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INTERIM REPORT:

RISK ASSESSMENT FOR PRODUCED WATER DISCHARGES TO LOUISIANA OPEN BAYS

Anne F. Meinhold, Michael P. DePhillips and Seymour Holtzman

Biomedical and Environmental Assessment Group
Analytical Sciences Division
Department of Applied Science
Brookhaven National Laboratory
Upton, New York

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Assistant Secretary for Fossil Energy
Dr. Brent Smith, Project Manager
Metairie Site Office
900 Commerce Road East
New Orleans, La 70123

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EXECUTIVE SUMMARY

Introduction

Potential human health and environmental impacts from discharge of produced water to the Gulf of Mexico concern regulators at the State and Federal levels, the public, environmental interest groups and industry. Current regulations require or propose a zero discharge limit for coastal facilities based primarily on studies performed in low energy, poorly flushed environments. However, produced water discharges in coastal Louisiana include a number of open bay sites, where the potential human health and environmental impacts are likely to be greater than the minimal impacts associated with offshore discharges, but smaller than those demonstrated for low energy canal environments.

Additional data and assessments are needed to support risk managers at the State and Federal levels in the development of regulations that protect human health and the environment without unnecessary cost to the economic welfare of the region and the Nation.

This report is part of a series of studies of the health and ecological risks from discharges of produced water to the Gulf of Mexico, supported by the United States Department of Energy (USDOE), Metairie Site Office. These assessments are being coordinated with a field study managed by USDOE titled "Environmental and Economic Assessment of Discharges from Gulf of Mexico Region Oil and Gas Operations" (USDOE Field Study).

This report is a preliminary, interim assessment of the human health and ecological risks associated with produced water discharges in open Louisiana bays. The initial human health and ecological risk assessments consist of conservative screening analyses meant to identify potentially important contaminants and ecological receptors and effects and exclude others from further consideration. A more realistic probabilistic risk assessment is presented for the human health effects of radium ingestion in fish. More detailed assessments are being completed for other contaminants. More comprehensive and realistic assessments will be completed in October, 1995.

Data used in the assessment are from two major sources:

- Data collected in the ongoing USDOE field study; and
- Data abstracted from the Louisiana Department of Environmental Quality permit files for open bay sites in Louisiana that plan to continue to discharge produced water until January, 1997.

Risk Assessment

Risk assessment can be defined as the process of estimating magnitudes and probabilities of potential adverse effects on human health or the environment. Risk management involves the political, economic and social decisions and actions taken to accept, mitigate, or control potential risks. Risk assessments provide risk managers with the scientific information needed to balance the degree of risk permitted against competing risks and the cost of risk reduction.

A human health risk assessment for an environmental pollutant describes the discharge of the contaminant, its transport and fate in the environment, and the resulting human exposure. Human-health risks are then calculated based on data and models that relate exposures to health effects.

The United States Environmental Protection Agency (USEPA) currently considers excess individual lifetime cancer mortality risks less than 1×10^{-4} (one in ten thousand) to 1×10^{-6} (one in one million) to be acceptable (Federal Register, 1991). No similar standard "acceptable risk" value is available for toxic effects -- estimated doses or intakes are usually compared to a chemical specific reference dose to determine if toxic effects are expected.

With some modifications and the addition of important uncertainties, the general paradigm developed for assessment of human health risks is now being applied to estimation of risks to the environment. The receptors or values of concern in an ecological risk assessment may range from individual organisms to entire ecosystems and fundamental ecological processes.

A tiered approach to human health and ecological risk assessment is logical and cost-effective. In a tiered approach to risk assessment, the initial analysis is a conservative (i.e. worst case) screening step, designed to screen out contaminants and pathways that are not of concern in terms of potential impacts to human health or ecological values.

If the risks estimated using conservative models and assumptions are small (i.e. individual lifetime fatal cancer risk less than 1×10^{-6} or no toxic effects predicted), no further analyses are needed. If a conservative analysis suggests that risks are high, a more detailed, comprehensive and realistic assessment is performed.

The state-of-the-science in risk assessment now uses a probabilistic approach that explicitly considers uncertainties and variability in assumptions, data and results. Probabilities of effects, and uncertainties are explicitly considered in both the analysis and the expression of its result.

Ecological risk assessments may be more qualitative than human health assessments because of the many sources of uncertainty in assessing risks to ecological values (USEPA, 1992).

Hazard Identification and Receptors

Many contaminants measured in produced water have known or suspected human health and or ecological effects at high exposures. Contaminants of special concern include toxic metals such as lead, mercury and cadmium; potentially toxic organic compounds such as phenol and PAHs, and known or suspected carcinogens such as benzene and radionuclides.

The ingestion of contaminated fish is expected to be the most important exposure route for people, because many of the contaminants found in produced water are known to accumulate in edible fish and shellfish. The important receptors for radium discharged in produced water are recreational fishermen and their families.

Potential ecological receptors for contaminants in produced water include recreationally and commercially important fish and shellfish species, benthic invertebrates living close to the platforms, and threatened and endangered species living in open Louisiana bays. Potentially important exposure pathways include direct exposure in water or sediment, and ingestion in food, water or sediment.

Risk Assessment Approach

The overall approach to the risk assessment was to use available data from the USDOE field study, as well as data and modeling analyses for continuing open bay discharges, in a screening assessment of human health and ecological risk. A probabilistic risk assessment was completed for the human health effects of radium.

Results of the screening analyses are described, the conservative nature of the assumptions and calculations reviewed, and the quantitative probabilistic assessments planned for important contaminants, receptors and exposure pathways discussed.

The data and modeling analyses that form the bases of the risk assessments presented here include:

- Data collected in the ongoing USDOE field study:

  -- PAH and metal concentrations in sediment near two open bay discharges;
  -- radium concentrations in edible biota near two open bay discharges;
  -- radionuclides in the effluent of two open bay discharges; and
  -- fish ingestion rates for recreational fishermen and their families.

- Data abstracted from LDEQ permit files for open bay sites in Louisiana that plan to continue to discharge produced water until January, 1997:

  -- location, depth and discharge rate data;
  -- data describing chemical concentrations in the effluents;
  -- data describing radionuclide concentrations in the effluents;
  -- modeling analysis to predict dilution with distance; and
  -- results of toxicity testing on effluents.

The state of Louisiana has identified a standard acute mixing zone of 50 feet, and a standard chronic and human health zone of 200 feet from produced water discharges. These distances imply a risk management decision about the "acceptable" location for environmental impacts. These distances were used in the current risk assessment.

USDOE Field Study Preliminary Data

<u>Background</u>

The risk assessments presented here are being done in parallel with a USDOE project titled " Environmental and Economic Assessment of Discharges from Gulf of Mexico Region Oil and Gas Operations" (referred to as the "USDOE Field Study").

Continental Shelf Associates, Inc. was contracted to conduct the field study. The study includes 4 technical tasks, two of which are relevant to the risk assessment presented here:

Task 4 - Monitoring of the Recovery of Impacted Wetland and Open Bay Produced Water Discharge Sites in Coastal Louisiana and Texas; and

Task 6 - Synthesis of Seafood Catch, Distribution and Consumption Patterns in the Gulf of Mexico Region.

Steimle & Associates, Inc. were subcontracted by CSA to perform the two tasks relevant to the risk assessments presented here (Tasks 4, 6). Preliminary results are available, and were used in the current analysis.

USDOE Open Bay Sites

The emphasis in the study of coastal sites is an assessment of the recovery of these sites from any impact from produced water discharges. Data were collected prior to the termination of discharge at three sites (including the two open bay sites discussed here), and several times after the discharge was terminated. The data used in the risk assessments were limited to those collected before termination of the discharges. The open bay study sites were located at Delacroix Island and Bay De Chene.

The Delacroix Island Oil and Gas Field is located approximately 5.5 miles southeast of Delacroix, Louisiana and has been in production since the first well was drilled in the field in 1940. The area is part of a subsiding delta, which results in broken marsh and numerous small water bodies with few large open bays. The tank battery studied was Tank Battery #1 and is located in approximately 1.5 meters of water and discharges approximately 2,000 bbl/day. The Delacroix Island site is not located in a completely open bay, but was used in the assessment presented in this report with the understanding that impacts at the site may over-estimate impacts from true open bay discharges.

The Bay De Chene Field is located approximately 13 miles west of north of Grand Isle, Louisiana and is part of the Barataria Basin. The field has been in constant production since the first well was drilled in 1942. The tank battery studied (Tank Battery #5) is located in Hackberry Bay, a large open bay typical of the Barataria system. The discharge is located in about 2.3 meters of water and discharges approximately 4,000 bbl/day.

Concentrations of ^{226}Ra, ^{228}Ra, ^{210}Pb, ^{210}Po and ^{228}Th were measured in discharges. Radium concentrations were measured in tissues of fish and shellfish collected using otter trawls, gill nets and crab traps at reference stations and the discharge station. Sediment PAH and metal concentrations were also available.

Benthos sampling, both pre- and post-termination was conducted at the study sites. Preliminary data are available for the Delacroix Island Field study site. The study found depressed numbers of species and individuals at the discharge sampling site during the pre-termination sampling (Mulino *et al.*, 1995). This suggests an impact on the benthos at a distance from the platform somewhere between 0 and 100 meters.

