LOOP MARINE AND ESTUARINE MONITORING PROGRAM, 1978–95

Edited by

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INTRODUCTION

Louisiana Offshore Oil Port

The Louisiana Offshore Oil Port (LOOP) facilities in coastal Louisiana provide the United States with the country's only Superport for off-loading deep draft tankers. The facilities are located, south of New Orleans in Lafourche Parish in southeast Louisiana and in adjacent offshore waters west of the Mississippi River Delta. The development is operated by LOOP LLC., a private corporation jointly owned by Shell Oil Company, Texaco Inc., Ashland Inc., Murphy Oil Corporation, and Marathon Pipeline Company.

LOOP INC., (later restructured as LOOP LLC.) was organized in 1972 as a consortium of companies to design, construct and operate a deepwater port on the Louisiana coast. Pre-permit baseline studies related to the proposed development were conducted from 1972 to 1975. Major documents related to these studies are listed in Table 1. State and federal licenses to own and operate a deepwater port were issued in January 1977, and accepted on 1 August 1977. The state license was issued to LOOP pursuant to the Louisiana Offshore Terminal Act (LA R.S. 34:3101 et seq.). A federal *License to Own, Construct and Operate a Deepwater Port* was issued to LOOP by the U.S. Department of Transportation (USDOT) pursuant to the federal Deepwater Ports Act (33 U.S.C. 1501, et seq.). The first oil tanker was offloaded on 5 May 1981.

Facility Description

The Superport complex consists of an offshore marine terminal located approximately 30 km from the mainland in the Gulf of Mexico, an onshore storage facility at the Clovelly salt dome near Galliano approximately 50 km inland from the coast, and a large diameter pipeline system including a pumping booster station onshore near Fourchon to deliver oil to the storage facility (Figure 1). The pipeline system also connects the Clovelly Storage Dome to transportation facilities on the Mississippi River. A large brine storage reservoir (101 ha) is positioned near the Clovelly Storage Dome. A small-boat harbor and logistics facility is located at Port Fourchon.

Table 1. List of reports produced for Superport planning (after Sasser et al. 1982).

Year	Title	Comment
1972	LOOP feasibility study	LOOP's Engineering Feasibility Study
1972	A Superport for Louisiana	Superport Task Force Report
1972	LSU Superport Study #1	Requested by Superport Task Force
1972	LSU Superport Study #2	Requested by National Sea Grant Program
1973	LSU Superport Study #3	Requested by LOTA to formulate EPP
1973	LSU Superport Study #4	Requested by LOTA to formulate EPP
1974	Alternate Site Location Evaluation	Prepared by Dames and Moore for LOOP, Inc.
1976	Environmental Baseline Studies Vols. 1–4	Prepared by LSU for LOOP, Inc.
1976	Environmental Impact Study	US Department of Transportation

The marine terminal consists of three Single Point Mooring (SPM) structures connected by pipelines to a platform-mounted pumping station in the Gulf of Mexico, 30 km southeast of Belle Pass, Louisiana. Water depth at the platform is 36 m. From the Offshore Terminal, crude oil is pumped northward through a large diameter (48 inch) buried pipeline, through the onshore booster station at Fourchon, to the Clovelly Storage Dome near Galliano. The crude oil is stored in caverns constructed in subterranean salt domes. These storage chambers were formed by solution mining utilizing local surface water in the area. A second pipeline extends southward parallel to the oil pipeline and carries brine leached from the Clovelly Storage Dome to the Brine Diffuser located in open Gulf of Mexico waters approximately 4.8 km offshore and adjacent to the LOOP oil pipeline. Additional distributary pipelines move oil from the Clovelly Storage Dome to outlying pipelines and refining centers.

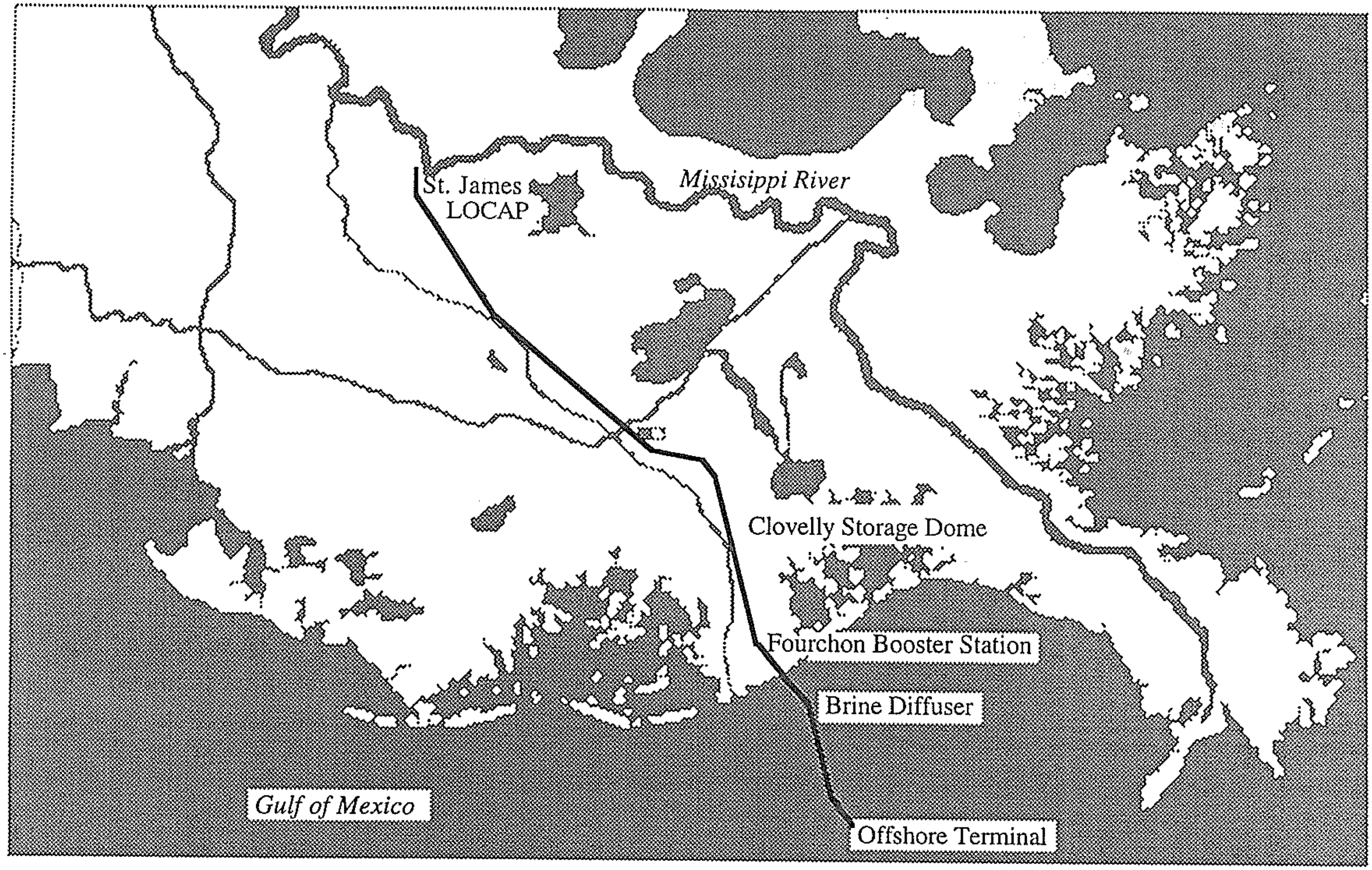

Figure 1. Location of the major components of LOOP operations. The pipeline north of the Clovelly Storage Dome is operated by LOCAP.

Project Area

The Barataria estuary and the offshore area where LOOP is located comprise an extremely diverse and complex natural system. Located in the Mississippi River Deltaic Plain, this region was formed and is continually influenced by processes associated with the deposition of massive amounts of sediments carried by the Mississippi River. The LOOP pipeline traverses the major wetland habitats in the Louisiana coastal area. The 159 km pipeline crosses the near-offshore Gulf of Mexico, beach/barrier headland, and estuary. Within the estuary, four salinity zones—saline, brackish, intermediate and fresh—are traversed, each providing a unique habitat supporting a variety of species.

The coastal marshes of Louisiana are among the most productive ecosystems in the world, supporting a wide variety of estuarine-dependent organisms. Louisiana leads fishery production within the northern Gulf of Mexico and is second only to Alaska among all states (NMFS 1997). Louisiana is the leader in the United States for the production of shrimp, blue crab, oyster, crawfish, tuna, red snapper, wild catfish, black drum, sea trout, and mullet (McKenzie et al. 1995). Ninety-five percent of the Louisiana fish and shellfish landings are estuarine-dependent species (McKenzie et al. 1995). The fish community of Barataria estuary is the most diverse of any estuary in Louisiana including 191 species from 68 families (Condrey et al. 1995).

Monitoring Program

In recognition of the potential for significant environmental impacts much attention was given to environmental safeguards by state and federal agencies and by the Superport developers (see review by Sasser et al. 1982). Because of the potential risks associated with the construction and operation of the Superport (e.g. bringing the world's largest oil tankers to one of the most productive fisheries resources in the world), both state and federal licenses required environmental monitoring of LOOP construction and operational activities. The environmental monitoring program (EMP) was developed under mandate of the Superport Environmental Protection Plan (revised, 1977), a regulation of the State of Louisiana implementing the Offshore Terminal Act. Ecological components of the estuarine/marine monitoring program include: water chemistry, physical hydrography (including brine discharge), zooplankton / ichthyoplankton, demersal nekton, benthos, and sediment quality. The Louisiana Department of Wildlife and Fisheries collected the data related to these components from 1978 to 1995. Vegetation and wildlife components were monitored by LSU (see Visser et al. 1996 and references therein). This report is the executive summary of a series of five reports that analyze the impacts of LOOP construction, operation, and maintenance on the estuarine/marine environment. These five reports include: 1) Water Chemistry, 2) Physical Hydrography, 3) Zooplankton and Ichthyoplankton, 4) Demersal

Nekton, and 5) Sediment Quality. Technical information, suggestions, and recommendations for future monitoring activity are included in the second section of these reports.

OBJECTIVES

The goal of the data analysis program was to analyze and report on the LOOP Marine/Estuarine environmental monitoring data collected from 1978-1995, with respect to the EMP objectives. The EMP (section 3.1, page 8, March 1986) lists the objectives of the monitoring program as:

(1) to obtain seasonal environmental and ecological data so that conditions existing during operation can be related to historical baseline conditions;

(2) to detect during the operation of the project any adverse alterations or damages to the environment so that corrective action can be taken as soon as possible;

(3) to obtain sufficient data to determine the cause or causes of environmental damages or alterations so that responsibility can be properly placed; and

(4) to provide information in order to evaluate long and short-term impacts of the project.

IMPACTS ANALYZED

The environmental baseline study evaluated potential environmental impacts of the construction, operation, and maintenance of the LOOP system (Gosselink et al. 1976). This study identified a number of potentially significant environmental impacts, which we divided into three groups—construction phase, brine discharge phase, and oil spills.

Construction Impacts

Construction impacts identified by Gosselink et al. (1976) include the disturbance of sediments along the pipeline route and the three facilities (Offshore Terminal, Fourchon Booster Station, and Clovelly Storage Dome) as well as the potential for the pipeline route to become a conduit for saline water into the upper estuary (including the potential for tidal channel formation where the LOOP pipeline crosses the beach).

Construction of the LOOP facilities and pipeline commenced in the first months of 1979 and continued through the end of 1980. The analyses for this impact therefore include the following time periods: Before construction (1978), During construction (1979–80), and After construction (1981–95). Impacts were evaluated for different sections of the coast, but at a minimum included estuarine and offshore impacts.

Brine Discharge Impacts

Part of the LOOP facility consists of storage chambers in a natural salt dome at Clovelly. These storage chambers were formed by solution mining utilizing local surface water in the area. The brine from the solution mining operation was transported via a pipeline parallel to the oil pipeline to the Brine Diffuser located in open Gulf of Mexico waters approximately 4.8 km offshore and adjacent to the LOOP oil pipeline. The discharge connected with the solution mining occurred from May 1980 through December 1982. In this period a total of 285 million barrels of brine with an average salinity of 201 ppt were disposed of in the near shore waters of the Gulf of Mexico (Figure 2). Observations at the diffuser documented an average vertical height of the brine plume of approximately 1–1.5 m off the bottom, and a maximum height of 5 m off the bottom.

After this period the Brine Diffuser was intermittently used to dispose of surplus brine from the storage pond at Clovelly during the period of January 1983 to December 1994. Within this period a total of 117 million barrels of brine with an average salinity of 196 ppt were disposed of in the near shore waters of the Gulf of Mexico.

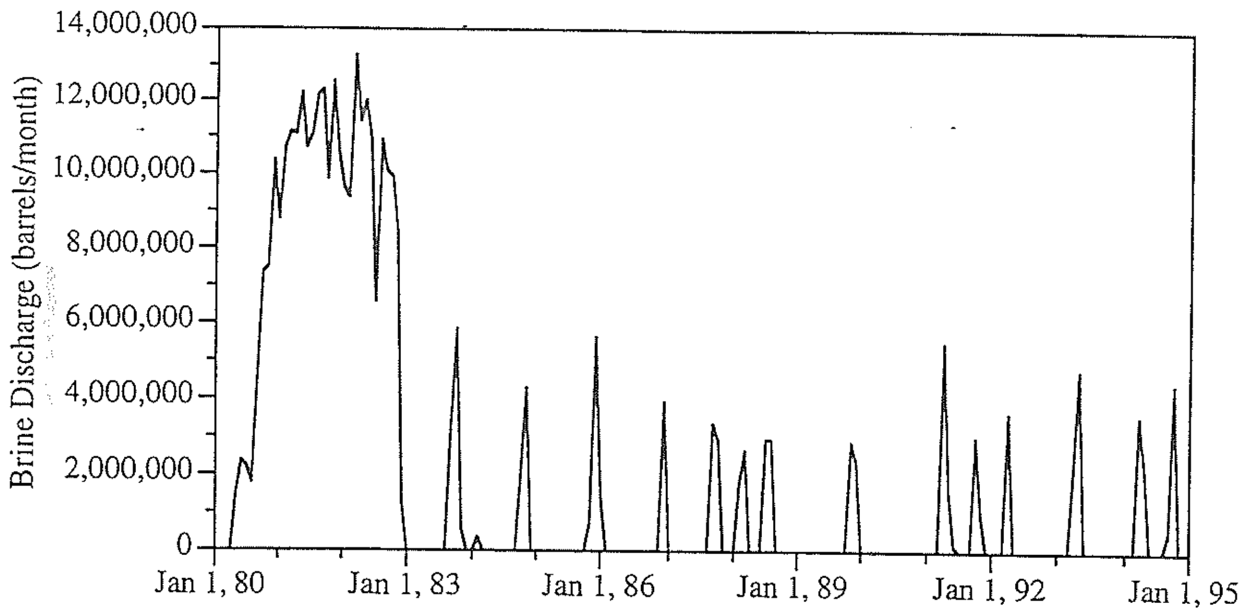

Figure 2. LOOP monthly brine discharge at the diffuser in the near shore region of the Gulf of Mexico.

