics

(7) The Final Supplement would be strengthened if the socioeconomic impacts could be more accurately defined. The two sets of assumptions and their possible and probable socioeconomic impact scenarios as presented on pages 4-28 through 4-33 describe a varied range of

impacts from none to moderately severe in regard to the effects upon public and private community services. Further evaluation should be exercised to more definitively assess which of the two scenarios would most likely occur. Additionally, the Final should identify the mitigation measures to be pursued by DOE to insure that socioeconomic impacts are minimized, whenever possible.

Oil Spill Control

(8) The Final EIS would be substantially strengthened if Appendix I included additional information identifying the measures to control impacts resulting from possible oil spills. Specifically, the Final EIS should provide assurances that a Spill Prevention Control and Countermeasure (SPCC) Plan will be developed in conformance to the rules and regulations identified in 40 CFR, Part 112 entitled, "Oil Pollution Prevention." Additionally, the Final EIS should explain that operation of the proposed expanded facilities will not be initiated until the SPCC Plan has been completed and approved by the appropriate State and Federal agencies.

These comments classify your Draft Supplement to the Final EIS as LO-2. Specifically, we have no objections to the Phase III expansion as described in the Draft Supplement; however, we are asking that the Final Statement be strengthened in the areas identified in the preceding comments. Our classification will be published in the Federal Register according to our responsibility to inform the public of our views on proposed Federal actions under Section 309 of the Clean Air Act.

Definitions of the categories are provided on the enclosure. Our procedure is to categorize the EIS on both the environmental consequences of the proposed action and on the adequacy of the EIS at the draft stage, whenever possible.

We appreciated the opportunity to review the Draft Supplement. Please send our office five (5) copies of the Final Supplement at the same time it is sent to the Office of Federal Activities, U.S. Environmental Protection Agency, Washington, D.C.

Sincerely,

Frances E. Phillips

Frances E. Phillips
Acting Regional Administrator

Enclosure

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

JUN 25 1981

C. Curtis Johnson, Project Manager
Strategic Petroleum Reserve Project
Management Office
U. S. Department of Energy
900 Commerce Road East
New Orleans, Lousiana 70123

Dear Mr. Johnson:

This is in response to your request for comments on Draft Supplement to the Final Environmental Impact Statement for the Strategic Petroleum Reserve Seaway and Texoma Groups of Salt Domes.

(1) We have reviewed the statement and determined that the proposed action has no significant radiological health and safety impact, nor will it adversely affect any activities subject to regulation by the Nuclear Regulatory Commission.

Since we made no substantive comments, you need not send us the Final Supplement to the Final Environmental Impact Statement when issued.

Thank you for providing us with the opportunity to review this Draft Supplement.

Sincerely,

Daniel R Muller

Daniel R. Muller, Assistant Director
for Environmental Technology
Division of Engineering

STATE CLEARINGHOUSE

30 EAST BROAD STREET • 39TH FLOOR • COLUMBUS, OHIO 43215 • 614 / 466-7461

81-06-25 P
09

C. Curtis Johnson, Project Manager
U. S. Department of Energy
Management Office
900 Commerce Road East
New Orleans, Louisiana 70123

RE: Review of Environmental Impact Statement/Assessment
Title: Draft Environmental Impact Statement on Strategic Petroleum Reserve--Phase III Development
SAI Number: 36-471-0014

Dear Mr. Johnson:

The State Clearinghouse coordinated the review of the above referenced environmental impact statement/assessment.

(1) This environmental report was reviewed by all interested State agencies. No reviewer has stated concerns relating to this report.

Thank you for the opportunity to review this statement/assessment.

Sincerely,

Judith Y. Brachman
Judith Y. Brachman
Administering Officer

JYB:alf

cc: DNR, Mike Colvin
EPA, Beth Whitman

Olin

120 LONG RIDGE RD., STAMFORD, CONN. 06904

July 7, 1981

Mr. C. Curtis Johnson
Project Manager
Strategic Petroleum Reserve Project
Management Office
U.S. Department of Energy
900 Commerce Road East
New Orleans, LA 70123

Dear Mr. Johnson:

(1) Olin Corporation submits the comments below following review of the Draft Supplement to the Final Environmental Impact Statements for the Strategic Petroleum Reserve Seaway and Texoma Groups of Salt Domes, Phase III Development, received May 12, 1981. Please note that in previous correspondence of May 13, 1981, Olin Corporation has expressed to you its opposition to the use of additional Olin-controlled salt dome property at the Hackberry location for the Strategic Petroleum Reserve.