Fishermen Survey

Commercial fishermen (including oystermen) and recreational fishermen were surveyed by personal interview from May through November 1993 to determine categories of seafood fished over the previous three months, types of license(s) held, and information on the number, gender and ages of individuals in the household and their seafood consumption habits. Respondents were also interviewed about locations fished, the estimated distances from oilfield structures, and species caught (Steimle & Associates, Inc., 1995).

In this preliminary assessment, ingestion rates for recreational fishermen of fish caught near coastal platforms was derived from the reported data on meals per week. The data reported for meals per week had an arithmetic mean of 1.8, a standard deviation of 97.80, and a range of 0 to 15. The distribution of meals per week used in the calculation of ingestion rate (g/d) was a lognormal distribution with the mean, standard deviation and range of the reported data.

Characterization of continuing discharges

Louisiana Regulations (Title 33, March 20, 1991) required the termination of all produced water discharges to natural or man-made water bodies located in intermediate, brackish or saline marsh areas after January 1, 1995, unless the discharge (s) have been authorized in an approved schedule for elimination or effluent limitation compliance. A variance through January, 1997 was granted (12/16/94) for permitted discharges located in open waters and at least 1 mile from any shoreline in Chandeleur Sound, Breton Sound, Barataria Bay, Caminada Bay, Timbalier Bay, Terrebonne Bay, East Cote Blanche Bay, West Cote Blanche Bay or Vermillion Bay. The Louisiana Department of Environmental Quality (LDEQ) identified produced water discharges in open bay areas that may qualify for this variance.

Information critical to an assessment of the environmental impact from a produced water discharge includes the depth of the platform and the rate of discharge. Water depths ranged from 4 to 18 feet (mean: 9.1 feet); and discharge rates ranged from 1 to 37, 113 bbl/day (mean: 4,527 bbl/day).

Chemical contaminants and radionuclides measured in open bay produced water discharges were abstracted from LDEQ permit files. Data describing effluent toxicity tests were also abstracted from LDEQ permit files.

The USEPA surface water transport model CORMIX (Doneker and Jirka, 1990) was used to estimate the dilution expected 50 and 200 feet from open bay discharges. A depth of 8 feet (2.44 m) was chosen to represent the assumed continuing open bay discharges in Louisiana. A range of discharge rates was modeled to cover the range of discharge rates for the open bay sites.

These data were used to derive an empirical relationship between discharge rate and dilution factor:

50 feet: $DF = 338.1 * (DISCHARGE)^{-0.3405}$ (R=0.88)

200 feet: $DF = 7315.6 * (DISCHARGE)^{-0.6473}$ (R=0.95)

These empirical relationships were applied to the distribution of discharge rates for the open bay discharges to produce a distribution of dilution factors for 50 and 200 feet. The dilution factor distributions were also used to develop a distribution of percent effluent expected in the water column at 50 and 200 feet.

Human Health Risk Assessment for Radium

Screening and probabilistic human health risk assessments were done for open bay radium discharges in Louisiana.

The two data sets used were:

- measured concentrations of ^{226}Ra, and ^{228}Ra in finfish and crustaceans caught near the discharge at the USDOE study sites; and
- measured concentrations of ^{226}Ra and ^{228}Ra in 47 open bay discharges combined with modeled dilution factors at 200 feet and radium bioaccumulation factors.

A screening assessment was performed using worst-case estimates of concentrations in fish, ingestion rates and dose-response factors to determine the need for a more quantitative analysis

In the conservative screening analysis, estimated risks for the ingestion of radium in fishes exceeded 1×10^{-6} in all cases. The estimated cancer risks for fish sampled at reference stations at Delacroix Island and Bay De Chene were similar to those for ingestion of fish caught near the discharges.

Predicted screening-level risks were greater than 1×10^{-3} for the modeled continuing discharges. These results are from a conservative, screening level assessment, and do not represent best estimates of risk associated with radium discharged by open bay platforms. They do, however, suggest the need for a more detailed, probabilistic assessment.

A probabilistic risk assessment was done using distributions of: radium concentrations in fish (from field sampling and modeling); fish ingestion rates (from USDOE fishermen survey); and risk factors.

Median individual lifetime fatal cancer risks for both USDOE study sites (Delacroix Island and Bay De Chene) were less than 1×10^{-6}, and median and 95th percentile risks were less than 1×10^{-5}. Median individual lifetime fatal cancer risks for continuing open bay discharges were 2.2×10^{-7}, and 95th percentile risks were 1.9×10^{-5}.

These results suggest that the ingestion of radium in fish near open bay produced water platforms does not present an important risk to human health.

Ecological Risk Assessment for Radionuclides

This assessment used concentrations of radionuclides measured in the effluent at the two USDOE study sites, and radium concentrations reported in permit files for continuing open bay discharges, to assess potential ecological effects from radionuclides discharged in produced water. Worst-case water concentrations were predicted using a dilution factor derived from modeling analyses. Predicted water concentrations were compared to screening dose-rate factors developed by IAEA (1988) that relate the radiation exposure to an organism to a unit concentration of the radionuclide in the water in which the organism lives. Estimated doses were compared to reference dose rates suggested by the National Council on Radiation Protection (NCRP, 1991).

No estimated doses exceeded the NCRP reference limit of 10 mSv/day. Several estimated doses exceeded the NCRP suggested screening level for detailed assessment (2.4 mSv/d).

Based on a simple conservative screening analysis, no doses to aquatic animals were predicted above the NCRP reference level of 10 mSv/d. Because of the conservative nature of this initial analysis, it can be concluded that no effects on aquatic animals from radionuclides discharged in produced water to open bays in Louisiana are expected. Additional quantitative assessments could be performed to assess the extent to which the NCRP screening level of 2.4 mSv/d are likely to be exceeded.

Human Health Risk Assessment for Chemical Contaminants

A screening human health risk assessment was done for metals and organic compounds measured in continuing open bay discharges. This analysis followed the USEPA approach to estimating risks from toxic materials and carcinogens by applying RFD (reference dose) and slope factor values to estimates of chemical intake rates (USEPA, 1989). Predicted water concentrations were also compared to USEPA and Louisiana human health water quality criteria.

Contaminants eliminated from further consideration were arsenic, chromium, copper, silver, naphthalene, toluene and xylenes. Contaminants of potential concern identified in this screening step included benzene, antimony, cadmium, lead, mercury, nickel, zinc and phenol. These contaminants will be analyzed in a more quantitative assessment. Because of the conservative nature of this screening analysis, no important effect on human health can be assumed. The analysis serves to eliminate contaminants that do not warrant further time and attention.

Major uncertainties and conservative assumptions in this screening assessment included:

1. use of worst-case water concentrations;
2. use of average chemical concentrations that excluded zero values;
3. use of conservative ingestion rates and exposure periods;
4. use of generic bioaccumulation factors; and
5. use of uncertain reference doses that include large safety factors or are not verified by USEPA (lead, mercury, antimony, nickel).

Hazard quotients for antimony, cadmium, nickel and zinc and water quality ratios for mercury, nickel and naphthalene exceeded one by less than an order of magnitude. The cancer risk estimate for benzene slightly exceeded 1×10^{-4}. Phenol exceeded the Louisiana water quality criteria only for the maximum effluent concentration. A more realistic and quantitative assessment using predicted dilutions for the entire range of discharges and effluent concentration distributions is expected to predict few exceedances. This analysis is being done.

Contaminants that exceeded hazard quotients by more than an order of magnitude were lead and mercury. These contaminants are being assessed in a quantitative, probabilistic risk assessment that includes best estimates of distributions for: dilution factors, effluent concentrations, bioaccumulation factors, ingestion rates, and dose-response relationships. Other contaminants that exceed hazard quotients or water quality ratios of one after a more quantitative assessment using dilution factor and effluent concentrations distributions will also be assessed using this more quantitative approach.

The major uncertainties and conservatisms in the screening assessment will be addressed in the analysis:

1. dilution factor distributions, rather than a single conservative value will be used;
2. chemical concentration distributions in the effluent will reflect values reported below the detection limit;
3. intake rate distributions derived from the field survey conducted in the USDOE field survey will replace the conservative assumption used in the screening analysis;
4. the conservative lifetime exposure period used in the screening analysis will be replaced by a more reasonable distribution of exposure periods;

5. literature on bioaccumulation of these contaminants will be reviewed and values relevant to fish living in the Gulf of Mexico derived; and
6. more up-to-date dose-response relationships will be used in the assessment.

Ecological Risk Assessment for Chemical Contaminants and Effluent

Three screening assessments were performed:

1. Screening assessment of sediment toxicity.

Sediment metal and PAH concentrations measured at the USDOE study sites were compared to proposed sediment quality criteria (ERM: Effects Range Median; ERL: Effects Range Low].

None of the measured concentrations of metals in sediment samples exceeded their respective ERM values. In general, measured sediment concentrations were below the ERL (minimal effects range), with the exception of arsenic and nickel. Each of these metals exceeded its ERL value in samples from at least one reference site, and each discharge site. There was no clear pattern of concentration with distance from a discharge.

With the exception of acenaphthene, individual and total PAH concentrations exceeded ERL criteria at, and 100 ft from the discharge site. Acenaphthene concentrations exceeded the ERL values at the discharge, 100, 300 and 500 ft sample sites. Neither individual nor total PAH concentrations in sediment samples from Delacroix Island exceeded ERM criteria.