In the analyses for brine impact, we used the following time periods in the analyses: Before (1978), During (1980–82), and After (1983–95). However, for several components insufficient data from Before brine discharge were available and the temporal variation was reduced to During and After.

Oil Spill Impacts

The date and amount of oil unintentionally released into the region due to LOOP operations were provided by LOOP LLC. The total oil spilled from May 1980 through December 1994 was 1,882 barrels of oil (135 barrels/year), and 95% of this oil was spilled offshore (Figure 3). Most ,of the oil spilled inshore (87%) occurred at the Clovelly Storage Dome, a few minor spills occurred at the small boat harbor at Fourchon, and only one spill each was recorded for the booster station and the diesel-fuel dock at Fourchon (see Figure 3).

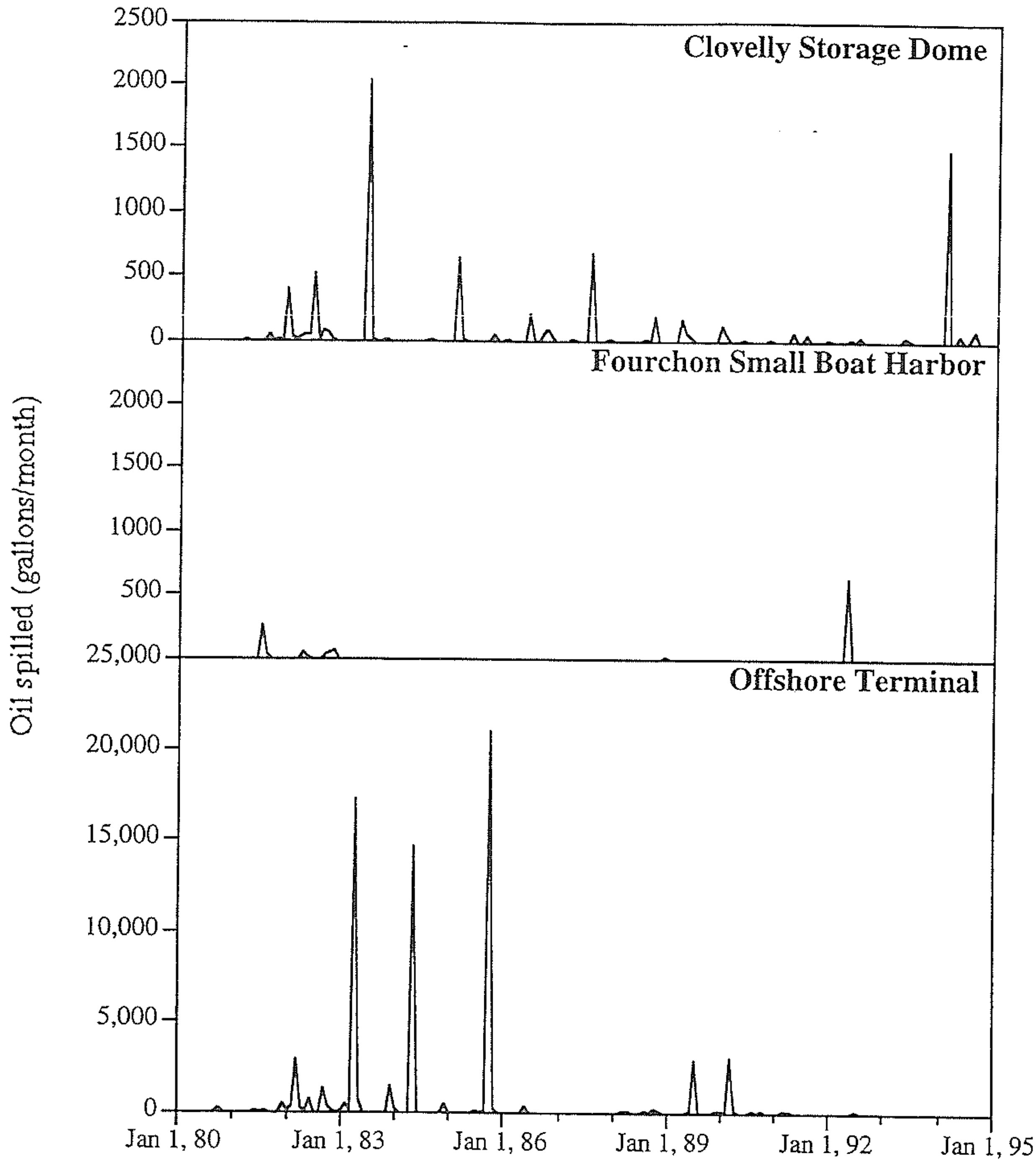

Figure 3. Monthly totals of oil spilled at three locations of LOOP operations. Not included in this figure are one spill at the Fourchon booster station of 2 gallons in October 1985 and another spill of less than a gallon at the Fourchon diesel fuel dock in June 1990.

WATER CHEMISTRY DATA ANALYSIS

Introduction

This section summarizes water chemistry, the first component in a series of five reports on the impacts of LOOP construction, operation, and maintenance on the estuarine/marine environment.

Data and Analytical Methods

The LOOP estuarine-marine water-chemistry data base comprised the following general groups:

1. Salinity
2. Chlorophyll
3. Dissolved Oxygen
4. Water Quality

The data were collected at a series of monthly and quarterly sampling stations (~40 stations) which were sampled along a gradient that ranged from the LOOP offshore terminal to the upper portion of the Barataria Bay system (Lake Salvador). Data were collected routinely from 1978 through 1995. There were also numerous additional (up to 40) stations that were intensively sampled only during the active phase of the LOOP construction (1978 through 1984).

All of the analyses of variance (ANOVA's) and Before-After, Control-Impact (BACI) statistical analyses were conducted using the data stations with the longest records (15 years or longer). Correlations among sample depths for each variable were also computed. Additional detailed statistical analyses included regression analysis and factor analysis.

Results and Discussion

Correlation between surface and bottom

The results of the correlation between surface and bottom water chemistry variables indicate that the surface and bottom values are well correlated for all variables at the estuarine stations. The offshore stations exhibit weak correlations between surface and bottom for all variables except for sulfate, total Kjeldahl nitrogen (TKN), and total phosphorus (TP).

Correlation among variables

The results of the factor analysis indicated in all cases that the variance in the data can be explained by four or five factors (groupings of inter-related variables). The factors explain approximately 73% of the total variance for the estuarine stations and 60–65% of the total variance in the offshore stations. In all cases, the first (and most important factor) was a salinity grouping which explained 20–36% of the variation. The remaining factors generally were composed of a "turbidity " (turbidity, total solids, suspended solids, total dissolved solids) factor, a "nutrient" factor (TKN, TP), an "oxygen" factor, and a "chlorophyll" factor.

Spatial patterns

The following discussion summarizes the general spatial patterns. Salinity showed an increase (from ~5 ppt to ~30 ppt) from the upper Barataria System to the offshore terminal. Total dissolved solids and total solids follow the same general pattern as salinity, since solids are highly correlated with salinity (the salt being a major component of the solids). Chlorophyll *a* as well as most of the nutrients (ammonia, phosphate, silica, TKN, and TP) show a pattern of decreasing values from the upper part of the Barataria system to the offshore terminal. The exception was nitrate-nitrite, which was lowest in the mid-portion of the Barataria system, and higher in the upper portion of the Barataria system and at the offshore stations. Turbidity and suspended solids had a similar pattern to the nutrients in that they decreased from the upper portion of the Barataria system to the offshore terminal. In addition, these variables also exhibit reduced variability in the offshore stations. Sulfate and calcium both show increases in magnitude as well as variability from the upper part of the Barataria system to the offshore terminal. Alkalinity had the same mean value (~100 mg/l) throughout the whole system, however the offshore stations showed reduced variability. Oxygen exhibited a pronounced seasonal variation in the upper portion of the Barataria system, however this seasonal pattern was much less pronounced at the offshore stations.

The brine diffuser began operations when bottom water oxygen concentrations began to decline in the general area (because of nutrient loading from the Mississippi River), but that change should not be attributable to LOOP Superport operations. The salinity, dissolved inorganic nitrogen and chlorophyll a concentrations varied tremendously from year to year. These changes are observed over the whole shelf and are part of a regional phenomenon attributable to changes in the Mississippi River water quality.

Temporal patterns

The mean trends for each area (inshore, offshore) were calculated using only the individual station trends that were significant at the 0.05 level. In general, only about a third of the water chemistry variables (of a total of 16) showed statistically significant and consistent temporal trends. These are presented in Table 2. The only variables which showed consistent spatial and temporal trends were TKN, TP, and sulfate. These three variables exhibited trends at surface and bottom in both the inshore and offshore environment. A total of 20 statistically significant trends were

Table 2. Significant temporal trends in water-chemistry variables if they occurred in a majority of either the inshore or the offshore stations.

Variable	Inshore		Offshore	
	trend	percent of stations	trend	percent of stations
A. Based on stations with monthly sampling of surface waters.				
Silica	decrease	100	decrease	57
Sulfate	decrease	64	decrease	100
Suspended Solids	decrease	82	decrease	100
Total Kjeldahl Nitrogen	increase	100	increase	100
Total Phosphorus	increase	91	increase	100
Turbidity	decrease	100	decrease	100
B. Based on stations with quarterly sampling of surface waters.				
Phosphate	decrease	75	decrease	3
Sulfate			decrease	100
Suspended Solids			decrease	100
Total Kjeldahl Nitrogen	increase	50	increase	100
C. Based on stations with monthly sampling of bottom waters.				
Alkalinity	decrease	20	increase	71
Nitrate-Nitrite	decrease	40	increase	100
Oxygen	decrease	40	decrease	100
Sulfate	decrease	100	decrease	60
Total Kjeldahl Nitrogen	increase	100	increase	100
Total Phosphorus	increase	100	increase	100
D. Based on stations with quarterly sampling of bottom waters.				
Silica	decrease	75		
Sulfate	decrease	25	decrease	86
Total Kjeldahl Nitrogen	increase	100		

detected in the monthly data. The quarterly data only detected 7 statistically significant trends. This suggests that quarterly sampling is not sufficient to detect long-term trends.

Impact analysis

Construction

The BACI analysis showed no statistically significant impacts that could be correlated with the construction of the LOOP facilities for the variables analyzed.

Brine Discharge

There were some statistical differences before and after the period of brine discharge (surface ammonia, surface sulfate, surface TKN, surface turbidity, bottom sulfate, bottom TKN, and bottom turbidity). However, the Before-After, Control-Impact interaction was not significant, indicating that these differences were not correlated with the brine discharge for the variables analyzed.

The Louisiana Department of Wildlife and Fisheries studied 32 brine plumes in bottom waters using a benthic sled equipped with dissolved oxygen, temperature,-and conductivity sensors. These results were used to plot the size of the plume vs. the discharge volume. From this we concluded that there was an increase in plume size with brine discharge amounts. The intercept at zero discharge was not statistically different from zero. The range of plume size values extended up to around 400 ha for the largest plume studied. On many occasions the monitoring stations were located outside of the brine plume. The monitoring station most likely to detect changes among the four stations closest to the brine diffuser is the west station (#475).

Clovelly Dome Storage Facility Oil Spills

Two statistically significant impacts that could be correlated with oil spills in the Clovelly Dome area were surface ammonia and surface turbidity. Surface ammonia decreased from 4.04 μg-at/l (before) to 2.01 μg-at/l (after) for the control classes, and decreased from 4.95 μg-at/l (before) to 4.45 μg-at/l (after) for the impact classes. Surface turbidity decreased from 86.0 NTU (before) to 17.5 NTU(after) for the control classes, and decreased from 93.4 NTU (before) to 10.1 NTU (after) for the impact classes. Although these changes were statistically significant they do not appear to be ecologically significant. Bottom turbidity showed a statistically significant interaction without a statistically significant oil covariate term, indicating an impact not correlated with oil spills. Again the changes were statistically significant, but not ecologically significant. Bottom turbidity decreased from 86.0 NTU (before) to 28.1 NTU (after) for the control classes, and decreased from 108.6 NTU (before) to 18.9 NTU (after) for the impact classes.

Offshore Terminal Oil Spills

We found a statistically significant difference before and after offshore oil spills in surface turbidity, along with a statistically significant difference between control and impact stations for bottom turbidity. However, the Before-After, Control-Impact interaction was not significant, indicating that these differences were not correlated with the oil discharge for the variables analyzed. Offshore ammonia did have a statistically significant impact that was correlated with oil spills. Surface ammonia decreased from 1.87 μg-at/l (before) to 1.13 μg-at/l (after) for the control classes, and decreased from 1.41 μg-at/l (before) to 1.10 μg-at/l (after) for the impact classes. These changes were statistically significant, but not ecologically significant.

The total amount of oil reported spilled during the study interval amounted to less than 2,000 barrels (Figure 3) and almost all of it was spilled offshore.

A recurrence interval analysis (Figure 4), using the 17 year long data record of oil spills, predicted that a maximum monthly oil spill between 1,000 and 10,000 barrels will occur once in 50 years. This result compares very well with a predicted return period for an individual spill predicted in the Environmental Impact Statement. That report estimated that a single spill of at least 10,000 barrels would occur once every 24 years (close to that predicted in Figure 4). The EIS also predicted that the maximum "credible" spill would be 240,000 barrels, but over a period longer than 50 years. That maximum credible spill is 500 times larger than observed to date, but within the predicted recurrence interval for an event of that infrequency (i.e., a large, but rare, spill).

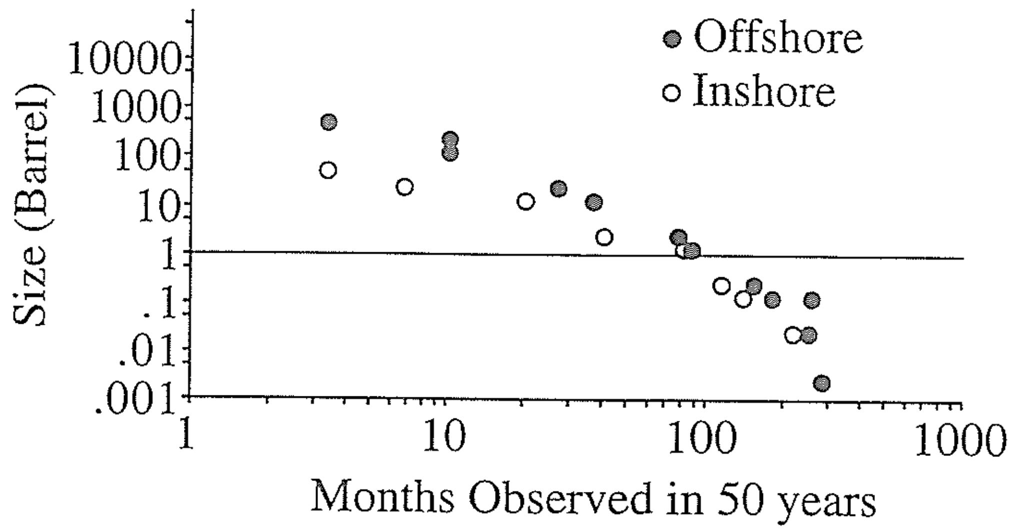

Figure 4. The recurrence frequency (calculated using the current oil spill record) of oil spill size for 50 years.