(2) In our review of this 500-page Impact Statement, we have found no mention of industrial use of the salt dome property which the Department of Energy proposes to acquire. The land which is owned by Olin and valued as an important business asset is referred to as "pasture land." While the surface of this land is leased for pasture use, the Department of Energy well knows that the true value lies beneath the surface in the salt.

Early in the 1930's the company leased salt dome brining rights and established itself with a plant location in nearby Lake Charles for production of soda ash by the Solvay process. During the following years it acquired fee property and renewed and maintained its leases in order to secure a long-term position. Eventually, approximately 480 acres were owned or leased. By 1972, manufacture of soda ash by the Solvay process had been rendered non-economic by development of soda ash production from the trona deposits of Wyoming and the Olin soda ash unit was shut down. By that time, however, the Lake Charles location had grown into a multi-product complex employing approximately 612 people and consuming substantial quantities of chlorine, which is produced from salt. Since then, employment has grown to more than 1,200.

To provide interim utilization of the salt property, the company initiated discussions with PPG Corporation in August, 1974 which eventually led to a contract for sale of brine to that company. PPG continues to consume brine produced by Olin today. In 1973 the company recognized the probable future utility of the property for underground storage of bulk liquid and gaseous chemicals; and early in 1974, started negotiations with landowners which eventually led to a formal agreement in August, 1976 commissioning Olin to pursue underground storage business for the joint benefit of the parties. The April, 1977 eminent domain taking of all of the existing caverns and a major portion of the undeveloped property removed a significant part of the asset which could have been used for an underground storage business effort. The subsequent "Phase II" taking removed more than 60 additional acres, leaving about 190, of which one-half may have limited utility because of its location on the edge of the dome.

(3) We now treasure the remaining 80 usable acres out of the original 480 acres, believing that it may still have significant commercial utility. However, the proposed Phase III expansion would remove more than 25% of that remainder. We believe the government should identify another route for the Phase III expansion.

(4) It is noted that fair valuation of property upon which future business opportunities may be based has proven to be difficult. In addition to the potential for future underground storage development, Olin values the salt properties as a raw material reserve for chlorine manufacture. The company is a significant factor in the chlorine business in the United States, with manufacturing facilities at four locations and an on-going expansion program. Because of market oppotunities in the area and internal chlorine consumption at Lake Charles, that location has important potential for future chlorine plant construction.

(5) These possibilities offer important socio-economic advantages for the area not mentioned in the Impact Statement, Section 3.2.4.8 (page 3-53). In Section 4.4.8 (page 4-63), the report refers to a possible adverse socio-economic impact in the "taking of existing properties and houses
(6) for the proposed expansion." We suggest that existing properties and houses can readily be replaced in the immediate area and that the community would likely prefer to retain the possibility of future expanded job opportunities.

We suggest as alternate courses of action:

1. To retain the original time schedule, utilize the land to the south of the original taking and leave the Olin property to the west for future Olin commercial development.

7 2. Accept a compromise in timing, as suggested in an alternate proposal on page VII (Section 2.5) and page 2-18 so that only 10 million barrels of the expansion occur at West Hackberry and 60 million barrels at Bryan Mound.

8 3. Simply enlarge the caverns currently under construction, or enlarge the caverns under construction as well as the original existing caverns. A 30 million barrel expansion could be accomplished in this fashion by adding less than two million barrels to each of the 16 caverns, a 19% expansion, which would require only slightly over a 4% change in cavern diameter.

Olin Corporation appreciates the opportunity to submit these comments and trusts that they will be given careful consideration by the Department of Energy.

Very truly yours,

C. L. Knowles, Jr./ves

C. L. Knowles, Jr.
Director, Environmental &
Energy Affairs

CLK/kle

bcc: L. B. Anziano
E. McI. Cover
L. Kerr
H. T. Lunn
G. C. Mott
W. A. Oppold
F. H. Romanelli
W. A. Sutton
G. E. Wood

Errors etc:

4-57
5-8
5-2
5-4
xx
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