Individual and total PAH concentrations exceeded ERL criteria at the discharge site, and 100 ft and 300 ft from the discharge). For Bay de Chene, individual and total PAH concentrations in samples from the discharge site exceeded ERM criteria.

Depressed numbers of individuals and numbers of species were found only at the discharge stations in preliminary results of the benthos sampling performed at the two platforms (Mulino et al., 1995). For Bay de Chene, the comparisons of PAH concentrations to ERM criteria were consistent with the results of benthos observations. Further work will be done to analyze the relationships of PAH concentrations to distance and depth, and to search for relationships to the benthos sampling results at the two stations.

These results are preliminary, and cannot be applied to all other open bay discharge sites with much confidence, but the discharge rates and depths of the Bay De Chene and Delacroix Island study sites are comparable (discharge rates are on high end of distribution) to those that are continuing to discharge.

2. Screening assessment of potential toxicity of individual contaminants in the water column.

Worst-case predicted water column concentrations of contaminants measured in continuing open bay effluents (LDEQ permit files) were compared to USEPA and Louisiana water quality criteria.

Worst-case predicted water concentrations exceeded acute water quality standards for copper, lead, nickel, silver and zinc. Chronic water quality criteria were exceeded for antimony, cadmium, copper, lead, mercury, nickel, silver, zinc and phenol. Contaminants eliminated from further consideration included arsenic, chromium, benzene, naphthalene and toluene.

Because of the conservative nature of this screening analysis, no important effect on aquatic biota can be assumed. The analysis serves to eliminate contaminants that do not warrant further time and attention.

Major uncertainties and conservative assumptions in this screening assessment include:

1. use of worst-case water concentrations;
2. use of average chemical concentrations that exclude zero values; and
3. simple comparison to water quality criteria with no reference to specific receptors or end-points of concern in open Louisiana bays.

Water quality ratios of one were exceeded by less than an order of magnitude for cadmium, silver, zinc, and phenol. A more realistic and quantitative assessment using predicted dilutions for the entire range of discharges and effluent concentration distributions is expected to predict few exceedances for these contaminants. This analysis is being done.

Water quality ratios exceeded one by more than an order of magnitude for copper, lead, mercury, and nickel. These contaminants are being assessed in a quantitative risk assessment that includes best estimates of distributions for: dilution factors, effluent concentrations, and dose-response relationships. Other contaminants that exceed hazard quotients or water quality ratios of one after a more quantitative assessment using dilution factor and effluent concentrations distributions will also be assessed using this more quantitative approach.

The major uncertainties and conservatisms in the screening assessment will be addressed in the quantitative analysis:

1. dilution factor distributions, rather than a single conservative value will be used;
2. chemical concentration distributions in the effluent will reflect values reported below the detection limit;
3. literature on dose-response functions for these contaminants will be reviewed and values relevant to fish living in the Gulf of Mexico derived.

3. Screening assessment of effluent toxicity.

Predicted water column concentrations of effluent were compared to results of acute and chronic toxicity test performed in the laboratory with standard test organisms.

These results suggest a potential for toxic effects for some discharges at 50 feet (acute) and at 200 feet (chronic). A more quantitative assessment will be performed to estimate the number of discharges where toxicity is expected for fish and crustaceans important in the Gulf of Mexico.

This quantitative assessment will:

1. Use distributions of percent effluent at 50 and 200 feet rather than maximum or average values;
2. Use statistical methods to estimate toxic effects in species important in the Gulf of Mexico from measured effects in *Mysidposis bahia* and *Cyprinodon variegatus;* and
3. Quantify risk by the degree of overlap between the distribution of percent effluent and the derived effect distributions for important ecological receptors.

Conclusions

The tiered approach to risk assessment is a cost-effective way to provide risk managers with information needed to make risk management decisions. This screening assessment for human health and ecological risks from open bay produced water discharges in Louisiana eliminated a number of contaminants from further consideration. More quantitative assessments are being performed on contaminants of potential concern.

Human health risks from radium in produced water appear to be small. Ecological risks from radium and other radionuclides in produced water also appear to be small.

Many of the chemical contaminants discharged to open Louisiana bays appear to present little human health or ecological risk and will not be analyzed further.

A conservative screening analysis suggested potential risks to human health from mercury and lead. Conservative screening analyses suggested a potential for risks to ecological receptors from total effluent, antimony, cadmium, copper, lead, nickel, silver, zinc and phenol in the water column and PAHs in sediment.

Quantitative risk assessments are being done for these contaminants.

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CONTENTS

Figures

Tables

ACRONYMS

BEAG	Biomedical and Environmental Assessment Group
BEDS	Biological Effects Database
BNL	Brookhaven National Laboratory
CORMIX	Cornell Mixing Zone Expert System Model
CSA	Continental Shelf Associates, Inc.
ERL	Effects Range Low
ERM	Effects Range Median
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IRIS	Integrated Risk Information System
LDEQ	Louisiana Department of Environmental Quality
LOAEL	Lowest Observed Adverse Effect Level
NCRP	National Council on Radiation Protection and Measurements
NOEL	No Observed Effects Level
NORM	Naturally Occurring Radioactive Material
PAH	Polycyclic Aromatic Hydrocarbon
RfD	Reference Dose
SEP	Sediment Equilibrium Partitioning
UF	Uncertainty Factor
USDOE	United States Department of Energy
USEPA	United States Environmental Protection Agency

1 INTRODUCTION

1.1 Problem

Produced water discharged to coastal waters in Louisiana can contain a number of contaminants, including oil and grease, organic compounds, metals and radionuclides. Many of these contaminants are toxic to marine organisms at high concentrations. Most contaminants discharged in produced water occur naturally in the geologic reservoir along with the oil and gas. Biocides or other chemicals that may be toxic to aquatic organisms are added to some effluents.

Potential human health and environmental impacts from discharge of produced water to the Gulf of Mexico concern regulators at the State and Federal levels, the public, environmental interest groups and industry. This area supports economically important commercial and recreational fisheries, unique, socially-valued ecosystems, and several endangered and threatened species.

In offshore and other high energy environments, produced water is diluted so rapidly that contaminants cannot be detected in the water column or sediment even a few meters from the outfall. Effects on marine life are likely to be minimal. In shallower, low energy coastal canal environments, contaminants were detected in water, sediment and organisms several hundred meters from the discharge. Effects on benthic organisms in shallow coastal settings and on organisms in the biofouling mat close to discharge points have been documented (Boesch and Rabalais, 1989a; Gallaway et al., 1981).

Current regulations require or propose a zero discharge limit for coastal facilities based primarily on studies performed in low energy, poorly flushed environments. However, produced water discharges in coastal Louisiana include a number of open bay sites, where the potential human health and environmental impacts are likely to be greater than the minimal impacts associated with offshore discharges, but smaller than those demonstrated for low energy canal environments.

Additional data and assessments are needed to support risk managers at the State and Federal levels in the development of regulations that protect human health and the environment without unnecessary cost to the economic welfare of the region and the Nation.

1.2 This Report

The United States Department of Energy (USDOE) has a program of research in the environmental aspects of oil and gas extraction. This program includes a project titled "Environmental and Economic Assessment of Discharges from Gulf of Mexico Region Oil and Gas Operations" (here called the USDOE field study). Part of this project involves a comprehensive sampling and analysis program for offshore and coastal platforms in the Gulf of Mexico. This sampling project will characterize the environmental impacts associated with the discharge of naturally occurring radioactive materials (NORM), metals and organics in produced water.

This report is part of a series of studies of the health and ecological risks from discharges of produced water to the Gulf of Mexico, supported by the United States Department of Energy (USDOE), Metairie Site Office. These assessments are being coordinated with the field study described above, using the collected data to perform human health and ecological risk assessments. These assessments will provide input to regulators in the development of guidelines and permits, and to industry in the development and application of appropriate discharge practices.

This report is a preliminary, interim assessment of the human health and ecological risks associated with produced water discharges in open Louisiana bays. The initial human health and ecological risk assessments consist of conservative screening analyses meant to identify potentially important contaminants and ecological receptors and effects and to eliminate others from further consideration. A more realistic probabilistic risk assessment is presented for the human health effects of radium ingestion. More comprehensive and realistic assessments will be completed in October, 1995.

Data used in the assessment are from two major sources:

- Data collected in the ongoing USDOE field study
  - -- contaminant concentrations in sediment at two coastal discharges
  - -- radionuclide concentrations in discharges and in edible biota at two coastal discharges
  - -- ingestion rates for recreational fishermen

- Data abstracted from the Louisiana Department of Environmental Quality permit files for open bay sites in Louisiana that plan to continue to discharge produced water until January, 1997
  - -- location, depth and discharge rate data
  - -- data describing chemical concentrations in the effluents
  - -- data describing radionuclide concentrations in the effluents
  - -- results of effluent toxicity testing

2 RISK ASSESSMENT OVERVIEW

2.1 Risk Assessment and Risk Management

Risk assessment can be defined as the process of estimating magnitudes and probabilities of potential adverse effects on human health or the environment. Risk management involves the political, economic and social decisions and actions taken to accept, mitigate, or control potential risks. Risk assessments provide risk managers with the scientific information needed to balance the degree of risk permitted against competing risks and the cost of risk reduction.

A risk assessment should be performed independently of risk management, but the needs and concerns of risk managers should be considered in the design of the risk assessment to ensure that the results are relevant, useable, and understandable to risk managers.