Discussion

Results from an analysis of the water quality parameters measured in this monitoring program showed limited evidence of extensive changes due to the brine disposal operations or the small (less than 100 barrels) oil spill. The variability introduced by the Mississippi River is a significant complication of the analysis because of its size and proximity to the monitoring stations. A change in the measured parameter values between a before-and-after impact analysis may not be due to the potential impact factor (brine), but actually be the result of long-term trends or events in environmental factors unrelated to the LOOP operations. The fixed location of the monitoring station network and sampling frequency are often too sparse to detect these impacts. Also, water masses are moving through the sampling area quickly. In other words, if an impact has occurred, it is likely that the water mass moved out of the area before the monthly sampling occurred.

The bottom sled sampling by the State Department of Wildlife and Fisheries clearly located a brine plume whose position on the bottom moves among the stations, adding variability to the measured parameters, and perhaps compromising the results of the BACI sampling design. The variability in bottom salinity at station 473, for example, probably reflects these movements among and between sampling locations. The BACI analysis cannot, a priori, determine if the plume is over a station or not and a nearby station may be an adequate control station in one month, but an impact station in another month. Fixed control and impact stations cannot, therefore, be assigned.

PHYSICAL HYDROGRAPHY DATA ANALYSIS

Introduction

This section summarizes physical hydrography, the second component in a series of five reports on the impacts of LOOP construction, operation, and maintenance on the estuarine/marine environment. The complex region of interest is associated with the Mississippi River Deltaic Plain. The hydrography of the estuarine portion (Barataria Basin) has resulted from the subsidence of abandoned river distributaries and associated marsh; the offshore region is strongly influenced by the discharge plumes from the present delta.

Data and Analytical Methods

The hydrographic data sets collected by LOOP are the longest continuous records from this region and clearly define the interannual and intra-annual hydrographic variability of the area. The most complete of these concern the temperature and salinity variations. These data sets are used to estimate statistics which objectively characterize the hydrography of the region, to estimate the presence of trends and/or changes in this character during the course of LOOP operations, and to determine the possible causes of any such changes identified.

The data were collected by LDWF using standard technologies. Some data sets were from continuous recorders while others were from stations sampled at nearly regular intervals. The records were quality-controlled and the final data sets analyzed using standard statistical techniques, both parametric and non-parametric. Particular emphasis was placed on estimating changes before and after important LOOP-related activities (construction, brine diffusion, oil spills) and significant environmental events (Hurricane Andrew, the active 1985 hurricane season, the freeze of 1989, variations in Mississippi River flow).

The region was divided into four sub-regions having different hydrographic characteristics and different dominant physics: an offshore region dominated (at least in the surface layers) by the effluent plumes of the Mississippi River; a nearshore region where the influence of the coast directed flow parallel to shore and shallow waters permitted strong air-sea interactions; a lower estuarine region where broad areas of open water connected to the nearshore region through multiple tidal inlets allowing significant exchange of estuarine and coastal water; and an upper estuarine region of broad shallow lakes interconnected by narrow bayous and tidal channels which restrict exchange processes. Each region was considered separately.

Results

Temporal and spatial trends

The seasonal variability in each region was consistent with patterns observed in earlier, less comprehensive studies. Temperatures varied in response to summer heating and winter cooling. Salinities responded to the discharge pattern of the Mississippi River and to local rainfall and evaporation. Interannual variability was less than intra-annual variability in both parameters.

Temporal trends in parameters were observed at many, but not all, stations. These trends were most common in temperature and were generally positive. Five near-bottom stations in the offshore region showed positive salinity trends. Other trends were not spatially coherent and often resulted from short records which could have been strongly influenced by climatological variability. The most spatially-coherent signals were increasing temperature trends at offshore stations. These may have been due to the effects of Loop Current rings. An adequate time series of Loop Current variability was not available to test this hypothesis.

Impact analysis

Construction

The only rational hypothesis for how LOOP activities could alter hydrographic variables is through alteration of estuarine flow patterns. There was no indication of such an effect, and the monitoring program was not designed to evaluate such impacts.

Brine Discharge

Brine discharge could potentially increase the salinity in the region surrounding the diffuser. However, BACI analyses did not indicate any statistically significant interaction term. Therefore, no significant impacts on hydrographic variables were detected for brine discharge: these results were based on hydrographic data sets; however, the brine-sled data, which was not analyzed, clearly indicated an impact on near-bottom salinities during periods of brine discharge.

Oil spills

BACI analyses did not indicate any statistically significant interaction term except for the analysis of oil spill impacts on bottom salinity at the offshore terminal. The before:after contrast, though, was insignificant suggesting that the control and impact stations were different, but not due to the spills.

Conclusions

We were unable to identify a clear change or trend in hydrographic variables attributable to LOOP activities. The hydrographic data set, though, defines the interannual and intra-annual variability of these parameters for comparison with biological and water chemistry parameters. This will allow identification of changes in covariates, if biological and chemical changes are observed. Continuation of this data set is probably advisable as proposed alterations to the Mississippi River discharge pattern may be expected to result in habitat alterations in the future.

ZOOPLANKTON AND ICHTHYOPLANKTON DATA ANALYSIS

Introduction

This section summarizes the zooplankton and ichthyoplankton component, the third in a series of five reports that analyze the impacts of LOOP construction, operation, and maintenance on the estuarine/marine environment.

Data and Analytical Methods

Over the course of the zooplankton and ichthyoplankton field-sampling program (February 1978 to December 1995), a total of 81 plankton sites(98 stations) were sampled at one time or another at environments ranging from freshwater to mid-continental shelf. Four sampling gears and six different sampling protocols were employed over the duration of the study. To examine the potential impacts of floating oil, surface tows were taken at inshore and offshore stations. Within inshore and offshore waters a 0.5 m plankton net with either 0.80 or 0.153 mm mesh was towed for one minute. In offshore waters and at one inshore station, a 1 m plankton net with 0.363 mm mesh was towed for 3–5 minutes. In deeper offshore waters, bongo nets were used to sample zooplankton and ichthyoplankton occupying various divisions of the water column where effects of aged and dispersed oil would most likely occur. This sampling involved various sampling protocols utilizing a 60-cm, hinged, paired bongo net frame (opening and closing) with 0.363 mm mesh netting towed in a horizontally stratified or oblique fashion for approximately 3–5 minutes.

Zooplankton and ichthyoplankton sampling was conducted monthly at most stations with quarterly sampling at others. Only seven stations were sampled continuously from early in the study, February to July 1978, to near its completion. At all sampling stations temperature, conductivity, salinity, and dissolved oxygen profiles were taken.

The zooplankton sampling program was revised a number of times, as the environmental program emphasis shifted from monitoring LOOP facility and pipeline construction and brine discharge, to monitoring potential impacts of ongoing operations including oil spill and dispersant use. Additional changes were implemented to streamline the sampling program (decrease field effort and sample processing time), to alleviate the accumulating backlog of unsorted and unidentified plankton collections, and to improve comparability among stations within the LOOP corridor while still providing adequate baseline monitoring data for decision-making.

Zooplankton biomass (standing stock) estimates (ml/m^3) and selected decapod crustacean taxa were identified and enumerated from plankton collections over most of the duration of the project and consisted of the early developmental stages of *Penaeus* spp., *Callinectes* spp., and

Portunus spp. Copepoda, Polychaeta, Gastropoda were often recorded as well. Ichthyoplankton identification for all the major taxa.were mostly complete after January 1981.

For a listing of the types of statistical analyses conducted and their time periods, control-impact station groupings, and the taxa considered see Table 3.

Results and Discussion

Spatial and temporal patterns

There were numerous significant or marginally significant ($P = \leq 0.1$) seasonal, annual, and spatial main effects and interactions which were identified that were not directly related to LOOP operations or impacts (Table 3).

Impact analysis

Only a few statistical analyses had significant or marginally significant Direct LOOP Impact implications (see DLI code in Table 3), while another test had results which appeared to have Indirect LOOP Impacts (ILI code). Some test results appear to be related to oil discharge or spills and/or subsequent clean up activities, while others were related to the construction phase. The discussion of marginally significant statistical results is environmentally, ecologically, and biologically meaningful because they suggest that those parameters are possibly sensitive to LOOP-related environmental perturbations. The zooplankton biomass data set was by far the most complete (longest times series and largest sample size) and had a greater number of significant and/or marginally significant test results.

Construction

A relevant finding involving zooplankton biomass occurred within the During-After, Control-Impact (DACI) Inshore, Long-term Construction Impacts Model, which had a marginally significant ($P = 0.0428$) During-After, Control-Impact interaction whereby mean zooplankton biomass at Impact stations was greater than the Controls (2.17 vs. 1.70 ml/m^3) During the construction phase, but was lower than Control estimates (1.48 vs. 1.81 ml/m^3) After construction. Perhaps construction disturbances initially stimulated the standing stock of zooplankton which later was depressed by chronic or long-term combinations of perturbations.

Table 3. Summary of parameters tested and their specific environmental impact test results which are given within the parentheses as actual P values for main effects, covariates or interactions versus the Bonferroni adjusted alpha values for that family of multiple tests. Also provided are test interpretation codes: Significant (S), Marginally Significant (MS), and Non-Significant (NS), with a probable explanation of significant observed differences, i.e., Direct Loop Impact (DLI), Indirect LOOP Impact (ILI), or Non-LOOP Impact (NLI). Also presented is a probable explanation of why marginally significant or non-significant responses were found, i.e., Parameter Insensitive to LOOP operations (PI), Parameter Sensitive But Variability too high to detect significant differences with the sampling design used (PSBV), or Parameter Sensitive to LOOP operations, but LOOP operations Not Implicated (PSNI).

Parameter Tested	Specific Test Results	Sig. Code	Prob. Explanation for Sig. or Marginal Sig.	Prob. Reason for Marginal Sig. or Non-Sig.
Zooplankton	BACI Inshore Combined Impact with oil as a covariate (2/78 - 12/94)			
biomass estimate	· Oil covariate (P = 0.0983 vs. 0.0167)	MS	DLI	PSBV
(settled or	· Before-After Season interaction (P = 0.0811 vs. 0.0167)	MS	NLI	PSNI
displacement	BACI Inshore Construction (2/78 - 8/85)	NS		PSBV
vol. - ml/m³)	DACI Inshore Construction (3/79 - 8/85)			
	· Season effect (P = 0.0005 vs. 0.0167)	S	NLI	
	· During-After, Control-Impact interaction (P = 0.0428 vs. 0.0167)	MS	DLI	PSBV
	DACI Offshore Brine Diffuser with brine as a covariate OM data only (8/80 - 12/95)	NS		PSBV
	· No brine data - During-After effect (P = 0.0303 vs. 0.0033)	MS	NLI	PSBV
	DACI Offshore Brine Diffuser with brine as covariate HL data only (5/80 - 7/86)	NS		PSBV
	· No brine data - Season effect (P = 0.0011)	S	NLI	
	· No brine data - During-After effect (P = 0.0510)	MS	NLI	PSBV
	· No brine data - During-After Season interaction (P = 0.0029)	S	NLI	
	· No brine data - During-After, Control-Impact interaction (P = 0.0566)	MS	ILI	PSBV
	CI Offshore Terminal Oil Impact with platform oil data as a covariate (5/81 - 12/94)			
	· Season effect (P = 0.0161 vs. 0.0033)	MS	NLI	PSNI
	· Year effect (P = 0.0079 vs. 0.0033)	MS	NLI	PSNI
	· Year Season interaction (P = 0.0003 vs. 0.0033)	S	NLI	
Polychaeta	BACI Inshore Construction Impact (2/78 - 6/82)			
	· Before-After Season interaction (P = 0.0112 vs. 0.0100)	MS	NLI	PSNI
Gastropoda	BACI Inshore Construction Impact (2/78 - 6/82)			
	· Season effect (P = 0.0001 vs. 0.0100)	S	NLI	
Copepoda	BACI Inshore Construction Impact (2/78 - 3/83)			
	· Season effect (P = 0.0637 vs. 0.0100)	MS	NLI	PSBV
	· Before-After Season interaction (P = 0.0027 vs. 0.0100)	S	NLI	

	· Control-Impact Season interaction (P = 0.0013 vs. 0.0100)	S	NLI	
	· Before-After, Control Impact interaction (P = 0.0991 vs. 0.0100)	MS	NLI	PSBV
	· Before-After, Control-Impact Season interaction (P = 0.0037 vs. 0.0100)	S	NLI	
Acartia spp.	BACI Inshore Construction Impact (2/78 - 3/83)			
	· Season effect (P = 0.0001 vs. 0.0100)	S	NLI	
	· Before-After Season interaction (P= = 0.0222 vs. 0.0100)	MS	NLI	PSNI
Decapoda	BACI Inshore Construction Impact (4/78 - 6/82)			
	· Season effect (P = 0.0001 vs. 0.0100)	S	NLI	
	· Before-After Season interaction (P = 0.0559 vs. 0.0100)	MS	NLI	PSNI
Penaeus aztecus	BACI Inshore Combined Impact with oil as a covariate (3/78 - 12/95)	NS		PSBV
	BACI Inshore Construction (2/78 - 8/85)			
	· Control-Impact Season interaction (P = 0.0543 vs. 0.0167)	MS	NLI	PSBV
	DACI Inshore Construction (3/79 - 8/85)	NS		PSBV
	DACI Offshore Brine Diffuser with brine as a covariate (10/80 - 12/95)	NS		PSBV
	· No brine data - Season effect (P = 0.0027 vs. 0.0033)	S	NLI	
	CI Offshore Terminal Oil Impact with platform oil data as a covariate (6/82 - 2/90)			
	· Season effect (P = 0.0001 vs 0.0033)	S	NLI	
	· Year effect (P = 0.0316 vs 0.0033)	MS	NLI	PSNI
	· Year Season interaction (P = 0.0001 vs 0.0033)	S	NLI	
Callinectes sapidus	DACI Offshore Brine Diffuser with brine as a covariate (1/81 - 12/95)	NS		PSBV
	· No brine data - Season effect (P = 0.0001 vs. 0.0033)	S	NLI	
	CI Offshore Terminal Oil Impact with platform oil data as a covariate (5/81 - 12/89)			
	· Season effect (P = 0.0002 vs. 0.0033)	S	NLI	
	· Control-Impact Season interaction (P = 0.0005 vs. 0.0033)	S	NLI	
	· Year effect (P = 0.0001 vs. 0.0033)	S	NLI	
	· Control-Impact Year interaction (P = 0.0001 vs. 0.0033)	S	NLI	
	· Year Season interaction (P = 0.0001 vs. 0.0033)	S	NLI	
	· Control-Impact, Year Season interaction (P = 0.0001 vs. 0.0033)	S	NLI	
C. similis	DACI Offshore Brine Diffuser with brine as a covariate (1/81 - 12/95)	NS		PSBV
	· No brine data - During-After effect (P = 0.0572 vs. 0.0033)	MS	NLI	PSBV
	CI Offshore Terminal Oil Impact with platform oil data as a covariate (5/81 - 2/90)			
	· Season effect (P = 0.0683 vs. 0.0033)	MS	NLI	PSNI
	· Year effect (P = 0.0333 vs. 0.0033)	MS	NLI	PSNI
	· Year Season interaction (P = 0.0001 vs. 0.0033)	S	NLI	
Portunus spp.	CI Offshore Terminal Oil Impact with platform oil data as a covariate (4/82 - 12/89)			
	· Season effect (P = 0.0066 vs. 0.0033)	MS	NLI	PSBV
	· Year effect (P = 0.0018 vs. 0.0033)	S	NLI	
	· Year Season interaction (P = 0.0007 vs. 0.0033)	S	NLI	

Osteichthyes	BACI Inshore Combined Impact with oil as covariate (3/78 - 12/95)	NS		PSBV
	· No oil data - Control-Impact effect (P = 0.0861 vs. 0.0167)	MS	DLI	PSBV
	BACI Inshore Construction Impact (5/78 - 8/85)	NS		PSBV
	DACI Inshore Construction (3/79 - 8/85)			
	· Season effect (P = 0.0023 vs. 0.0167)	S	NLI	
	· During-After Season interaction (P = 0.0046 vs. 0.0167)	S	NLI	
	· Control-Impact Season interaction (P = 0.0962 vs. 0.0167)	MS	NLI	PSBV
Brevoortia patronus	DACI Offshore Brine Diffuser with brine as a covariate (12/80 - 12/95)	NS		PSBV
	CI Offshore Terminal Oil Impact with platform oil data as a covariate (10/82 - 2/90)			
	· Season effect (P = 0.0248 vs. 0.0033)	MS	NLI	PSBV
	· Year effect (P = 0.0849 vs. 0.0033)	MS	NLI	PSBV
	· Year Season interaction (P = 0.0656 vs. 0.0033)	MS	NLI	PSBV
Anchoa spp.	DACI Offshore Brine Diffuser with brine as a covariate (2/81 - 12/95)	NS		PSBV
	· No brine data - Season effect (P = 0.0001 vs. 0.0033)	S	NLI	
	· No brine data - During-After Season interaction (P = 0.0755 vs. 0.0033)	MS	NLI	PSBV
	CI Offshore Terminal Oil Impact with platform oil data as a covariate (6/81 - 9/89)			
	· Oil covariate (P = 0.0991 vs. 0.0033)	MS	DLI	PSBV
	· Season effect (P = 0.0023 vs. 0.0033)	S	NLI	
	· Year effect (P = 0.0006 vs. 0.0033)	S	NLI	
Myctophidae	DACI Offshore Brine Diffuser with brine as a covariate (1/81 - 12/95)	NS		PI
	CI Offshore Terminal Oil Impact with platform oil data as a covariate (5/82 - 2/90)			
	· Season effect (P = 0.0004 vs. 0.0033)	S	NLI	
	· Year effect (P = 0.0247 vs. 0.0033)	MS	NLI	PSBV
	· Year Season interaction (P = 0.0962 vs. 0.0033)	MS	NLI	PSBV
Chloroscombrus chrysurus	DACI Offshore Brine Diffuser with brine as a covariate (5/81 - 12/95)	NS		PSBV
	· No brine data - Season effect (P = 0.0001 vs. 0.0033)	S	NLI	
	· No brine data - During-After Season interaction (P = 0.0745 vs. 0.0033)	MS	NLI	PSNI
	CI Offshore Terminal Oil Impact with platform oil data as a covariate (8/81 - 9/89)			
	· Year effect (P = 0.0565 vs. 0.0033)	MS	NLI	PSBV
	· Year Season interaction (P = 0.0770 vs. 0.0033)	MS	NLI	PSBV
	· Control-Impact, Year Season interaction (P = 0.0271 vs. 0.0033)	MS	DLI	PSBV
Cynoscion arenarius	DACI Offshore Brine Diffuser with brine as a covariate (4/82 - 12/95)	NS		PSBV
	· No brine data - Season effect (P = 0.0071 vs. 0.0033)	MS	NLI	PSNI
	CI Offshore Terminal Oil Impact with platform oil data as a covariate (4/82 - 9/89)	NS		PSBV
Sciaenops ocellatus	DACI Offshore Brine Diffuser with brine as a covariate (8/81 - 12/95)	NS		PI

Blenniidae	DACI Offshore Brine Diffuser with brine as a covariate (3/81 - 12/95)	NS		PI
	· No brine data - Season effect (P = 0.0117 vs. 0.0033)	MS	NLI	PI
	· No brine data - During-After effect (P = 0.0713 vs. 0.0033)	MS	NLI	PSBV
	· No brine data - During-After Season interaction (P = 0.0809 vs. 0.0033)	MS	NLI	PSBV
	CI Offshore Terminal Oil Impact with platform oil data as a covariate (8/81 - 6/89)			
	· Season effect (P = 0.0044 vs. 0.0033)	MS	NLI	PSBV
	· Year Season interaction (P = 0.0247 vs. 0.0033)	MS	NLI	PSBV
Gobiidae	DACI Offshore Brine Diffuser with brine as a covariate (1/81 - 12/95)	NS		PI
	· No brine data - During-After Season interaction (P = 0.0333 vs. 0.0033)	MS	NLI	PI
Scombridae	DACI Offshore Brine Diffuser with brine as a covariate (7/81 - 12/95)	NS		PI
	· No brine data - Season effect (P = 0.0194 vs. 0.0033)	MS	NLI	PI
	CI Offshore Terminal Oil Impact with platform oil data as a covariate (8/81 - 9/89)			
	· Year effect (P = 0.0111 vs. 0.0033)	MS	NLI	PSBV
Peprilus spp.	DACI Offshore Brine Diffuser with brine as a covariate (4/81 - 12/95)	NS		PI
	CI Offshore Terminal Oil Impact with platform oil data as a covariate (11/81 - 3/88)	NS		PSBV
Bothidae	DACI Offshore Brine Diffuser with brine as a covariate (1/81 - 12/95)	NS		PI
	CI Offshore Terminal Oil Impact with platform oil data as a covariate (5/81 - 6/89)	NS		PI
Symphurus spp.	CI Offshore Terminal Oil Impact with platform oil data as a covariate (5/81 - 9/89)	NS		PI

Brine Discharge

Some marginally significant test results were more difficult to explain in terms of Indirect LOOP impacts, such as the During-After, Control-Impact interaction (P = 0.0566) seen within the zooplankton biomass data in the DACI Brine Diffuser model run on the HL data set over the May 1980 to July 1986 time period. Mean zooplankton biomass at Impact stations was less than Controls within the During period, but was greater than Controls After.

Oil Spill

The most relevant test finding resulted from the BACI Long-term, Inshore, Combined Impacts Model (February 1978 to December 1994) which entered the Clovelly Storage Dome oil spill data as a covariate. The oil covariate proved to be marginally significant (P = 0.0983, Table 3) and showed an inverse (negative) relationship with zooplankton biomass.

The Offshore Terminal Oil Impact analyses, which used the platform oil spill data set as a covariate, produced a number of significant and marginally significant temporal (in this case seasonal and annual) results (Table 3). However, two test results relate directly to the discussion of LOOP-related environmental impacts. Densities for *Anchoa* spp., a very abundant, and ecologically important, coastal taxonomic group, displayed a marginally significant (P = 0.0991) negative (inverse) relationship with the offshore oil covariate. This negative relationship was not strong and appeared to be influenced by the five largest oil spill points. Although the negative relationship was not additionally supported by significant Control-Impact (spatial) interactions, the analysis was able to identify significant temporal relationships. The second noteworthy impact-related finding occurred with *Chloroscombrus chrysurus*, another very abundant coastal species. *Chloroscombrus chrysurus* displayed a marginally significant Control-Impact-Year-Season interaction (P = 0.0271). This statistical result was mostly a reflection of the mean density values for the Control stations during the summer/fall time period in 1981 (13.97 larvae/100m^3) and 1985 (45.27) being an order of magnitude greater than the Impact station densities (3.84 and 0.81, respectively). Control station densities were also an order of magnitude greater than Impact during the high abundance peak in the spring/summer period of 1982 (63.82 vs. 4.24 larvae/100m^3, respectively). Such a statistical finding may be indicative of environmental impact(s) associated with less clearly defined spatial and temporal events, such as relatively small, chronic oil spills.

Conclusions

In summary, the negative relationship between the Clovelly oil spill data and zooplankton biomass, and the zooplankton biomass during-after, control-impact interaction within the DACI inshore long-term construction model provide the clearest implications for LOOP-related impacts inshore. In the coastal/offshore environment, there were two indicators of potential environmental impact from LOOP-related activities. The control-impact, Offshore LOOP terminal oil impact analysis of zooplankton and ichthyoplankton densities used the platform oil spill data set as a covariate, and season and year as main effects. The negative relationship between spilled LOOP offshore terminal oil and *Anchoa* spp. densities and the Control-Impact-Year-Season interaction within the *Chloroscombrus chrysurus* analysis, both indicate that these taxa are sensitive to LOOP-related environmental impacts. It is important to point out that when the data sets were large, continuous, or involved abundant taxa, the analysis was sensitive enough to observe potential environmental impacts.

DEMERSAL NEKTON DATA ANALYSIS

Introduction

This section summarizes demersal nekton, the fourth in a series of five reports analyzing the impacts of LOOP construction, operation, and maintenance on the estuarine/marine environment.

Data and Analytical Methods

As part of the Environmental Monitoring Plan, demersal nekton (i.e., bottom-oriented fishes and large invertebrates that are active swimmers but susceptible to trawl capture) were sampled at monthly intervals at several stations along the LOOP pipeline and in adjacent areas.

Between February 1978 and December 1995, a total of 3,193 samples were collected using 4.9 and 15.2 m trawls. Nekton were identified, weighed, and counted to provide information on species abundance and community structure (i.e., the proportional composition of species in the community). A total of 2,528,703 organisms from 288 taxa (i.e., species or higher levels of systematic organization) was collected with a total biomass of 39,396 kilograms. Forty taxa were common and included in some aspects of the analyses. However, several taxa had to be excluded from the species-level analyses because they were a combination of two or more species at the generic level. The remaining 37 species were each analyzed in up to four size classes (generally small juveniles, juveniles, subadults, and adults), because some species use different habitats at different life stages (i.e., ontogenetic changes). Using a size-class approach, we were able to detect six additional impacts that were not apparent for the species as a whole, and we were able to identify the life history stage affected.

Because there was no *a priori* association of control and impact stations, a principal components analysis was used to identify highly correlated environmental variables, to reduce the variables to a lesser number of environmental factors (i.e., three independent axes of correlated variables), and to assist in pairing control and impact stations for the Before-After, Control-Impact (BACI) analyses. The three new statistically independent axes, Factors 1-3, characterized spatial and temporal variation in the environment and explained 75.5% of the variance in the system (i.e., six variables were reduced to three axes while retaining > 75% of the original variation). Depth and turbidity weighed heavily in the first axis (Factor 1) and were inversely related to each other. This large-scale spatial axis reflected the salinity classification of stations into inshore, middle, and offshore zones, and arranged the shallow, turbid stations at one end and deeper, clearer stations at the other (Figure 5). The second axis (Factor 2) was weighted heavily for chlorophyll *a* and salinity, which were also inversely related to each other. Since chlorophyll *a* concentrations provide an index to productivity, this axis was interpreted as a productivity-salinity axis. In the third axis (Factor 3), temperature and dissolved oxygen weighed heavily and were inversely related to each other, reflecting in part the seasonality of environmental variation in the year-round sampling program.

The LOOP sampling stations showed strong separation along the first two axes, but not along the third axis (Figure 5). From the plot of stations in factor space (Figure 5), we were able to identify five groups of environmentally similar stations for the BACI analyses as shown in Table 4.

Station 19_I was located near a Shell Oil pipeline that was constructed at the same time as the LOOP pipeline to carry crude oil from the Clovelly terminal to Shell's refinery in St. James, Louisiana. Although this station was not constructed by LOOP, Inc., it was treated as a LOOP-related impact station for analytical purposes because the pipeline was built to carry oil from the LOOP pipeline. Stations 1_C, 4_C, 37_C, 41_C, and 42_C were not similar enough to any other impact stations to be grouped, and were excluded from the BACI analysis.

Common species and community characteristics at impact stations along the pipeline were compared to control stations in a modified BACI statistical design to test whether the construction and/or operation of the LOOP pipeline significantly influenced demersal nekton. The BACI design analyzes environmentally related changes in spatial and temporal patterns to examine the null hypothesis of no LOOP-related impact on common species or community characteristics by testing the spatial-temporal interaction term.

The number of analyses was determined by the number of impact stations, the number of impact events, the number of community characteristics, the number of species, and the number of size classes within species. In all, over 2,200 separate analyses were conducted and fourteen significant impacts were detected of LOOP construction and operation on species and size classes of demersal nekton.

Results and Discussion

Spatial and temporal trends

We detected significant temporal trends in the analyses of LOOP construction and operation for 31 size classes of 16 species that did not have significant interaction terms (i.e., these were not statistically demonstrated to be LOOP-related impacts). In the analysis of the construction phase, significant temporal effects were detected for 11 size classes of seven species with non-significant interaction terms (Table 5). In the analysis of the brine discharge at the brine diffuser station (Station 36_I), significant temporal effects were detected for nine size classes of five species with non-significant interaction terms (Table 6).

Figure 5. Three dimensional environmental factor space showing the relationships of stations to the factors. The diameters of the balloons encompass one standard error.

Table 4. The five groups of environmentally similar nekton stations for the Before-After, Control-Impact analyses.

Groups	Impact Stations *	Control Stations *
1. Furthest Inshore stations	19_I	14_C and 17_C
2. Middle zone stations	7_I	2_C, 6_C, 8_C, 9_C, and 10_C
3. High salinity, coastal stations	33_I	3_C, 5_C, and 43_C
4. Offshore Stations	22_I, 31_I, and 36_I	21_C, 35_C, and 44_C
5. Offshore Terminal Stations	53_I, 54_I, and 55_I	52_C

*Subscripts I and C indicate designation of impact and control stations, respectively (e.g. station 19_I is an impact station and station 14_C is a control station).

Impact analysis

LOOP construction and brine discharge significantly influenced size classes of several species, including spotted seatrout and southern flounder. No effects on species abundance or community characteristics were detected from the two largest oil spills that we examined. We were unable to examine several spills at the Clovelly Dome Storage Facility because no nekton samples were collected there.