2.2 Human Health Risk Assessment

A health risk assessment for an environmental pollutant describes the discharge of the contaminant, its transport and fate in the environment, and the resulting human exposure. Human-health risks are then calculated based on data and models that relate exposures to health effects.

The most commonly used framework for human health risk assessment includes the following four phases (NRC, 1983):

- Hazard identification;
- Dose-response assessment;
- Exposure assessment; and
- Risk characterization.

Hazard identification involves the use of exposure and effects data from the laboratory and the field to determine whether the agent of concern can cause health effects and to identify what those effects are (NRC, 1983).

Dose-response assessment characterizes the relationship between administered dose and the incidence of an adverse effect. Dose-response information is usually derived from animal toxicology studies or from clinical studies or epidemiology studies of people exposed at high levels. Assumptions must be made about the comparability of the response in laboratory animals to that of humans. Statistical methods are usually necessary to extrapolate the dose-response function from high experimental doses to the generally much lower doses in the human population.

Exposure assessment estimates the magnitude, frequency and duration of exposure, and characterizes subgroups of the human populations subject to different levels of exposure. This phase includes estimating the source term, fate and transport of the contaminant(s) of concern, and subsequent human exposure.

Risk characterization integrates the results of the previous phases, estimates the incidence of an adverse human health effect under conditions defined in the exposure assessment, and describes the uncertainties in the data and assumptions. Human health risks are described as the probability of an adverse health effect (e.g., cancer death or toxic effect) in an individual of an exposed population (individual risk), or the number of health effects expected in the population (population risk) during a given time interval.

The United States Environmental Protection Agency (USEPA) currently considers excess individual lifetime cancer mortality risks less than 1×10^{-4} (one in ten thousand) to 1×10^{-6} (one in one million) to be acceptable (Federal Register, 1991). USEPA recently proposed standards for radionuclides in drinking water that the agency considers to be associated with an individual lifetime cancer fatality risk of 1×10^{-4} (Federal Register, 1991). No similar standard "acceptable risk" value is available for toxic effects -- estimated doses or intakes are usually compared to a chemical specific reference dose to determine if toxic effects are expected.

2.3 Ecological Risk Assessment

Early environmental decision-making was based on qualitative descriptions of effects of pollutant discharges on organisms and the environment, with some reliance on the assumption that protection of human health would ensure adequate protection of the environment. Current information and environmental regulations suggest a need for a risk-based approach to decision-making for environmental protection.

With some modifications and the addition of important uncertainties, the general paradigm developed for assessment of human health risks is now being applied to estimation of risks to the environment. The field is new and definitions are not standardized. For the purposes of this report, "environmental risk assessment" refers to an assessment of the risks to man from contaminants in the environment (air, water, soil or food). "Ecological risk assessment" refers to an assessment of risks to the natural environment (Suter, 1993). The receptors or values of concern in an ecological risk assessment may range from individual organisms to entire ecosystems and fundamental ecological processes.

Because of the number of different species in a community and the complexity of inter-species interactions and basic ecological processes, the level of organization for which the assessment is performed can vary widely (individual, population, community, ecosystem), and the potential endpoints for the assessment are many (death, acute or chronic toxicity, reproductive or developmental effects, disruption of basic processes). USEPA (1992) proposed a framework for ecological risk assessment that includes three phases:

- Problem formulation;
- Analysis (exposure and effects assessment); and
- Risk characterization.

The problem formulation phase identifies the factors to be considered in the assessment, and determines the scope and objectives of the analysis. This phase includes the preliminary data gathering and conceptual development needed to define the problem. Specific steps in the problem formulation phase include planning, identification of stressor characteristics, description of the ecosystem potentially at risk, identification of potential ecological effects, endpoint selection, and development of a conceptual model for the assessment.

In exposure assessment, environmental concentrations of the contaminant are described, and exposure of the organisms and ecosystems of concern are estimated. The exposure assessment estimates the transport of the contaminant through the environment, including its transformation and uptake by organisms.

In effects assessment, a dose-response relationship between exposure and effects is developed. An effects assessment determines the relationship between exposure to the contaminant and effects on the measurement endpoint. An effects assessment is usually based on extrapolating results of toxicity studies on standard individual test organisms to effects on individuals of other species, populations, communities and ecosystems.

Risk characterization integrates the estimates of exposure and dose-response relationships developed in the analysis phase to produce an estimate of the risk to the identified assessment endpoint.

2.4 Tiered Assessments

A tiered approach to human health and ecological risk assessment is logical and cost-effective. In a tiered approach to risk assessment, the initial analysis is a conservative (i.e. worst case) screening step, designed to screen out contaminants and pathways that are not of concern in terms of potential impacts to human health or ecological values.

If the risks estimated using conservative models and assumptions are small (i.e. individual lifetime fatal cancer risk less than 1×10^{-6} or no toxic effects predicted), no further analyses are needed. If a conservative analysis suggests that risks are high, a more detailed, comprehensive and realistic assessment is needed.

Ecological risk assessments may be more qualitative than human health assessments because of the many sources of uncertainty in assessing risks to ecological values (USEPA, 1992).

2.5 Probabilistic Analysis and Uncertainty

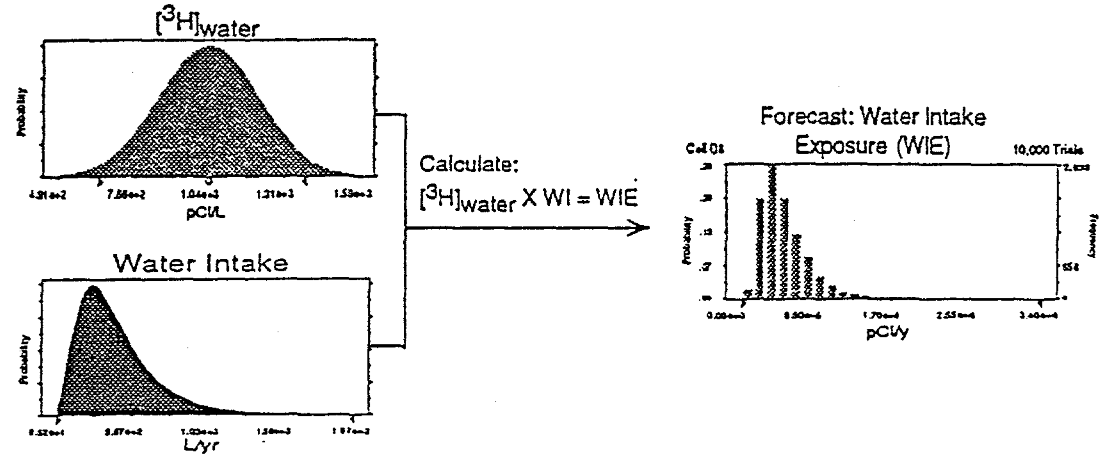
The current application of the National Research Council risk assessment paradigm (NRC, 1983) to estimation of human health and ecological risk requires explicit description of uncertainties in assumptions, models and parameters, and incorporation of these uncertainties in a final expression of risk. Until recently, the common practice in risk assessment was to use conservative assumptions in a "worst case" analysis rather than to estimate uncertainty. This approach: obscures recognition of the degree of conservatism and the uncertainties in risk estimates; allows for improbable scenarios and results; and ignores the potentially excessive costs of decisions made based on conservative assumptions (Burmaster *et al.*, 1990; Paustenbach *et al.*, 1991).

As discussed above (Section 2.4), a conservative, screening level assessment is an appropriate first step in an assessment. A more quantitative and realistic analysis can be performed when the potential risks (or costs of control) are high. The state-of-the-science in risk assessment now uses a probabilistic approach that explicitly considers uncertainties and variability in assumptions, data and results. Probabilities of effects, and uncertainties are explicitly considered in both the analysis and the expression of its result.

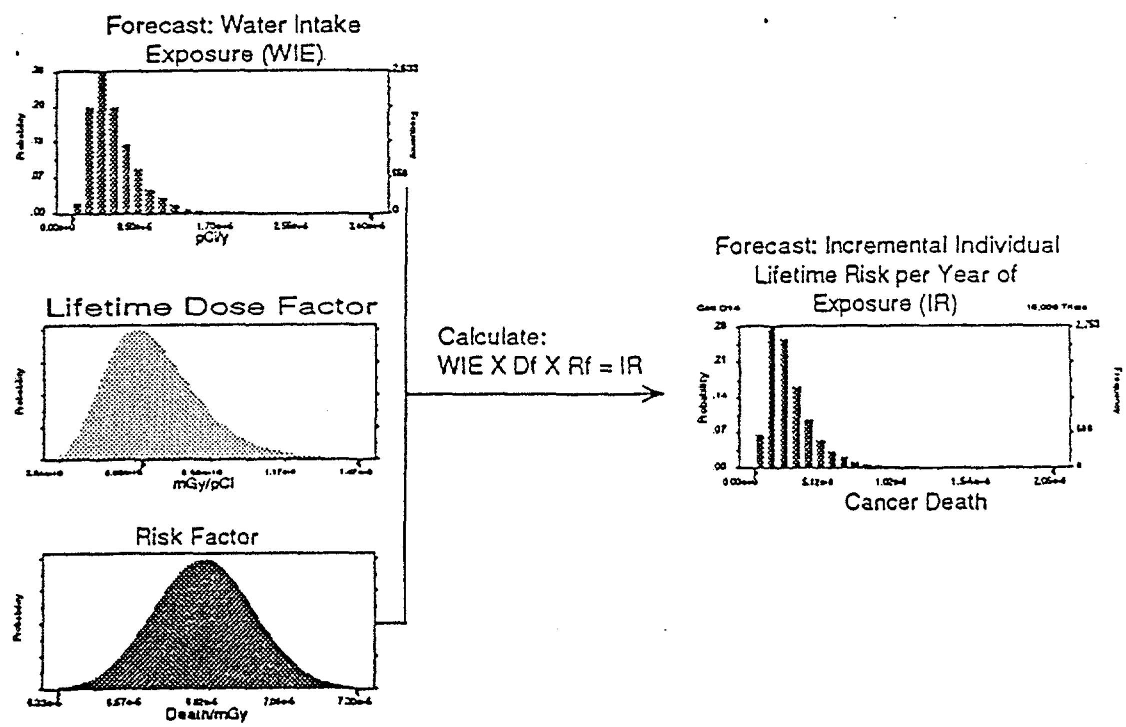
A commonly used tool in probabilistic, quantitative risk assessment is Monte Carlo analysis. In a Monte Carlo analysis, a sample from the distribution of an input parameter is placed into a simulation to interact in a model with samples from other input parameters. The frequency of sampling within an independent variable depends on the relative frequency of a value in the frequency distribution (Paustenbach *et al.*, 1991). Figure 2-1 demonstrates how variables described by distributions interact in a Monte Carlo analysis. The probabilistic analyses described in this report were produced with a Monte Carlo analysis.

Figure 2-1. Example Monte Carlo analysis: estimation of individual lifetime risk of cancer mortality from ingestion of tritium in drinking water.

Step 1. a). Develop an assumption about the distribution of tritium concentations in drinking water ($[^3H]_{water}$).
b). Develop an assumption about the distribution of drinking water intake (WI).
c). Calculate exposure to tritium in drinking water (WIE).



Step 2. *a). Develop an assumption about the dose factor for tritium ingestion (Df).*
b). Develop an assumption about the risk factor for tritium ingestion (Rf).
c). Calculate incremental individual lifetime risk for cancer mortality (IR).



3 RISK ASSESSMENT APPROACH

3.1 Background and Overall Approach

The risk assessment presented in this report is an interim, preliminary analysis. Screening-level assessments were performed to identify potentially important contaminants and ecological receptors, and to eliminate others from further consideration. Based on the results of this preliminary analysis, additional probabilistic risk assessments are being done for specific contaminants and ecological receptors. A probabilistic analysis was completed for radium ingestion by recreational fishermen and their families and is presented in this report.

Two sources of data were used in the risk assessments: data collected in the USDOE field study and data abstracted from LDEQ permit files. These data sets and associated modeling analyses were used to assess potential human health and ecological risks associated with continuing open bay discharges of produced water in Louisiana.

This section:

- presents the hazard identification step for the human health and ecological risk assessments;
- briefly describes the data and modeling analyses used in the risk assessments presented in this report (given in detail in section 4 and 5 and Appendices A and B); and
- outlines the approach used in the human health and ecological risk assessments (presented in sections 6 through 9).

3.2 Hazard Identification

Hazard identification involves the use of exposure and effects data from the laboratory and field to determine whether the agent of concern can cause health effects and to identify what those effects are (NRC, 1983). In the context of this report, hazard identification includes: identification of contaminants of potential concern in produced water, identification of important human receptors and exposure pathways, and a description of potentially important ecological effects and receptors.

3.2.1 Contaminants

Many contaminants measured in produced water have known or suspected human health and or ecological effects at high exposures. Contaminants of special concern include toxic metals such as lead, mercury and cadmium;

potentially toxic organic compounds such as phenol and PAHs, and known or suspected carcinogens such as benzene and radionuclides.

Radionuclides

Radionuclides known to occur in produced water above background surface water concentrations include ^{226}Ra, ^{228}Ra, and ^{210}Pb. Other decay products of radium (^{210}Po, ^{228}Th, ^{222}Ra) may also be expected in produced water.

The health effects of radionuclides can be attributed to their radioactive emissions. The alpha, beta and gamma radiation released by the decay of radionuclides cause ionization of cellular components which may result in the mutation or death of affected cells.

Current practice in radiation protection is to assume there is a cancer risk associated with even very small doses of radiation. Risk factors are derived from epidemiological data and extrapolated down to low doses to describe the cancer risk associated with small exposures. See Appendix C for a more detailed discussion.

Most of the available studies of the effects of radiation on aquatic organisms are concerned with the induction of deterministic, somatic effects. These effects include increases in mortality and pathophysiological, developmental and reproductive effects. There is little information available concerning induction of cancer and genetic effects, although a few studies of stochastic genetic effects in organisms are available (Anderson and Harrison, 1986).

The National Council on Radiation Protection and Measurements reviewed the literature on the effects of ionizing radiation on aquatic organisms, and suggested reference levels that would protect aquatic populations (NCRP, 1991). Potential effects on aquatic organisms and the NCRP reference levels are discussed in more detail in Appendix C.

Chemical Contaminants

USEPA has published cancer slope factors, reference doses or other estimates in the IRIS data base (Integrated Risk Information System) and water quality criteria for many of the contaminants commonly found in produced water. As a first level screen, chemical contaminants with published water quality criteria, slope factors and reference doses were included in the analysis. Published reference values suggest a potential concern for human health effects.

Most chemical contaminants discharged in produced water present a potential human health hazard because of toxicity associated with ingestion in fish and shellfish. A few of the chemical contaminants found in produced water are suspected or known human carcinogens including benzene and arsenic.

Effects on aquatic organisms may be associated with a number of contaminants found in produced water discharges. Water and sediment toxicity studies, and water quality criteria are available for a few contaminants suggesting reasonable concern for potential ecological effects. Toxicity testing of produced water effluents using standard laboratory test animals has shown a range of acute LC_{50}s and NOELs, again suggesting the potential for concern about effects to fish and shellfish species.

Effects on sediment communities have also been demonstrated (Armstrong *et al.*, 1977; Rabalais *et al.*, 1991), but the relationship between effects on number of species and individuals and chemical contaminants in sediments were site specific and not consistent across all studies. These studies suggest a potential for toxic effects to benthic communities living close to platforms.

3.2.2 Exposure Pathways and Receptors

The ingestion of contaminated fish is expected to be the most important exposure route for people, because many of the contaminants found in produced water are known to accumulate in fish and shellfish. The important receptors for radium discharged in produced water are recreational fishermen and their families. Recreational fishermen are important receptors because they may fish close to a platform, return often to the same fishing spot, and ingest a large percentage of fish caught near a platform. Mollusks and crustaceans are commercially important in the Gulf of Mexico, but most of the seafood caught near platforms by recreational fishermen are fish.

There may be some commercial fishing near coastal platforms but the amount of fish and shellfish impacted by contaminants discharged in produced water will be small because of the dilution with distance from a platform. Commercially caught fishes are marketed widely, making the prediction of an individual's consumption from a single source difficult (USEPA, 1990). Because the catch of sports fishermen is not diluted in this way, they represent the population most vulnerable to exposure by consumption of contaminated fishes from one location (USEPA, 1990). Some sports fishermen may sell or give away the fish they catch, but an analysis of their consumption and risk will result in a more conservative estimate of risk than an assessment of risk for the general public. Recreational fishermen may also include commercial fishermen who fish near offshore platforms and eat some of their catch.

Potential ecological receptors for contaminants in produced water include recreationally and commercially important fish and shellfish species, benthic invertebrates living close to the platforms, and threatened and endangered species living in open Louisiana bays. Potentially important exposure pathways include direct exposure in water or sediment, and ingestion in food, water or sediment.

3.3 Risk Assessment Approach

The overall approach to the risk assessment was to use available data from the USDOE field study, as well as data and modeling analyses for continuing open bay discharges, in a screening assessment of human health and ecological risk. A probabilistic risk assessment was completed for the human health effects of radium.

Results of the screening analyses are described, the conservative nature of the assumptions and calculations reviewed, and the quantitative probabilistic assessments planned for important contaminants, receptors and exposure pathways discussed.

Data and Modeling Analyses

The data and modeling analyses that form the bases of the screening and probabilistic risk assessments presented here include:

- Data collected in the ongoing USDOE field study:

  -- PAH and metal concentrations in sediment near two open bay discharges;
  -- radium concentrations in edible biota near two open bay discharges;
  -- radionuclides in the effluent of two open bay discharges; and
  -- fish ingestion rates for recreational fishermen and their families.

- Data abstracted from LDEQ permit files for open bay sites in Louisiana that plan to continue to discharge produced water until January, 1997:

  -- location, depth and discharge rate data;
  -- data describing chemical concentrations in the effluents;
  -- data describing radionuclide concentrations in the effluents;
  -- modeling analysis to predict dilution with distance; and
  -- results of toxicity testing on effluents

Data and modeling analysis that form the basis of the risk assessments are described in detail in sections 4 and 5. Section 4 describes the USDOE field study. Preliminary results of sampling conducted at the two coastal sites in Louisiana are summarized. The results of the survey of recreational fishermen in Louisiana are described and a distribution for fish ingestion rates derived. These data were used in the risk assessments presented in sections 6 through 9.