Construction

We detected several significant construction-related trends in nekton species and size class abundance in the BACI analysis. Summaries of 11 LOOP impact findings for species and size classes with significant (MIXED procedure, $p < 0.05$, Dunn-Sidák adjustment) interaction terms indicate that LOOP construction influenced the Catch Per Unit Effort (CPUE) of important nekton species. An additional 13 temporal or spatial effects (i.e., main effects) associated with these impacts (i.e., interactions) were also detected. Significant interactions (Least Squares Means Test, $p < 0.05$, Tukey-Kramer adjustment) that imply LOOP impacts, the significant effects (i.e., spatial, temporal, or interaction), the trend direction, if any, and probable causes of the observed effects are summarized in Table 5 and indicate a predominance of negative trends (i.e. 17 decreases, 3 increases, and 4 other).

Brine Discharge

We also detected significant (MIXED procedure, $p < 0.05$, Dunn-Sidák adjustment) LOOP-related influences of brine discharge at the brine diffuser (Station 36_I) on size classes of two species, gulf menhaden and southern flounder. Both impacts were also associated with significant downward temporal trends. Significant interactions (Least Squares Means Test, $p < 0.05$, Tukey-Kramer adjustment) that imply LOOP impacts, the significant effects (i.e., spatial, temporal, or interaction), the trend direction, and probable causes of the observed effects are summarized in Table 6 and indicates that all trends were negative.

Oil spills

In the analyses of three oil spill events at the offshore oil port, we did not detect any significant interactions for any of the size classes of the 37 species analyzed. Nevertheless, we did detect significant temporal trends for 11 size classes of six species. Although these temporal trends could not be attributed directly to LOOP activities, they indicate the dynamic nature of marine and estuarine nekton populations.

Table 5. Significant effects, trend direction, if any, and probable causes of the observed effects for the statistical tests run to test the construction impacts on demersal nekton.

Station	Species	Size Class (mm)	Significant Effect	Trend	Cause of Difference
Station 31					
	Lesser blue crab	< 15	Temporal	Increase	LOOP construction
			Interaction	Increase	LOOP construction
	Southern kingfish	30 to 100	Temporal	Decrease	LOOP turbidity increase
			Spatial	High at 31_I	Non-LOOP
			Interaction	Decrease	LOOP turbidity increase
Station 33					
	Lesser blue crab	< 15	Temporal	Increase *	Non-LOOP
			Interaction	Decrease *	LOOP construction
	Bay whiff	≥ 100	Temporal	Decrease *	LOOP construction
			Interaction	Decrease *	LOOP construction
	Mantis shrimp	≥ 100	Temporal	Decrease *	Non-LOOP
			Interaction	No trend *	Non-LOOP
	Spotted seatrout	30 to 100	Temporal	Decrease *	LOOP construction
			Interaction	Decrease *	LOOP construction
	Spotted seatrout	All sizes	Temporal	Decrease *	LOOP construction
			Interaction	Decrease *	LOOP construction
Station 36					
	Southern flounder	≥ 100	Temporal	Decrease *	LOOP turbidity increase
			Interaction	Decrease *	LOOP turbidity increase
	Southern flounder	All sizes	Temporal	Decrease *	LOOP turbidity increase
			Interaction	Decrease *	LOOP turbidity increase
Station 53					
	Atl. brief squid	≥ 100	Temporal	Decrease *	LOOP construction
			Spatial	High at 53_I	LOOP construction
			Interaction	Decrease *	LOOP construction
Station 54					
	Atl. brief squid	≥ 100	Spatial	High at 54_I	LOOP construction
			Interaction	Decrease *	LOOP construction

[a] Impact station compared to appropriate control station(s).
* Species estimates were not available for the before-construction phase, so trends refer to the during-construction and after-construction phases.

Table 6. Significant interactions that imply LOOP impacts on demersal nekton, how it affects the species, the trend direction, and probable causes of the observed effects for the influences of the brine diffuser.

Species	Size Class	Significant Effect	Trend	Cause of Difference
Gulf menhaden	30 to 100 mm	Temporal	Decrease	LOOP turbidity increase
		Interaction	Decrease	LOOP turbidity increase
Southern flounder	$\geq$ 100 mm *	Temporal	Decrease	LOOP turbidity increase
		Interaction	Decrease	LOOP turbidity increase

* The only individuals collected were in the size class $\geq$ 100 mm; therefore, the species-level comparisons for southern flounder were identical.

Discussion and Conclusions

The construction and operation of the LOOP pipeline did significantly influence some nekton species abundance, but the analyses were not as robust as possible because of factors related to the monitoring program design. The most notable impacts included a significantly negative influence on southern flounder resulting from brine discharge, and a positive short-term influence of construction on spotted seatrout at Station 33_I. Some of the apparently positive influences, however, may translate to negative or neutral impacts away from the particular impact station. This is because the locally increased relative abundance of a size class or species may influence densities elsewhere. Individuals responding to locally favorable conditions may be drawn from nearby locations where densities diminish and the overall density of the population over a broader area remains unchanged. Therefore, we cannot conclude that apparent positive LOOP-related effects are enhancements to the nekton populations or to the whole nekton community.

To evaluate changes in sensitivity with increased sampling frequency in an environmental monitoring plan, we used Atlantic brief squid (> 100 mm), a common species at the offshore terminal stations, which had a marginally significant interaction term ($p > 0.067$) for a moderate oil spill (21-October-1985). The currently available data set with 220 samples was sufficient to detect a CPUE difference of about 85% between stations before and after the spill. To detect a 50% change in the CPUE of Atlantic brief squid, the sample size should be about 430 for the six-year period surrounding the spill (three years before and three years after). The current sampling intensity will only generate 144 samples for the six-year period.

No significant LOOP-related spatial, temporal, or interaction effects on community descriptors (i.e., species diversity, richness, and evenness, total individuals, total fishes, total invertebrates, total decapods, and contribution of rare species) were detected for the construction or operation phases, and we did not detect significant effects for the majority of the size classes or species. This does not necessarily lead to the conclusion that LOOP-related construction, brine discharges, and/or oil spills were benign. While the impact events may not have been biologically or statistically significant for most nekton, a variety of factors could reduce the sensitivity of BACI analyses to detect significant events, including the absence of samples or the small number of before-construction samples at some stations, the absence of appropriate impact and control stations, the use of less than optimal control stations for some impact stations, discontinuity in the monthly sampling at some stations, and the possibility of a LOOP-related influence on a scale large enough to include the designated control stations. Thus failures to reject the null hypothesis tested on most species and size classes do not mean that the null hypothesis was correct.

From a total of over 2,200 comparisons, only 14 significant interactions were detected. There are several possibilities why we did not detect more significant differences. It is possible that LOOP did not impact any more demersal nekton. Nevertheless, the variability of the CPUE estimates was high, due to the natural variability inherent in nekton populations, low trawl replication, and discontinuous monthly sampling. Significant temporal effects for size classes and species without significant interaction terms may still be related to the LOOP pipeline if the sphere of influence of the LOOP construction and operation extended to the chosen control stations. If control stations were even slightly influenced by LOOP activities, then the sensitivity of the BACI comparisons would be reduced. Another possibility is that short-term impact events, such as oil spills, may not have occurred at a sensitive stage in the life cycle of the observed species. The absence of an impact from an oil spill does not necessarily indicate that the system is insensitive to the spill, but may only be less sensitive to the spill at certain times of the year, when sensitive life history stages of nekton species are not present. Additionally, the tested oil spills were relatively small. Larger spills would probably have a greater influence on demersal nekton.

SEDIMENT QUALITY DATA ANALYSIS

Introduction

This section summarizes the sediment quality, the 5th component in a series of five reports that analyze the impacts of LOOP construction, operation, and maintenance on the estuarine/marine environment.

Methods

Methods for measuring petroleum hydrocarbons changed during the course of the LOOP monitoring effort. The early measurements of light oil, heavy oil, and condensate were reasonably state-of-the-art methods at the time this monitoring effort was being planned and implemented. However, as improved analytical methods became more available in later years, and because of increasing interest in the polynuclear aromatic hydrocarbons (PAHs) in petroleum, the decision was made to switch to more modern methods that were less susceptible to interference, much more sensitive (greatly improved detection limits), and enabled the analysis of many individual PAHs with a high level of confidence in the analytical results. High resolution gas chromatography with flame ionization detection (GC/FID) was the primary analytical tool from 1985 on where mass spectroscopy (GC/MS) was used for detection on selected samples for confirmation of the FID results.

The light oil and heavy oil analyses used in the early years apparently resulted in reporting of much higher levels of petroleum hydrocarbons than the compound-specific analyses used in later years, thus these two data sets (early years and later years) are not compatible. This is likely due to some extraction of non-petroleum organic humic materials from sediments along with the oil. These humic materials are components of the several percent organic matter in typical fine textured sediments. Also, the primary reason for the incompatibility is that the light oil/heavy oil measurement is fundamentally different from the PAH analysis. Crude oil contains hundreds of individual petroleum compounds and many are far more abundant than the PAHs. The light oil/heavy oil analysis is intended to extract all of these, including PAHs which might make up a small part of the total. On the other hand, the PAH analysis focuses on relatively few of the persistent compounds commonly found in petroleum hydrocarbons that tend to be more toxic and more of an environmental problem in other ways than other classes of petroleum hydrocarbons.

Because of the incompatibility of the data sets, the light oil and heavy oil data from the early years cannot be combined with the analytical data on individual PAH compounds collected in later years. Thus these data sets were analyzed separately to answer the pertinent questions on both an "early years" and "later years" basis. The light oil and heavy oil analyses were only available at most for the 5 years from 1979 through 1984, but for many stations, less than the full 5 years data were collected. The individual PAH compounds were measured more consistently for a 10-year period. Thus in the statistical evaluations of the Sediment Quality Data, both the light/heavy oil data and the "total" PAH data are presented and discussed, but, it should be noted these are measuring very different components in petroleum hydrocarbons.

LOOP oil spill reports indicate most spills occurred in the Clovelly dome storage facility and the Offshore terminal. Two approaches were used to test for LOOP activity effects on petroleum hydrocarbon content in sediments. One was to evaluate differences in petroleum hydrocarbon levels in designated control stations versus potential impact stations where reported spills occurred during the 6 months (two quarters) prior to the sampling quarter. This was done with the realization that due to degradation and other factors (such as possible transport or burial processes), the effects of a spill are usually not permanent. Thus we looked for effects of reported spills close to the time when the spills occurred. The other approach was a simple comparison of petroleum hydrocarbon levels in sediments of potential impact stations versus controls. Repeated spills or releases may contribute to some long-term elevation of petroleum hydrocarbons in sediments.

Results and Discussion

Oil spill impacts

Clovelly Storage Dome

The data indicated that reported spills were significantly related to elevated sediment light oil concentrations within 6 months of the spill during the early years, and that considered over the entire early period when light oil was measured, the sediments at Clovelly contained significantly more light oil than control sediments. However, heavy oil at these potential impact stations was not significantly different at the 5 or 1% levels of significance, neither in association with spills nor when potentially-impacted stations were compared to control sites over all the years these fractions were measured. For the period 1985-1995 when individual PAH compounds were measured, no significant spill effect was detected and the potentially impacted stations were not significantly different from the control stations. For these later years, the average and maximum levels of PAH compounds measured at the impact sites appear reasonably similar to the control sites.

Clovelly area (canals and bayous leading away from the storage facility)

In the early years (1980–1984) when light oil and heavy oil were measured, and during the period 1985–1995 when individual PAH compounds were measured, there was no significant effect of reported spills in elevating petroleum hydrocarbons at potential impact sites versus control sites. However, long-term differences in levels at control and potential Clovelly area impact sites were shown to be significant for both heavy oil (early years) and total PAH compounds for the later years. It appears two of the eight Clovelly area stations likely contributed to the significant differences for PAHs.

Even though the impact sites are statistically elevated in PAHs, the data suggest the contamination is not substantial. Also, it should be noted that impacts in canals and bayous around Clovelly may or may not be due to LOOP activities as these are generally public waterways and contamination could have occurred from non-LOOP sources. Station 625, located in King's Canal, is an example where sediment contamination has apparently occurred due to non-LOOP boating activity.

Offshore terminal

At the offshore terminal where tankers transfer their load to the pipeline, in the early years there was a significant relationship between reported spills and sediment light oil content. A total of 12 spills exceeding 500 gallons were reported for the period March 1982 through May of 1994. Heavy oil in the early years and total PAHs for the period 1985–1995 did not show a significant effect. When the potentially impacted station (Station 481) was compared with the offshore controls over the entire early years (1980–1984) and later years (1985–1995), heavy oil at the impact site was significantly higher than the control stations, but, light oil for the early years and total PAHs for the last 10 years were not significant. Thus the data for the Offshore station suggests that though some significant increases in petroleum hydrocarbons may have occurred, impacts are not long-lasting since no significant difference was noted for the period 1985–1995.

Brine diffuser

The statistical results show no differences in oil associated with the sediments at the brine diffuser outlet during and after the major pumping for the excavation of the dome. Also, there was no significant difference in light and heavy oil between the diffuser stations and the control over the early years, nor between these stations between 1985 and 1995 when PAH compounds were measured. Thus there was no significant impact of the brine discharge on the petroleum hydrocarbon content of the sediments at the brine diffuser.

LOOP diesel dock

Stations near the LOOP diesel dock showed the highest amount of total PAH compounds of any stations associated with LOOP activities. The PAH levels were elevated not on just a few, but on very many of the sampling dates. Considering the fact that there is a lot of other boating activity (docks and other services for commercial and private vessels) in the immediate area, the significantly elevated levels of PAHs in the area of the LOOP Diesel Dock cannot be attributed to any one source. For example, the worst contaminated station in the LOOP monitoring study in terms of average concentration of total PAHs was Station 625, located on King's Canal, where heavy vessel traffic from non-LOOP activities apparently resulted in unusually high PAH concentrations on several of the sampling dates.

Brine Discharge Impacts

No statistical effect was seen of brine discharge on pore water salinity. A visual examination of the pore water salinity data indicate that fairly narrow ranges of salinity occur at all offshore stations and the averages of all the stations were near the same. The variability of the salinity data was much less than found for the petroleum hydrocarbon data.

Conclusions

Only the offshore terminal, the Clovelly storage dome, and the area around the pipeline, should a rupture occur, are likely to be impacted by LOOP activities. No spill associated with the pipeline has occurred. For the offshore pumping station and the Clovelly storage dome, a statistically significant increase in petroleum hydrocarbons was noted for the early years. No difference between potential impact sites and control sites were noted for the last 10 years of monitoring. If impacts occurred, they are apparently not long-lasting.

The canals around the Clovelly storage dome and the LOOP diesel dock area sediments showed statistically significant increases in petroleum hydrocarbons. For these sampling stations in the area around Clovelly, the data suggest increased levels (which were modest) could have been due to non-LOOP activities since only a few stations, mostly public waterways some distance away from Clovelly, showed these increases. The sediments near the LOOP diesel dock showed substantial, long-term elevations in PAH compounds relative to control sites. Again, however, extensive boating activities other than for LOOP are associated with this area, so it is not possible to identify the source.