Section 5 summarizes the data abstracted from the LDEQ permit files for assumed continuing open bay discharges in Louisiana. Discharge rates and platform depths are summarized. Available chemical and radionuclide effluent data are described. Data summarizing acute and chronic toxicity studies are also presented. A surface water transport model was used to estimate dilution factors at 50 and 200 feet from the discharges, and this modeling analysis is presented. These data and modeling results were used in the risk assessments given in sections 6 through 9.

Human Health and Ecological Risk Assessments

Human health and ecological risk assessments are presented separately. Risk assessments for radium and other radionuclides in produced water are presented separately from assessments for chemical contaminants.

The state of Louisiana has identified a standard acute mixing zone of 50 feet, and a standard chronic and human health zone of 200 feet from produced water discharges. These distances imply a risk management decision about the "acceptable" location for environmental impacts. These distances were used in the current risk assessment.

<u>Human Health Risk Assessment for Radium</u>

Screening and probabilistic human health risk assessments were done for open bay radium discharges in Louisiana.

The two data sets used were:

- measured concentrations of ^{226}Ra, and ^{228}Ra in finfish and crustaceans caught near the discharge at the USDOE study sites; and
- measured concentrations of ^{226}Ra and ^{228}Ra in 47 open bay discharges combined with modeled dilution factors at 200 feet and radium bioaccumulation factors.

A screening assessment was performed using worst-case estimates of concentrations in fish, ingestion rates and dose-response factors to determine the need for a more quantitative analysis. Based on the results of this analysis, a probabilistic risk assessment was done using distributions of: radium concentrations in fish based (from field sampling and modeling); fish ingestion rates (from USDOE fishermen survey); and risk factors (Meinhold et al., 1995).

Ecological Risk Assessment for Radionuclides

This assessment used concentrations of radionuclides measured in the effluent at the two USDOE study sites, and radium concentrations reported in permit files for continuing open bay discharges. Worst-case water concentrations were predicted using a dilution factor derived from the modeling analyses presented in section 5. Predicted water concentrations were compared to screening dose-rate factors developed by IAEA (1988) . These dose-rate factors relate the radiation exposure to an organism to a unit concentration of the radionuclide in the water in which the organism lives. Estimated doses were compared to reference dose rates suggested by the National Council on Radiation Protection (NCRP, 1991).

Human Health Risk Assessment for Chemical Contaminants

A screening human health risk assessment was done for metals and organic compounds measured in continuing open bay discharges. This analysis followed the USEPA approach to estimating risks from toxic materials and carcinogens by applying RfD (reference dose) and slope factor values to estimates of chemical intake rates (USEPA, 1989a). Predicted water concentrations were also compared to USEPA and Louisiana human health water quality criteria.

Ecological Risk Assessment for Chemical Contaminants and Effluent

Three screening assessments were performed:

1. Screening assessment of sediment toxicity.

Sediment metal and PAH concentrations measured at the USDOE study sites were compared to proposed sediment quality criteria.

2. Screening assessment of potential toxicity of individual contaminants in the water column.

Worst-case predicted water column concentrations of contaminants measured in continuing open bay effluents (LDEQ permit files) were compared to USEPA and Louisiana water quality criteria.

3. Screening assessment of effluent toxicity.

Predicted water column concentrations of effluent were compared to results of acute and chronic toxicity test performed in the laboratory with standard test organisms.

Section 6 presents the screening and probabilistic risk assessments for the human health effects of radium. Section 7 gives the screening assessment for ecological effects of radium and other radionuclides. Section 8 is the screening risk assessment for the human health effects from metals and organic contaminants. The screening risk assessment for the ecological effects of individual produced water contaminants and effects associated with the total effluent is presented in section 9.

4 USDOE FIELD STUDY PRELIMINARY DATA

4.1 Background

This report is part of a series of studies of the human health and ecological risks from discharges of produced water to the Gulf of Mexico, supported by USDOE, Metairie Site Office. These risk assessments are being done in parallel with a USDOE project titled " Environmental and Economic Assessment of Discharges from Gulf of Mexico Region Oil and Gas Operations" (referred to as the "USDOE Field Study").

Continental Shelf Associates, Inc. (CSA) was contracted to conduct the field study. The objective of the project is to increase the base of scientific knowledge concerning the following topics:

- The fate and environmental effects of contaminants found in produced water;
- The economic impacts of proposed regulations on offshore oil and gas producers of the Gulf of Mexico region; and
- The catch, consumption, and human use patterns of seafood species collected from coastal and offshore waters of the Gulf of Mexico.

The study includes 4 technical tasks, two of which are relevant to the risk assessment presented here:

Task 4 - Monitoring of the Recovery of Impacted Wetland and Open Bay Produced Water Discharge Sites in Coastal Louisiana and Texas; and

Task 6 - Synthesis of Seafood Catch, Distribution and Consumption Patterns in the Gulf of Mexico Region.

Steimle & Associates, Inc. were subcontracted by CSA to perform the two tasks relevant to the risk assessments presented here (Tasks 4, 6). Preliminary results from Tasks 4 and 6 are available, and were used in the current analysis. The following sections summarize the preliminary data available from the Task 4 and Task 6 work, and derive or summarize the data used in subsequent sections of the report.

4.2 Task 4 -- Open Bay Sites

The data and descriptions of the study sites were abstracted from material provided by Steimle & Associates, Inc. The emphasis in the study of coastal sites is an assessment of the recovery of these sites from any impact from produced water discharges. Data were collected prior to the termination of discharge at three sites (including the two open bay sites discussed here), and several times after the discharge was terminated. The preliminary data presented in this section are limited to those collected before termination of the discharges.

4.2.1 Site Descriptions

Delacroix Island

The Delacroix Island Oil and Gas Field is located approximately 5.5 miles southeast of Delacroix, Louisiana and has been in production since the first well was drilled in the field in 1940. The area is part of a subsiding delta, which results in broken marsh and numerous small water bodies with few large open bays. The tank battery studied was Tank Battery #1 and is located in approximately 1.5 meters of water. The Delacroix Island site is not located in a completely open bay, but will be used in the assessment presented in this report with the understanding that the impacts from the site may over-estimate impacts from true open bay discharges.

Salinities in the Delacroix Field vary widely between seasons and years, with late summer/fall salinities being the most stable. Spring salinities are the lowest experienced during the year due to the influence of the Mississippi River. The influence of the Mississippi River is particularly noticeable in this area because of the proximity of the Caernarvon Diversion.

The bottom substrate in areas of subsiding marsh like the Delacroix Island area varies from soft, fine grained sediments in open water to old root mat which is firmer and may persist for many years.

The Delacroix Island area is typical of many brackish habitats in Louisiana inshore waters in that its inhabitants are eurytolerant opportunistic species. Commercially important species in this area include the American Oyster (*Crassostrea virginica*), the blue crab (*Callinectes sapidus*), brown shrimp (*Penaeus aztecus*) and white shrimp (*Penaeus setiferus).*

The area around the Delacroix Field is marginal for oysters, although during some years oyster crops can be successful. Crabs are harvested extensively year round. Commercial and recreational shrimping is conducted in this area. Recreational and commercial finfishing is also popular. Red drum or redfish (*Sciaenops ocellatus)* and speckled trout (*Cynoscion nebulosus*) are the most prized species in inshore areas. Both of these species are most available in the late fall and winter months. Flounder (*Paralicthys lethostigma*) are most abundant in the fall months and croaker (*Micropogonias undulatus*), spot (*Leiostomus xanthurus*), sand seatrout (*Cynoscion arenarius),* black drum

(*Pogonias cromis*) and sheepshead (*Archosargus probatocephalus*) are fished inshore year round.

Bay De Chene

The Bay De Chene Field is located approximately 13 miles west of north of Grand Isle, Louisiana and is part of the Barataria Basin. The field has been in constant production since the first well was drilled in 1942. The tank battery studied (Tank Battery #5) is located in Hackberry Bay, a large open bay typical of the Barataria system. The discharge is located in about 2.3 meters of water.

Salinities in the Bay De Chene Field vary during the year with the lowest salinities occurring when the Mississippi influences the area. The bottom substrate in most open water areas is soft fine grain sediments. Portions of the bay have been altered by the planting of Rangia shell by the Louisiana Wildlife and Fisheries for oyster cultch. One of these planted areas on the west side of the bay was chosen as a reference site because no drilling was allowed on shell plants.

The Bay De Chene habitat is mesohaline (5 to 18 ppt) most of the year, and the organisms that characterize this habitat are euryhaline and opportunistic.

Commercially harvested species are identical to those harvested at Delacroix. The American Oyster (*Crassostrea virginica*) is cultivated on numerous leases in the area. Blue crab (*Callinectes sapidus*) are harvested year round. Brown (Penaeus aztecus) and white (*Penaeus setiferus*) shrimp are harvested commercially and recreationally.

Recreational and commercial finfishing are also conducted in this area. Red drum or redfish (*Sciaenops ocellatus*) and speckled trout (*Cynoscion nebulosus*) are the most prized species in inshore areas. Both of these species are most available in the late fall and winter months. Flounder (*Paralicthys lethostigma*) are most abundant in the fall months and croaker (*Micropogonias undulatus*), spot (*Leiostomus xanthurus*), sand seatrout (*Cynoscion arenarius*), black drum (*Pogonias cromis*) and sheepshead (*Archosargus probatocephalus)* are fished inshore year round.

4.2.2 Discharge and Sampling Information

Delacroix Island Tank Battery #1

Discharge rates available in LDEQ files (Discharge Monitoring Reports) for 1990-1992 average 1,741 BPD for this discharge. At the time of termination (April 1993) the volume of produced water fluctuated between 1,964 and 1,978 BPD for the period 26 March to 19 April 1993 when there were 11 wells in production. Discharge volumes from 19 to 25 March ranged from 2,246 to 2,256 BPD with 12 wells in production.

Sampling at the Delacroix Island study site was conducted according to the station layout shown in Figure 4-1. Tissues were collected using otter trawls, gill nets and crab traps at the two reference stations (R1 and R2) and the discharge station. Only species of commercial or recreational importance were retained. Tissues were placed on ice and frozen within 12 hours of collection.

Bay De Chene Tank Battery #5

Data in the LDEQ data base from a one time sampling record a volume of 3,666 BPD. The discharge terminated on 15 October 1993. At the time of the pre-termination survey, data provided by Texaco indicated that the discharge was for four wells with a discharge volume of 3,825 BPD.

Sampling at the Bay De Chene study site was conducted according to the station layout in Figure 4-2. Tissues were collected using otter trawls, gill nets and crab traps at the two reference stations and the discharge station. Only species of commercial or recreational importance were retained. Tissues were placed on ice and frozen within 12 hours of collection.

4.2.3 Radionuclides in Water and Biota

Average concentrations of radionuclides in the discharges are given in Table 4-1. Preliminary results of tissue analyses for ^{226}Ra and ^{228}Ra are given in Appendix A. Maximum concentrations of ^{226}Ra and ^{228}Ra measured in croaker, spot, sea trout, blue crab and shrimp at the discharge and highest of the reference stations for each site are given in Table 4-2.

Table 4-1. Concentrations of radionuclides measured in discharge at Delacroix Island and Bay De Chene.

Radionuclide	Delacroix Island (pCi/l)	Bay De Chene (pCi/l)
^{210}Pb	78.0	60.3
^{210}Po	<1.1	<2.0
^{226}Ra	218.5	162.5
^{228}Ra	264.5	317.5
^{228}Th	154.5	15.0

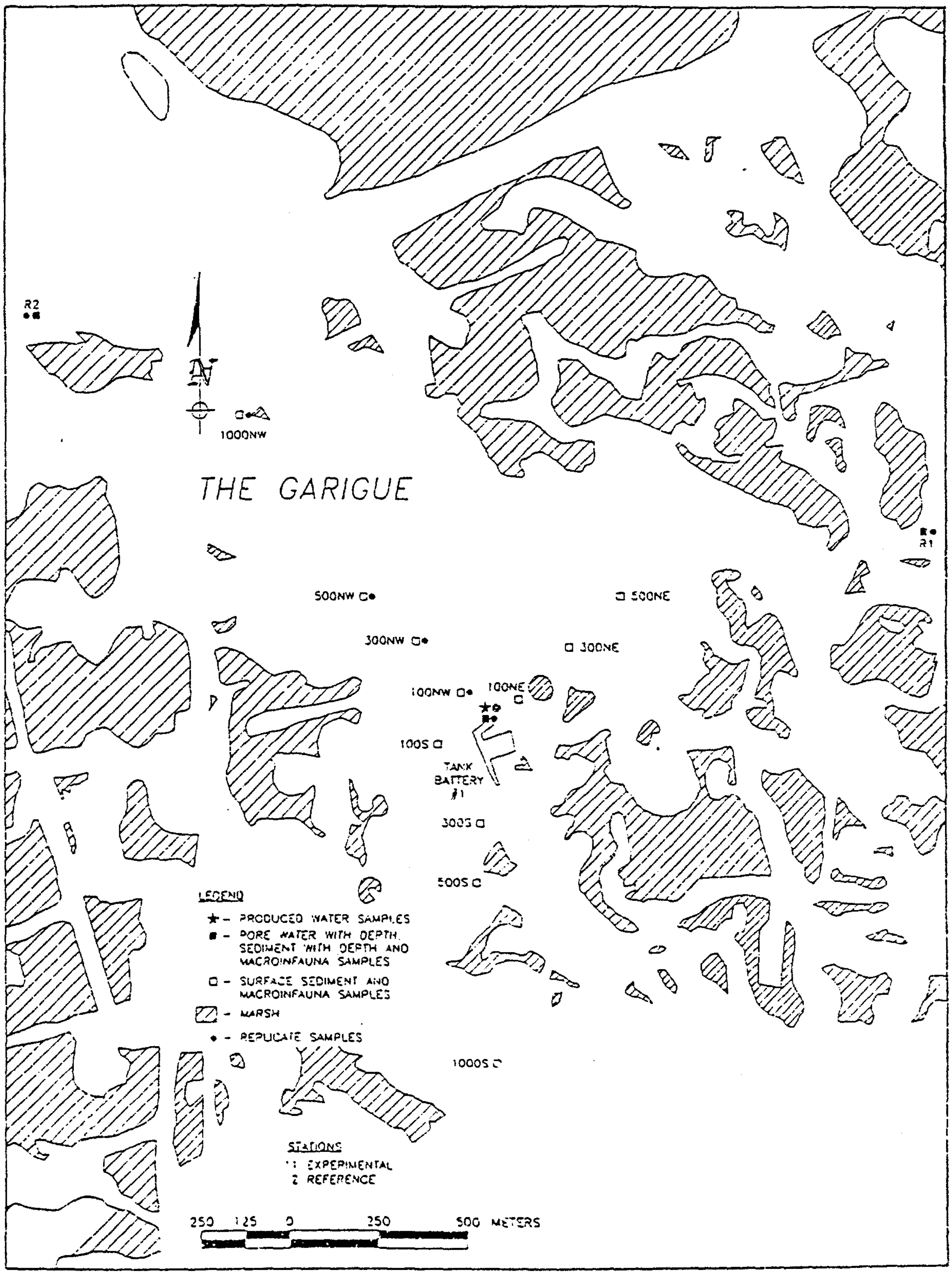


Figure 4-1. Delacroix Oil and Gas Field Tank Battery #1 sampling locations.

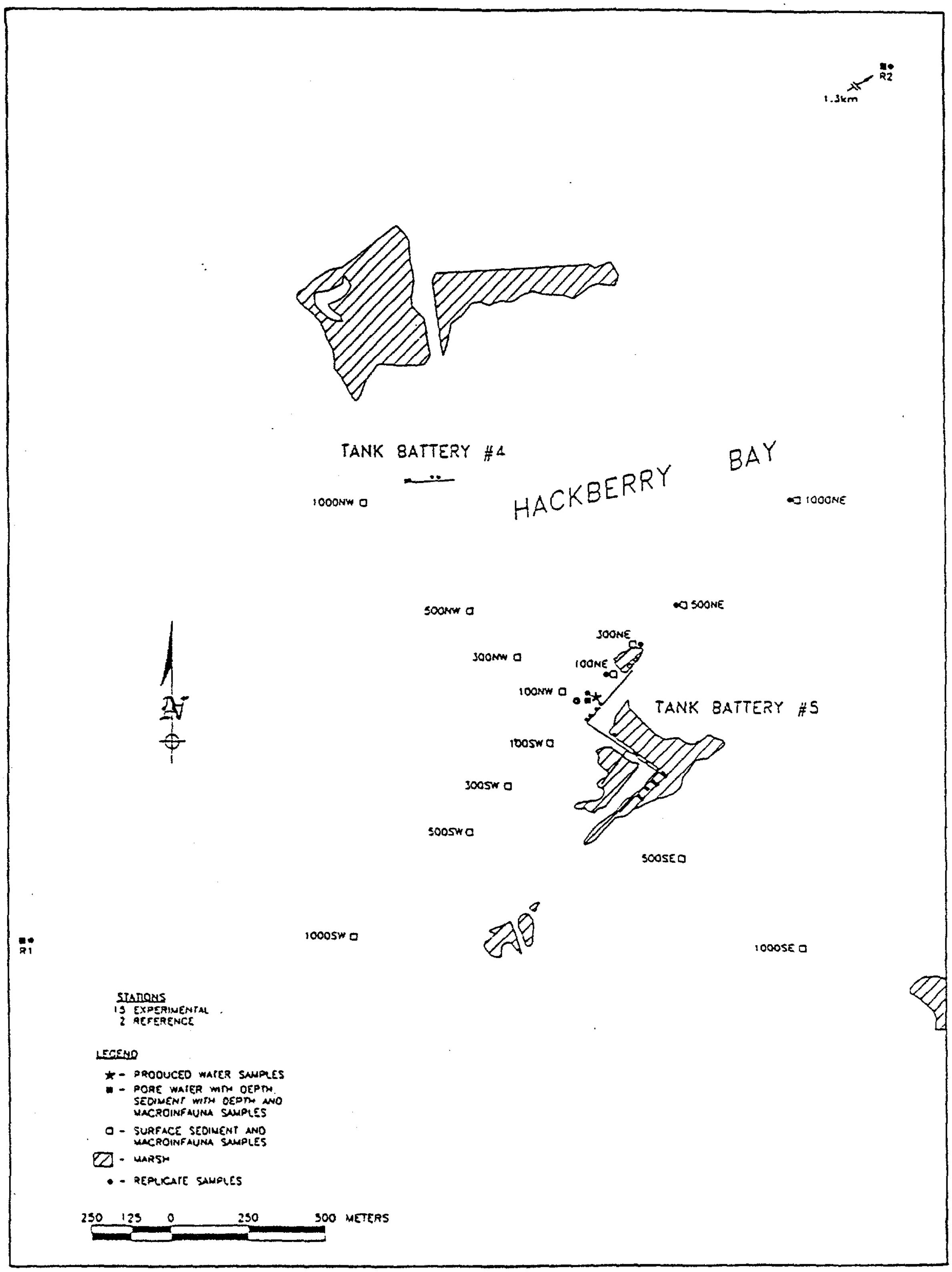


Figure 4-2. Bay De Chene Field Tank Battery #5 sampling locations.