In conclusion, the data indicate that some modest, relatively short-term impacts have occurred in terms of petroleum hydrocarbon levels in sediments of sampling stations. Where highest levels were found, boating and other petroleum activities other than those associated with LOOP are contributing sources.

No effect of brine discharge was seen on pore water salinity.

CONCLUSIONS FROM THE 1978-95 DATA ANALYSIS

Introduction

The results of data analyses from the Water Chemistry, Physical Hydrography, Zooplankton and Ichthyoplankton, Demersal Nekton, and Sediment Quality sections of the LOOP EMP (Volumes 2-6) are summarized herein. The analyses of benthos data were not included in this project. The major statistically-significant results and their implications are summarized below.

Spatial and Temporal Variation

Consistent temporal trends in some variables were recorded in the data analyses. In addition, in most of the major components of the analyses the question of spatial variability and its change through time was mentioned in relation to some variables. Both of these kinds of observations point to the dynamic nature of the Louisiana coastal zone. The rapid subsidence of the coast and its influence on the spatial landscape of the estuaries has been documented extensively in the scientific literature. There are ambitious plans to address this subsidence through major diversions of the Mississippi River into the estuaries, by restoration of barrier islands, and by a large number of smaller hydrologic restoration projects within the estuaries. These changes will inevitably alter both the spatial pattern within the Barataria estuary and the temporal gradients that were observed in this analysis. Thus, it is clear that the baseline developed over the past 18 years is not a static one, and will soon be obsolete.

LOOP Related Environmental Impacts

Water Chemistry

Construction – no impacts were detected.

Brine Discharge – some variables were significantly different before the period of maximum discharge compared to after, but they were not apparently brine-related.

Clovelly Dome Oil Spills – Surface ammonia and turbidity were elevated, but the magnitude of the effect is not considered ecologically significant.

Offshore Terminal Oil Spills – Surface ammonia was elevated, but again the impact is not considered ecologically significant.

Physical Hydrography

No LOOP-related impacts were detected, but the primary value of this data set is as a co-variable to help explain effects in other components of the overall study.

Zooplankton and Ichthyoplankton

Inshore Construction – Zooplankton biomass was high during construction, depressed after it.

Inshore Oil spills – Zooplankton biomass was depressed by inshore oil spills.

Offshore Oil Spills – Anchovy abundance was depressed by oil spills (marginally significant). Marginally significant Atlantic Bumper abundance depression, probably related to chronic, small oil spills.

General – several other significant or marginally significant effects are classified as indirectly related to LOOP activities, since oil or brine were not significant covariates in the BACI or DACI analyses.

Demersal Nekton

Construction –

At Station 31 (near shore pipeline) lesser blue crab ≤15 mm increased due to construction, while Southern kingfish decreased.

At Station 33 (inshore pipeline) lesser blue crab ≤15 mm, bay whiff ≥100 mm, and all sizes of spotted sea-trout decreased due to construction.

At Station 36 (brine diffuser) southern flounder, and at stations 53 (offshore terminal) and 54 (offshore pipeline) Atlantic brief squid ≥100 mm decreased due to construction-related turbidity increases.

Brine – Gulf menhaden 30-100 mm and southern flounder ≥100 mm decreased due to increased turbidity.

No oil spill related impacts were detected.

Sediment Quality

Oil Spills – At the offshore pumping station and the Clovelly Dome there were increases in petroleum hydrocarbons in early years. The canals in the environs of the Clovelly dome and the LOOP diesel dock had elevated PAHs during the past 10 years (when PAH was measured). In both these areas considerable non-LOOP boat traffic occurs, contributing to the elevated hydrocarbon levels.

No brine discharge related impacts were detected.

The Sensitivity of the Monitoring Program

Critical for the evaluation of the results from the long-term data analyses is the sensitivity of the design of the monitoring program to detect ecologically significant impacts. In other words, is the failure of the analyses to detect large LOOP impacts due to the insensitivity of the monitoring design or were the effects of LOOP's construction and operation, including oil spills, really fairly benign ecologically? The answer comes from two lines of argument.

First, the data sets and analyses were clearly sufficient to detect some changes in forcing functions when they occurred, not only those due to LOOP, but also due to other unidentified environmental forces. For example in the water chemistry component TKN, TP and sulfate changed consistently over the period of sampling, the first two increasing, sulfate decreasing. In the hydrography component a consistent trend toward increasing temperatures in the offshore zone was detected. The analyses did identify consistent changes in the estuarine and marine ecosystems, and these temporal changes were pervasive throughout the data-sets (and thus not accidental). The ability to detect an environmental response to the offshore oil spills is extremely important. Our analyses were able to detect changes in water quality and plankton abundance related to oil spills that occurred during the data collection, which were much smaller (about 1%) than the largest anticipated spill. Thus the monitoring program is shown to be sensitive to events smaller than those anticipated when the program was established.

A second way to answer the question about the sensitivity of the data analyses is to consider, from the statistical data, the magnitude of the environmental change required to show statistical significance. This can be determined from the relationship of the mean value of a variable to its standard deviation. This varies widely from analysis to analysis depending on the number of samples, the number of replications, the length of the time series, etc.. It should be pointed out that in an uncontrolled environment, especially for aquatic variables that are not fixed in space, the uncontrolled variability is generally extremely high, leading to standard deviations that are often at least 20-30% of the mean. An example from our data is Atlantic brief squid, for which a change in CPUE required to show a significant difference between treatments is 85 %. Increasing the number of replications, which would double the number of samples, is expected to increase the power of the analysis so that a 50% change would be significant. This is not an exceptional example, at least for mobile, and especially for schooling, organisms. From this point of view a statistically significant result in the data analysis must be considered to be also ecologically significant, since it signals large changes in the variable of interest. This kind of evaluation suggests that the data analyses may well be missing ecologically important information simply because part of the monitoring design is inadequate to detect it.

Conclusion

The analyses of the long term LOOP marine/estuarine data (excluding benthos) identified modest impacts of construction, brine disposal, and oil spills. It is clear from our data analyses that, in order to meet the objectives of the EMP (listed on page 5), the revised LOTA environmental monitoring program must include adequate continued data collection to sufficiently address the data needs to characterize both spatially and temporally the estuarine and marine ecosystems. Specific technical information, suggestions, and recommendations for program revision are provided in the following section.

TECHNICAL INFORMATION FOR THE LOOP MARINE AND ESTUARINE MONITORING PROGRAM REVISIONS

Introduction

This section of the Executive Summary reports on the Task 3 portion of the LOOP Marine and Estuarine Monitoring Program, 1978-95, data analysis project. The objective of Task 3 is to provide LOTA and the Program Review Committee the technical information needed for revising the LOOP Marine and Estuarine Monitoring Program.

Monitoring Program

In recognition of the potential for significant environmental impacts much attention was given to environmental safeguards by state and federal agencies and by the Superport developers (see review by Sasser et al. 1982). Because of the potential risks associated with the construction and operation of the Superport (e.g. bringing the world's largest oil tankers to one of the most productive fisheries resources in the world), both state and federal licenses required environmental monitoring of LOOP construction and operational activities. The environmental monitoring program (EMP) was developed under mandate of the Superport Environmental Protection Plan (revised, 1977), a regulation of the State of Louisiana implementing the Offshore Terminal Act. The EMP (section 3.1, page 8, March 1986) lists the objectives of the monitoring program as:

(1) to obtain seasonal environmental and ecological data so that conditions existing during operation can be related to historical baseline conditions;

(2) to detect during the operation of the project any adverse alterations or damages to the environment so that corrective action can be taken as soon as possible;

(3) to obtain sufficient data to determine the cause or causes of environmental damages or alterations so that responsibility can be properly placed; and

(4) to provide information in order to evaluate long and short-term impacts of the project.

Ecological components of the estuarine/marine monitoring program include: water chemistry, physical hydrography (including brine discharge), zooplankton / ichthyoplankton, demersal nekton, benthos, and sediment quality. The Louisiana Department of Wildlife and Fisheries collected the data related to these components from 1978 to 1995. Vegetation and wildlife components were monitored by LSU (see Visser et al. 1996 and references therein).

As mentioned above, the objective of Task 3 is to provide LOTA and the Program Review Committee the technical information needed for revising the LOOP Marine and Estuarine Monitoring Program. The technical information, suggestions, and recommendations presented are based upon the four objectives of the EMP as influenced by the results of the data analyses. Specifically, after evaluation in light of the data analyses we endorse the four objectives of the EMP:

(a) Seasonal environmental and ecological data acquisition (EMP objective 1) is recommended because the analyses show degradation of environmental information when the frequency of sampling is reduced. Virtually all phenomena measured vary seasonally, and most nekton and plankton have complex lifecycles that involve different habitats in different seasons. A number of significant effects were lost when comparing quarterly to monthly sampling (c.f., Table 2). Furthermore, because of the large natural variability of most plankton and nekton populations, the power of the current sampling and analytical protocol to detect ecologically significant changes is often marginal.

(b) Maintenance of a historical baseline (EMP objective 1) for analyses of possible oil spills or other environmental incidents has been shown to be critical in all components of the monitoring program because of the temporal and spatial dynamics of the inshore and offshore ecosystem. For example, clear temporal trends unrelated to the LOOP operation were shown for a number of water quality and hydrographic variables. Further, the subsidence of the coast, loss of wetlands, and planned restoration projects are changing the spatial pattern of the estuary. Thus a baseline must be kept current in this environment. However, in some cases it may be possible to optimize the sampling schedule to ensure an adequate baseline while at the same time reducing costs (c.f., plankton recommendations).

(c) We believe that continued environmental monitoring is also prudent because of the importance of the commercial fisheries in the environs of the LOOP operation, and the potential for damages to this valuable resource (EMP objective 2 and 3).

(d) Finally, the requirement to evaluate both short- and long-term impacts (EMP objective 4) requires continuation of the LOTA Environmental Monitoring Program.

In light of these considerations the following specific recommendations for each monitoring component (Water Chemistry, Physical Hydrography and Brine Monitoring, Zooplankton and Ichthyoplankton, Demersal Nekton, and Sediment Quality) assume the continuation of an environmental monitoring program based on about the same level of information acquisition as previously. The fact that we were able to detect a number of temporal trends and some impacts of

LOOP operations indicates that the present monitoring program is responsive to the spirit of the EMP objectives. However, a number of changes are recommended to (1) increase the sensitivity of certain critical environmental variables to possible impacts; (2) make sampling more efficient, hence reducing costs; and (3) eliminate elements of the present monitoring program that appear to be insensitive to LOOP operations or are otherwise unnecessary.

Water Chemistry Recomendations

We have made suggestions and recommendations regarding possible revisions to the LOOP Estuarine/Marine Monitoring Program based upon the analysis of the LOOP water chemistry data (Task 2). These recommendations are designed both to improve the sampling program and to reduce effort either by eliminating variables and/or sample stations, whenever possible. We have attempted to formulate recommendations that are based upon the four objectives stated above. We briefly summarized the pertinent findings from the Task 2 to support these recommendations when appropriate. In some instances the recommendations are based upon professional judgment.

We have organized our recommendations into three basic categories:

(1) overall recommendations
(2) specific sampling recommendations
  (a) variables to be measured
  (b) frequency and depth of sampling
  (c) station distribution
(3) other recommendations

Overall Recommendations

- **The monitoring program will be improved simply by extending the data base; in other words, the monitoring should be continued.**

The long-term nature of the monitoring effort has numerous invaluable benefits for the State, LOOP, LLC., and the various agencies involved. The LOOP facility is unique to the lower 48 states, and is of unprecedented economic significance in terms of tonnage handled and its strategic economic positioning. It is located, however, directly in the middle of the finest and largest continental shelf fishing zones in the US. The water chemistry data sets we examined are useful for the intent of the monitoring program as identified in the original environmental management plan. The Superport is still operating and all significant impacts have probably not occurred (e.g., the unrealized large oil spill). The responsibilities for management have not diminished with time. Rather, these responsibilities have increased in the last 2 decades as our knowledge of how human use affects living resources has expanded.

The variability introduced by the Mississippi River is a significant complication of the analysis because of its size and proximity to the monitoring stations. A change in the measured parameter values between a before-and-after impact analysis may not be due to the potential impact factor (e.g., brine), but actually be the result of long-term trends or events in environmental factors unrelated to the LOOP facility use. Adequate monitoring of these long-term trends and events is required to determine responsibility for an impact (EMP Objective 3).

The maximum 'credible oil spill' estimated in the original EIS was 240,000 barrels, which is 500 times larger than that spilled through 1996. It is based on a pre-project spill recurrence interval that is substantiated by experience since 1978, and which includes a total spill volume of about 1,883 barrels. In other words, the recurrence interval graph of the original projections in the EIS and the subsequent events are nearly coincidental. Fortunately, this very large spill has not happened (yet). These results and observations suggest that a credible monitoring program should take into account the information needs of this larger, yet unrealized oil spill.

- **We recommend more frequent sampling be anticipated when a large spill occurs (sampling at more than four times/month) at the long-term monitoring stations.**

Current speeds throughout the region suggest that water masses are replaced in days, not weeks or months. Events like a large (yet unobserved) oil spill similar to that predicted in the original environmental management plans, must be sampled within weeks of the event to establish reasonable baseline conditions against which to measure impacts (EMP Objective 1). If the region were homogeneous, not near the Mississippi River, etc., then baseline conditions might be more safely predicted from less frequent sampling (e.g., quarterly). A second related issue is that the monitoring program should be prepared to mobilize for a Mega-oil spill. The dispersal of surface water and oil will be spread far beyond the LOOP Superport vicinity, and probably spread westward (assuming that is the dominant current direction). However, below the surface, there may be effects spreading in different directions from that in the surface layer.

Specific Sampling Recommendations

- **We recommend sampling all present water quality variables except for Alkalinity, Calcium, Sulfate, Total Dissolved Solids, and Total Solids.**
  1) Alkalinity: This variable shows very little spatial variation and no temporal trends. Therefore it is probably insensitive to any impacts.
  2) Calcium: This variable showed no temporal trends, and was not considered to be an important covariate, Therefore it is probably not useful in the determination of impacts.
  3) Sulfate: This variable is highly correlated with salinity (R=0.86 for surface values and R=0.84 for bottom values).
  4) Total Dissolved Solids This variable is highly correlated with salinity (R=0.97 for surface values and R=0.87 for bottom values).
  5) Total Solids: This variable is highly correlated with salinity (R=0.96 for surface and bottom values).

- **We recommend monthly sampling of the water chemistry.**

Temporal trends were calculated for two cases (1) using the monthly data, and (2) using the quarterly data. Trends were calculated for surface and bottom variables and for both the inshore and offshore environments. Using the monthly data, a total of 20 (8 inshore trends, 12 offshore) trends were detected. Using the quarterly samples, only 7 (2 inshore, 5 offshore) trends were detected. Clearly, quarterly sampling is not sufficient to detect the long-term trends needed to evaluate possible impacts of LOOP (EMP Objective 4).

- **We recommend surface sampling inshore, surface and bottom sampling offshore with occasional mid-depth samples to define important water column structure (e.g., oxygen minimum layer, halocline).**

Correlation analysis indicated a high degree of correlation (correlation coefficients of ~0.9 for 13 variable, >0.7 and <0.9 for 3 variables) between surface and bottom for all the inshore water chemistry variables.

The offshore variables had much lower correlation coefficients (only 2 variables had correlation coefficients >0.8; 9 variables had correlation coefficients <0.5) between surface and bottom.

The mid-depth data did not add much information because it did not define the structure of the water column. A possible modification to the mid-depth sampling would be to use this sample to identify major structures (*e.g.*, low oxygen layer) in the water column. This sample would only be collected when such structure is detected by profile sampling.

- **The stations need to be distributed to cover the LOOP pipeline route, as well as other LOOP potential impact areas with sufficient impact and control stations in each area.**

The general station distribution that we recommend has a total of 28 stations, and is described below. This distribution would have enough stations to monitor the LOOP pipeline, the Clovelly Dome, the brine diffuser, and the offshore terminal. The existing stations can be used in a majority of the cases. The actual number could be less since some of the Clovelly dome stations may also be part of the upper Barataria system pipeline route stations.

The station distribution should have two controls and two impact stations in the following inshore areas along the pipeline route:

(1) The upper portion of the Barataria Bay System (four station total)
(2) The middle portion of the Barataria Bay System (four station total)
(3) The lower portion of the Barataria Bay System (four station total)

Eighty-seven percent of the inshore oil spills occurred at the Clovelly salt dome site (Station no. 38). There are 24 stations with record lengths > or = 10 years, but only one at Clovelly (no. 38). Station 39 is within 1.5 km of no. 38 (WSW), no. 16 is within 2.5 km (WSW), and no. 464 is within 4 km (NE). At least one more impact station should be added at the Clovelly Dome and a second station added within 1.0 km of the Clovelly Dome, resulting in a total of six stations near the Clovelly dome.

The station distribution should have two controls and two impact stations in the following offshore areas:

(1) The brine diffuser (four station total)
(2) The offshore terminal (four station total)

Two controls at a point midway between the brine diffuser and the offshore terminal.

Other Recommendations

- **The analysis of the water chemistry data should be integrated with the biological data sets, particularly with the benthic community analyses.**

The benthic community is the logical analytical subject for competent investigation of impacts near the brine disposal and for oil spills (past and present). The benthic community is subject to a probable enhancement around the diffuser if results from other studies are appropriate for this site. The immediate area of the brine plume (about 4 km^2 for a 1+ ppt plume) sweeps over an area of 16 km^2. The plume orientation is very responsive to currents, and the plume may move between the stations without detection by the present sampling grid. The benthic community is exposed to chronic conditions and some animals will remain for weeks and months within this brine plume shadow. The benthic data were not analyzed as part of this analysis and requires, as far as we can tell, annotations to make it usable. This data should be analyzed by independent benthic ecologists to check on the implications of the results in this report, including: (1) the possibility of a brine plume 'halo' or disturbance area around the brine diffuser; (2) the presence of brine or oil spill chemical markers in sediments and appearing coincidentally in time or space with changes in the water chemistry, nekton and plankton; and, (3) detection of long-term trends in the benthic data that may be explained by the regional influences of the Mississippi River.

- **The data from the bottom sled (brine) could be improved by sampling sufficiently in the field to go in all directions until a baseline value is found in all directions, and the salinity contours closed.**

The bottom (brine) sled surveys are an excellent addition to the monitoring, but the contouring is frequently incomplete.

The sled sampling by the State Department of Wildlife and Fisheries clearly located a brine plume whose position on the bottom moves among the stations, adding variability to the measured parameters, and perhaps compromising the results of the BACI sampling design. The variability in bottom salinity at station 473, for example, probably reflects these movements among and between sampling locations (see Figure 15). The BACI analysis cannot, a priori, determine if the plume is over a station or not, and a nearby station may be an adequate control station in one month but an impact station in another month. Fixed control and impact stations cannot, therefore, be assigned.

Some sort of adaptive sampling scheme (network of vertical profiles, towed vehicle) to collect data on the three-dimensional structure of the brine plume should be implemented if major brine discharges occur. This will supply data that can be used to more adequately determine any short-term impacts of brine discharge (EMP Objective 4) and to close the contour profiles outlining the plume in both horizontal and vertical directions.

- **The area is accumulating sediments, so dated cores might be useful to investigate the halo, if present, around the plume and to retrospectively determine impacts near the brine diffuser.**

The water column turns over in a matter of days because of currents. The sediments are also the best depository of information on the effects (if any) of a large oil spill (of presently experienced spill or future larger sized spill).

- **It would be useful to explore ways to open up these efforts to serious scientific efforts and to publish analyses of the data arising from them.**

This monitoring program is an exceptionally valuable opportunity for science and management interests. It would be useful to explore ways to open up these efforts on an ongoing basis to provide data for other scientific efforts, and to publish analyses of the data arising from them.

Given the fact that we were unable to identify alterations to the temperature or salinity of the waters sampled (aside from the near bottom layer of abnormally high salinity associated with brine discharge), we assume that, in the absence of future construction, the role of hydrographic monitoring will be to provide a co-variate to be used in the analysis of biological data. A recurrent theme in the following recommendations is that monthly samples are too infrequent to properly define the sources of variability, while the number of stations presently sampled provide unnecessary redundancy. While it is impossible to estimate the effects of sampling less frequently than necessary at all stations, such effects are derivable for the stations with continuous recorders. For example, at station 317, 37 percent of the salinity variability in a nearly continuous 3.5 year subset of the record would have been missed by monthly sampling. Fewer samples, carefully situated in space, will allow improved resolution of the temporal variability, the means, and the variance structure. This, in turn, will allow better association of observed variations with their causes.

Physical Hydrography Recommendations

Offshore

- **Two moorings should be maintained with continuously recording temperature and salinity sensors at near-surface and near-bottom depths. One should be near the offshore terminal and the other should be approximately mid-way to the coast. These should sample at hourly intervals to resolve tidal and lower frequency signals. All other stations should be discontinued.**

The offshore region exhibited significant, spatially coherent trends in bottom salinity, bottom temperature and surface temperature. It is difficult to conceive of a process whereby LOOP operations could have been responsible for these trends. Furthermore, no BACI analyses indicated that LOOP operations had any negative effect on hydrographic properties in this region. Finally, it is difficult to attribute the thermal trends to atmospheric forcing since the scale of such forcing would require a similar (or enhanced) response in the shallow estuarine waters, a response which was not observed.

The most likely cause of the observed trends is intrusion of Loop Current rings, with the lack of a signal in surface salinity being due to the higher natural variability in this signal. Unfortunately, we have not yet been able to identify an adequate time series of Loop Current ring paths with which to test this hypothesis. It should be mentioned that the time scale of this phenomenon is very long. Rings are shed approximately once per year and existing records (of about 20 years) are not yet long enough to define the low-frequency variability of the signal. Thus, any conclusions concerning trends which were influenced by this process must be tempered by the assumption that the record is too short to properly define a reliable trend.

The analysis of offshore data was hampered by samples which were clearly erroneous (probably instrument error) and a process which was undersampled, i.e. important, deterministic and stochastic variability in the measured parameters which occurred on time scales much shorter than the sampling period was not resolved (wind-driven and tidal variability has time scales shorter than one month). On the other hand, the coherence length scales, distances over which the hydrographic properties varied in a coherent manner, for hydrographic parameters in this region are large, on the order of 10 to 20 km, at least. Mid-depth samples are not required, as the dominant stratification is defined by a strong halocline. Two stations located along a cross-shore transect will help define the large-scale mean spatial variability. Since the surface waters of this region are dominated by a river plume which is highly variable in space and time, additional moorings placed along isobaths would assist in defining the spatial patterns at any given instant in time. It is not clear that the added information provided by such moorings would warrant the cost of their deployment.

Nearshore

- **Two moorings, oriented along a cross-shore line, should be maintained with continuously recording temperature and salinity sensors at near-surface and near-bottom depths. These should sample at hourly intervals to resolve tidal and lower frequency signals. All other stations should be discontinued.**

The nearshore region exhibited no significant, spatially coherent temporal trends in either temperature or salinity. It is difficult to conceive of a process whereby LOOP operations could have been responsible for such trends, if they had been identified. Furthermore, no BACI analyses indicated that LOOP operations had any negative effect on hydrographic properties in this region. This is a region of strong cross-shelf gradients in properties, but smaller alongshelf gradients. Flow is strongly wind-driven and highly variable. Two moorings oriented cross-shelf will characterize the strong offshore gradients in water properties.

- **As an additional option, we suggest that two bottom-mounted acoustic Doppler current profilers which transmit data to shore in real time be deployed: one nearshore and one near the offshore terminal.**

The current meter records from this region were too short and too intermittent to be of great use in characterizing the region. Acquisition of accurate current meter data from such environments is notoriously difficult. It is not clear, now that construction and brine pumping are completed, whether such data are warranted. In the event of a spill, though, this information would permit accurate tracking of the potential region of impact. If significant further brine discharge is anticipated, this information from a site near the diffuser would assist brine plume tracking (see below).

Lower Estuary

- **Assuming that the stations 315 and 317 will be continued as part of LDWF's long-term monitoring program for other purposes, similar instrumentation should be deployed at two other sites in the lower estuary, stations 322 and 7. Sampling should occur, at least hourly. Other stations should be discontinued.**

The lower estuarine region exhibited no significant, spatially coherent trends in either temperature or salinity. Furthermore, no BACI analyses indicated that LOOP operations had any negative effect on hydrographic properties in this region. Spatial gradients are large in this region and time scales vary from the semi-diurnal to the interannual. Hourly recordings are necessary to adequately describe this variability, particularly in order to distinguish natural variability from possible LOOP-induced variability in case of events which impact the estuary. It is imperative that these stations be continued as proposed alterations in the amount of river water diverted from the Mississippi River to the Barataria Basin may invalidate all existing records as a basis against which to compare future potential impacts of LOOP activities.

- **A tide gauge should be deployed at the Clovelly Storage Dome.**

Water level is recorded by NOAA/NOS at Grand Isle. This identifies the apparent sea level rise at this location. It was unfortunate that a similar gauge was not deployed at LOOP facilities within the estuary (upper or lower) to identify possible construction-induced subsidence effects. While we are aware that a tide gauge was deployed in Little Lake and another south of the dome, we believe that these would have had to have been deployed within a few hundred meters or less of the construction in order to resolve the weak, but potentially important, signals expected from construction activity.

Upper Estuary

- **Stations 320, 324, and 12 should be continued and instrumented with hourly recording instruments similar to those recommended above. Other stations may be discontinued. An array of appropriate rainfall gauges would also be beneficial in helping to understand the salinity variability in the region.**

The upper estuarine region exhibited no significant, spatially coherent trends in either temperature or salinity. Furthermore, no BACI analyses indicated that LOOP operations had any negative effect on hydrographic properties in this region.

Spatial gradients are important in this region and time scales of variability range, again, from the semi-diurnal to the interannual. Never-the-less, spatial scales are larger than the existing station spacing in some cases, providing unnecessary redundancy. Again, proposed river diversions to the basin obviate the use of the existing data sets as controls against which to test for future changes in characteristics or against which to identify the cause of alterations to the environment. The complexity of the region suggests that deployment of current monitoring stations would not be cost effective in this area. The upper estuary consists of a few large open water bodies connected by multiple channels, tidal creeks, and bayous. The cost of placing current meters in these channels in sufficient number to define the flow regime is prohibitive. Furthermore, it is not clear scientifically exciting information that would be derived from such an investment is necessary for the monitoring that LOOP is tasked to maintain.

Brine Monitoring

- **In the event that significant brine monitoring should again take place, continuous recorders, deployed at increasing distances around the diffuser, should be used to delineate the temporal and partially delineate the spatial variability of the plume size and the strength of its associated salinity anomaly. A minimum of six bottom temperature and salinity sensors should be deployed uniformly around the diffuser. (An additional six at a greater distance would enhance the program.) Adaptive sampling of a predetermined grid of stations is recommended for brine plume mapping, in preference to towing a sled. Information concerning the preferred direction of plume advance should be derived from continuous monitoring of near-bottom currents and radio telemetry of the data to the sampling boat, thus requiring deployment of an appropriate near-bottom current meter and telemetry package.**

Plumes, both positively and negatively buoyant ones, are highly dynamic features. They respond to changes in sources strength and to ambient conditions of stratification, flow and mixing characteristics. Time scales on which these vary range from a few hours to seasons. Attempts to map the extent of a negatively buoyant plume must account for this space-time variability. The temporal variability can only be resolved through continuous monitoring. Records from the sled suggested that the sled structure may have been disturbing the interface between the brine plume and the ambient water. As an alternative, a salinity sensor could be carefully lowered to a specified distance above bottom at pre-specified grid stations. Stations could be added to or dropped from the sampling plan according to pre-decided criteria such as the absence of brine at two consecutive stations on a given transect. Continuous onboard monitoring of the shape of the brine patch using optimal interpolation and a laptop computer, or even hand contouring of the data, would allow stations to be added to the grid when the plume was observed to continue in a given direction. In order to understand the area of impact of the brine plume, such monitoring would need to include a variety of wind and stratification conditions and not be limited to fair-weather conditions.

General Discussion

The potential remains that past or future LOOP activities could modify flow patterns, particularly within the estuarine reaches of the study area, to an extent that they impact the hydrography and, consequently, the biology. In fact, alterations of the flow regime could impact the biology without a concomitant change in temperature or salinity. It has been mentioned above, that the cost of maintaining a long-term current monitoring program adequate to define the flow regime of the estuary would be high. One might ask whether or not modeling protocols could be developed or applied which would resolve the potential effects of slow, long-term changes in the estuarine environment such as rerouting of flows. Models of this region have been developed and the potential exists for developing others. A major missing parameter is an accurate bathymetry of the region. Mixing coefficients (engineering parameters which describe the effects of small scale flow features not resolvable on the model grid), adequate forcing (wind fields, rainfall fields, water levels at the tidal passes), and sufficient computing power to run the models in a realistic time frame are presently not available. Progress in this field of research can and is being made. The models presently in existence, though, might be indicative of potential responses, not definitively predictive. If it is suspected that such slow, long-term changes might be occurring, additional monitoring and modeling efforts are advisable. It seems unlikely that such changes would be clearly detected with the program recommended above. This is designed to capture changes in the large scale hydrographic fields occurring on time scales of a few days to years.

Zooplankton and Ichthyoplankton Recommendations

- **We recommend reducing the number of sampling gears from 4 to 3, the number of sampling protocols from 6 to 3, and the total number of sampling stations from 98 (throughout history of study or from 19 - 21 in recent years) to a total of 14.**

The following monthly sampling stations should be maintained: pipeline and Clovelly Storage Dome impact stations 7, 15 and 38 and control 12, 13, 14 - all HL sampling stations; Brine Diffuser impact station 36 and control 21 and 22 - all OM sampling stations, and LOOP Offshore Terminal impact stations 55 (OM) and 708 (BH) with controls 52 (OM) and 704 and 706 (BH). These stations have the strongest continuous data sets and are therefore in the best position to accomplish EMP Objectives 1 through 4. If the Brine Diffuser pumping schedule is expected to remain at current low levels, then Brine Diffuser sampling could possibly be discontinued, which would further lower the total number of stations sampled to 11.

- **All station sampling should be replicated a minimum of 3-5 times**

So as to better estimate the within station variability and thereby increase the power and resolution of statistical analyses, which is in furtherance of EMP Objectives 2 and 3.

- **Monthly samples should be collected each year (with extreme care taken toward ensuring long term preservation) but routinely worked up (taxonomically) every other year.**

Thus, complete sample sorting and identification of all larval fish and the commercially-important decapods (i.e., *Penaeus* spp., *Callinectes* spp., and *Portunus* spp.) and zooplankton biomass estimation (from displacement volume methodology) would be available for an alternating year, time-series (trend connection) going back to the present 18 year data-set. At the same time the availability of archived samples would insure that at any given point in time, if there were to be a major oil spill or another catastrophic event, the subsequent BACI statistical analysis would have at least a two-year Before period of available samples. The BACI statistical design would also greatly benefit from the increased power that the station sample replication would bring to bear. This recommendation is in furtherance of all EMP Objectives.

- **Supporting environmental data are needed to supplement/complement the zooplankton and ichthyoplankton sampling program.**

  Monthly water column profiles at each station for temperature, salinity, conductivity, turbidity, dissolved oxygen, and surface estimates for chlorophyll are needed. In addition, brine and oil spill data for inshore (Clovelly Storage Dome) and LOOP Brine Diffuser and Offshore Terminal sites are needed for future analyses as covariates. This recommendation is in furtherance of EMP Objectives 1 through 4.

- **Moored current meter arrays around the Offshore Terminal are needed to guide adaptive zooplankton and ichthyoplankton sampling responses to predicted major offshore oil spills.**

  This recommendation is in furtherance of EMP Objective 3.

- **Resource managers need to formulate a specific oil spill response plan for the Offshore Terminal that would include sampling at the long-term monitoring stations in that area at an increased frequency and with additional replication (EMP Objective 2).**

- **Any new construction or planned discharge scenario should have an adequate Before sampling data collection period (2-3 years of pre-Impact data collection) in furtherance of EMP Objectives 1 through 4.**

Demersal Nekton Recommendations

We have identified possible improvements to the sampling program that relate to temporal and spatial patterns of sampling, sample replication, and the number of environmental variables measured in conjunction with demersal nekton trawls.

- **The monitoring of nekton associated with the LOOP pipeline should be continued on a monthly basis each year, with increased replication in the event of a potential impact.**

Environmental monitoring is intended to provide data for the detection of impacts, and to provide a baseline for restoration in the event of an impact. A potential impact event may be associated with clearly defined temporal and spatial events, such as construction and post-construction phases. In this case the clearly defined periods can be tested as "before" and "after," which facilitates statistical testing. Impacts may also be associated with less clearly defined temporal and spatial events such as relatively small, chronic spills. The gradual changes occasioned by this type of event are much more difficult to detect and require long, continuous periods of sampling to develop trend analyses. In the case of the LOOP project, the most important reason for monitoring is to provide a continuous baseline of the status of the environment to meet all four of the objectives of the Environmental Monitoring Plan. A continuous baseline of data preceding a biologically significant, but non-catastrophic event will be necessary to determine the impact of the event and the measures necessary for mitigation and restoration.

Continuing the nekton sampling protocol is also vital for understanding the influences of LOOP-related activities. The Gulf coastal waters are biologically dynamic. We detected significant temporal trends for 21 size classes of 17 species that did not detectably result from LOOP-related activities. This suggests that species abundances are changing over time. As the baseline shifts, continued monitoring is needed to maintain the validity of the pre-impact data base in the event of a future LOOP impact. To ensure an accurate assessment of potential impacts, data reflecting current conditions are required. Many of the stations were discontinued in the early 1980's. For example, sampling at Stations 17C and 19I was discontinued in January 1982, and the data collected from those stations are now outdated because of changing temporal and spatial patterns of nekton distribution and abundance. While appropriate to assess influences related to the initial LOOP construction phase, the now terminated data sets are inadequate to provide a baseline for future potential impacts. Old data probably will not provide convincing results in a changing baseline situation. Testing the effects of future impacts against data over a decade old will reduce the accuracy of the analyses, and will cast considerable doubt on the conclusions.

The present level of monthly sampling seems adequate for maintaining a robust baseline, but resource managers should consider a response plan to increase the frequency of sampling in the event of a major, but non-catastrophic, impact (e.g., a moderate to major oil spill) for more statistical sensitivity. In order to conduct a powerful BACI analysis with a chance of detecting a 50 % change in CPUE of a typical species, three years of post-impact data would be compared to the preceding nine years of data. This requires continuous, long-term baseline data at control and impact stations. Under the current sampling intensity, the three years after a potential impact event at the offshore port would only generate 144 samples with 2 control and 2 impact stations (currently there are one control and three impact stations, but see recommendations for the Offshore Port below). To evaluate changes in sensitivity with increased sampling frequency in a response plan, we used Atlantic brief squid (> 100mm), a common species at the offshore port stations, which had a marginally significant interaction term ($p > 0.067$). The current data set with 220 samples was sufficient to detect a CPUE difference of about 85 % between control and impact stations before and after a moderate oil spill (21 October, 1985). To detect a 50 % change in the CPUE of Atlantic brief squid CPUE the sample size would have to be about 430. Because of the transient nature of most impacts, a three year time frame for impact assessment should be used for planning. By sampling three times per month at four stations for three years, 432 samples can be collected. Alternatively, with only one sample per station per month, either nine years of data would be needed, which would be insensitive to short-term effects, or three times the number of impact and control stations would be required.

- **If additional major construction is proposed, sampling at appropriate impact stations and control stations should be conducted for at least two years, twice monthly, to ensure adequate before-construction data for impact analysis (higher sampling rates over one year would be a less powerful alternative).**

The lack of adequate pre-construction estimates of species abundances at many of the impact stations limited the utility of the BACI analyses. Pre-construction estimates are vital to the BACI analysis because the pre-impact measurements are used as a reference for subsequent comparisons. The estimates from the control stations do not always adequately represent conditions at the impact stations prior to the impact. Without an adequate pre-impact estimate, a convincing assessment of the observed differences at the impact station may not be possible. The purpose of the BACI analysis is to test for impacts that are demonstrated by a change at the impact station that does not correspond to changes at the control stations. For example, a convincing assessment of a positive or negative impact on southern kingfish can be made at Station 31I, because the before-construction phase was adequately characterized. Southern kingfish between 30 and 100 mm were significantly more abundant at Station 31I than at the control stations prior to construction, but significantly less abundant during and after construction. This interaction between the temporal and spatial effects indicates a negative impact due to construction. In contrast, at Station 33I, the lack of adequate sampling before construction precluded accurate impact assessment on spotted seatrout which were significantly more abundant during and after construction at Station 33I than at the control stations (see Table 9 in Task 2 report). If the mean CPUE at Station 33I before construction was near zero, as it was at the control stations, then LOOP construction would have been interpreted as having had a net positive influence on spotted seatrout. Moreover, if the mean CPUE at Station 33I was near 49 individuals per hour before construction, as it was during construction, then spotted seatrout would have decreased in the post-construction phase (a negative influence). Without the pre-construction estimate, we can only deduce that spotted seatrout mean CPUE decreased after construction relative to during construction. The recommended two-year bimonthly sampling protocol will provide 48 seasonally balanced samples at each station, which should provide adequate data for a more robust analysis of the influence of the new construction.

- **Control stations without appropriate impact station pairings should be discontinued, unless these stations are necessary for the evaluation of impacts related to variables in other datasets (e.g., Plankton, Water Chemistry, etc.).**

Several nekton stations in the sampling design could not be incorporated into the analyses. Stations 1C, 4C, 37C, 41C, and 42C were not similar enough to any other stations to be grouped, and were excluded from the BACI analysis. Serious consideration should be given to dropping these stations for nekton sampling and other monitoring components if no valid reason can be identified for retaining them. Alternatively, they may be grouped with new impact stations to provide a more robust baseline for the control stations in an impact assessment.

- **Additional impact and control stations are necessary inshore of Station 7_I.**

Currently, coverage along the pipeline north of Station 7_I is nonexistent. Only one impact station, Station 19_I, existed inshore from Station 7_I, and it was discontinued in 1982. This arrangement leaves over 30 km of the LOOP pipeline, as well as the entire LOCAP pipeline, unmonitored. Since this area of the pipeline is unmonitored for nekton, no impact assessment of a potential pipeline failure or oil spill along the corridor could be made. Coverage at locations where the pipeline crosses a lake or major bayou is essential to provide adequate data for impact assessment. Specifically, impact and control stations should be established in the canal system surrounding the Clovelly Dome Terminal. This terminal was the site of recurring minor and moderate oil spills, but these could not be assessed because no nekton samples were collected from the area. If a large spill were to occur, no baseline data would be available for impact assessment. Consideration should also be given to adding two impact and four control stations in the middle and inshore zones where coverage is currently scant. Perhaps sampling could be restarted at Station 15_I as an impact station, with Station 14_C as its control, or Stations 1_C and 41_C could be paired with Station 38_I at the freshwater intake for the Clovelly Dome Terminal.

- **An additional control station is required in conjunction with the Offshore Oil Port, and one of the impact stations could probably be dropped.**

Only one control station (Station 52_C) exists for the three monitored Offshore Platform stations (Stations 53_I, 54_I, and 55_I). Because this control station is east of the pipeline, an additional station should be established west of the pipeline. The Gulf coastal waters have large-scale gradients related, in part, to the Mississippi River plume. A single control station cannot adequately account for these gradients, whereas two stations, straddling the pipeline, could. It is necessary to account for the influence of these gradients on nekton so that an observed difference between the control and impact stations will not wrongfully be attributed to LOOP activities. If necessary, station 55_I could be dropped, because of its proximity to Station 53I, and because it has the least complete data.

- **Assignment of control stations to impact stations for comparisons should be made a priori, if possible.**

Significant differences in environmental conditions between control and impact stations in all three zones were detected for depth, but these differences were probably due to the lack of an a priori selection of stations as control or impact for this analysis. Choosing stations based on environmental similarity after all the samples have been collected reduces the likelihood of finding a LOOP-related impact because we are restricted to trying to detect differences between the most similar stations. If the observed environmental similarity used to group stations was enhanced by LOOP, the species and community differences will be minimal. Association of control and impact stations should have been made a priori or at least based on pre-construction data analysis; however, the lack of adequate pre-construction sampling did not permit this designation method. This problem should be addressed in the establishment of future stations, but the a posteriori association has the effect of making our current identification of LOOP impacts more conservative in favor of LOOP.

- **Monitoring of the current environmental variables, species, and sizes, used in the nekton data analyses should continue.**

The list of environmental variables measured with nekton samples, including water temperature, salinity, dissolved oxygen, turbidity, depth, and chlorophyll a, should be continued, and not reduced, with continued monitoring. The identification of species should be continued and improved in the case of important species (i.e., anchovy species, roughneck shrimp species, and tonguefish species). During continued monitoring, the lengths (sizes) of individuals should continue to be measured at 1 mm intervals, as initiated in January 1992, and weights should continue to be measured in grams.

Sediment Quality Recommendations

The recommendations below are primarily designed to reduce the cost of monitoring while retaining the ability to assess the degree and areal extent of contamination should a major spill associated with LOOP activities occur.

- **Reduce sampling frequency for sediment quality monitoring to once a year**

PAHs degrade slowly in sediments, but they are relatively persistent and significant impacts due to a spill should be evident for many months to many years, depending on the magnitude of contamination. If a spill results in a measurable impact in terms of PAH levels that can be detected for only less than a year, it is likely not an ecologically significant impact. Of course, if a major spill occurs, then sampling should be done soon and more frequently than annually. But, for baseline monitoring where spills are not known to have occurred, annual measurements of sediment PAH levels should be sufficient.

- **Eliminate all on-shore stations intended to be controls if the Louisiana Oil Spill Coordinator's office completes an on-going three-year baseline monitoring study**

This study is measuring more than 65 different petroleum hydrocarbon compounds in marsh soils and sediments at approximately 1,000 coastal sites, and LOOP areas are well represented. The analytical protocol and quality control procedures are very exacting and the data being generated are supposed to be reviewed by an expert before they are accepted. If a LOOP related spill should occur, then at the same time impacted areas are being sampled, LOOP control sites (selected ones used in this project) should be sampled at the same time for comparison to the impact site data.

- **Add at least two more stations near the LOOP offshore terminal**

Currently, there is only one station very near the center of the ship unloading facility. Depending on wind and current direction at the time of a spill, the one station could easily miss an impact as spilled oil may move in a direction away from any single monitoring station.

- **Retain measurements for the usually measured 10 to 15 primary Polynuclear Aromatic Hydrocarbons, (Naphthalene, Acenaphthene, Fluorene, Phenanthrene, Anthracene, Fluoranthene, Pyrene, Benzanthracene, Chrysene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Benzo(a)pyrene, Indenopyrene, Dibenz(a,h)anthracene, Benzo(g,h)perylene, and Total Parent PAH Compounds), sand and clay content, organic matter content, bottom and pore water salinity, and sediment moisture content**

LOOP now has ten years of good data on the PAH compounds. The PAH compounds and the other parameters mentioned are the important parameters associated with an oil spill or likely important covariables, and will provide data that will help interpret sediment PAH levels.

- **Eliminate most other measurements not listed above unless they are needed for evaluating impacts on benthic organisms**

For the purpose of evaluating PAH data needed to determine the impact of an oil spill, most other measurements, including the alkylated PAH compounds, chloride, metals, chemical oxygen demand, Kjeldahl nitrogen, phosphorous, pH, and sulfide, are not essential.

- **Consider adding sampling for measuring the sedimentation rate near the offshore terminal and at stations along the pipeline**

There may be substantial sedimentation occurring in some of these areas which would be important should a spill occur in planning sampling depths for monitoring purposes and considering natural burial rates of petroleum hydrocarbons from a spill that becomes associated with the sediment surface.

- **Consider up to three separate subsamples for each station sampled where subsamples are collected something like 50 meters apart**

This change would allow evaluation of the within-sample variability, increasing the power of the statistical models to detect between-sample differences.

- **In future sampling in open waters and all other locations, use modern differential GPS instrumentation to more precisely locate sampling stations and to facilitate returning to the same sampling location**

  This should reduce variability associated with sampling.

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