Table 4-2. Maximum radium concentrations in biota measured at Delacroix Island (Spring, 1993) and Bay De Chene study sites (pCi/g).

	Delacroix Island				Bay De Chene			
	Discharge		Reference		Discharge		Reference	
	^{226}Ra	^{228}Ra	^{226}Ra	^{228}Ra	^{226}Ra	^{228}Ra	^{226}Ra	^{228}Ra
croaker	0.005	0.112	0.063	0.021	0.024	0.094	0.032	0.05
spot	0.002	0.076	0.002	0.107	0.034	0.086	0.029	0.01
sea trout	NS	NS	NS	NS	0.021	0.159	0.016	0.042
blue crab	0.025	0.09	0.012	0.046	0.023	0.059	0.024	0.01
shrimp	NS	NS	NS	NS	0.011	0.01	0.027	0.124

NS = no sample

4.2.4 Chemicals in Sediment

Preliminary results of the chemical analysis (PAHs and metals) in sediments are given in Appendix A.

4.2.5 Benthos Sampling

Benthos sampling, both pre- and post-termination was conducted at the study sites. Preliminary data are available for the Delacroix Island Field study site. The study found depressed numbers of species and individuals at the discharge sampling site during the pre-termination sampling (Mulino *et al.*, 1995). This suggests an impact on the benthos at a distance from the platform somewhere between 0 and 100 meters.

Interpretation of these data has been initiated. The sediment chemistry and grain size data will be correlated with benthos populations to identify the factors that affect the distribution and recovery of organisms at a terminated produced water discharge.

4.3 Task 6 - Fishermen Survey

4.3.1 Survey and Overall Results

The following material and data from the fishermen survey and its preliminary results were abstracted from Steimle & Associates, Inc.(1995).

Commercial fishermen (including oystermen) and recreational fishermen were surveyed by personal interview from May through November 1993 to determine categories of seafood fished over the previous three months, types of license(s) held, and information on the number, gender and ages of individuals in the household and their seafood consumption habits. Respondents were also interviewed about locations fished, the estimated distances from oilfield structures, and species caught.

To determine the distribution of the catch, all fishermen were asked to estimate by species the percentage sold, the percentage given away to others, and the percentage kept for personal consumption. Fishermen were also asked to estimate the frequency of seafood consumption and cooking methods employed.

Processing plants and wholesalers were surveyed in Texas and Louisiana to determine their sources of seafood (i.e. in-state vs. out-of-state) and the origin of the seafood sold (i.e. fishing zones and ports of commercial fishermen). Site surveys of seafood retailers were conducted to determine the types of shellfish and saltwater finfish sold, the parts of the seafood sold, and the types of prepared seafood sold. Restaurant surveys asked respondents about the source, quantities and method of preparation of seafood sold/served by the restaurant.

Average results reported for the Louisiana recreational fishermen surveys are given below.

Finfishing was the most popular form of recreational fishing (95%) with most fishermen possessing an in-state license (92%). The majority of respondents fished from a private boat inshore (62%), often near an oilfield structure, and most commonly caught speckled sea trout and red snapper.

On average, fishermen reported keeping 80% of the finfish; 97% of the blue crab catch; and 83% of shrimp for personal consumption. They reported serving seafood 1.8 times per week. Their preference was to consume the meat only from the fish over 90% of the time, and the most popular cooking method was frying (30%).

4.3.2 Estimation of Intake Rates

Variables needed for the human health risk assessment include those that contribute to an estimate of the ingestion rate of fish caught near (less than 1,000 ft; 300 m) a coastal platform in Louisiana. Data collected by the survey (Steimle & Associates, Inc., 1995) include the following :

- amount of fish caught per trip
- number of seafood eaters in fishermen's family
- number of trips near structures
- number of trips inshore vs. offshore
- fraction of catch kept
- number of days since last seafood meal
- number of times per week fish served

In this preliminary assessment, ingestion rates for recreational fishermen of fish caught near coastal platforms was derived from the reported data on meals per week (Figure 4-3).

The data reported for meals per week had an arithmetic mean of 1.8, a standard deviation of 97.8, and a range of 0 to 15. The distribution of meals per week used in the calculation of ingestion rate (g/d) was a lognormal distribution with the mean, standard deviation and range of the reported data.

The ingestion rate distribution was derived as follows:

$$FI = \frac{M \times MS}{7d \times week^{1}}$$

where:
FI = derived ingestion rate (g/d)
M = meals per week (assumed lognormal distribution: arithmetic mean 1.8; sd 97.8; range 0-15)
MS = g/meal (150; USEPA, 1989a).

This derived distribution (Figure 4-4) had a mean value of 10 g/d, a median value of 0.7, a standard deviation of 31.8 and a 95th percentile value of 51.8; range 0 to 320.

Figure 4-3. Number of times per week fish served.

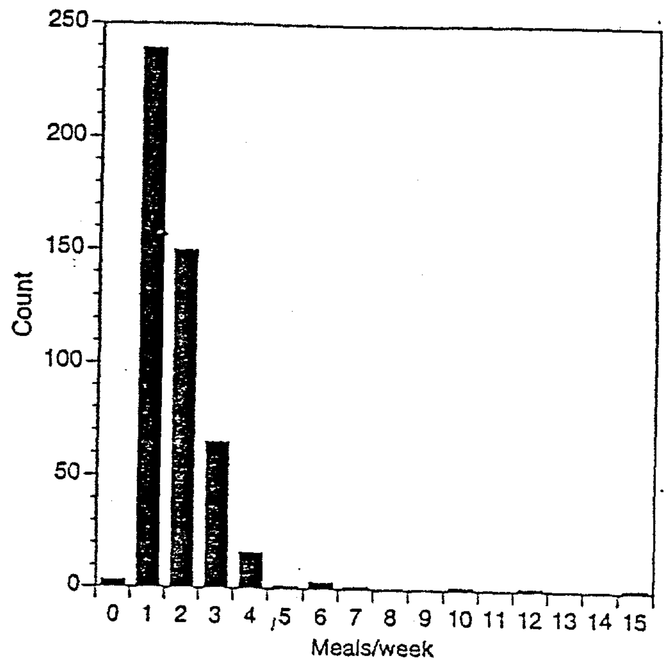
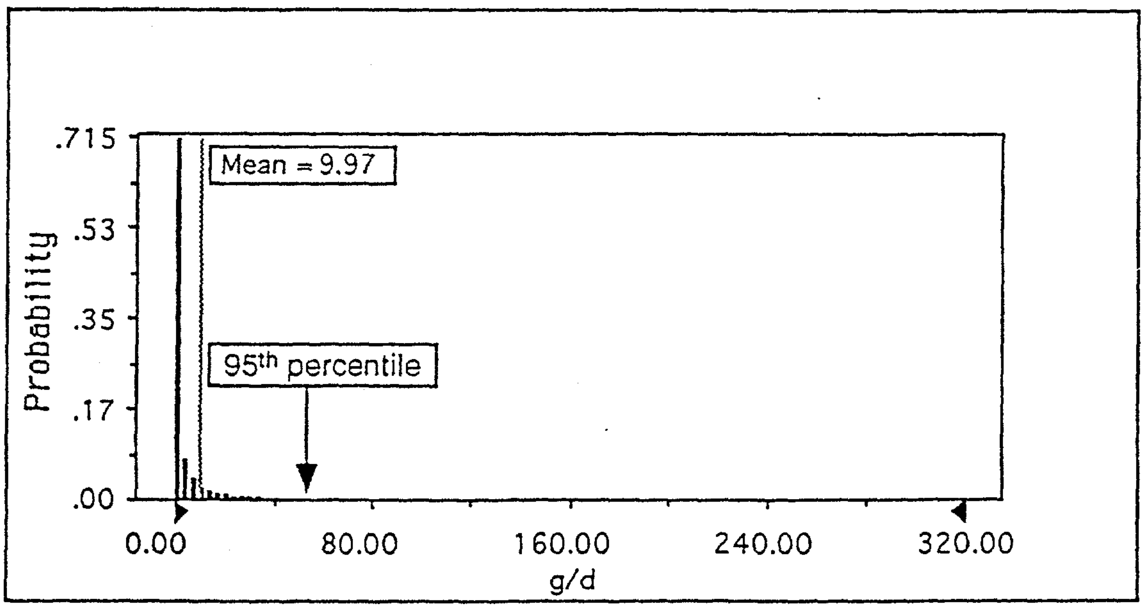


Figure 4-4. Derived ingestion rate for recreational fishermen and their families.



5 CHARACTERIZATION OF CONTINUING DISCHARGES

5.1 Identification Of Continuing Discharges

Louisiana regulations (Title 33, March 20, 1991) required the termination of all produced water discharges to natural or man-made water bodies located in intermediate, brackish or saline marsh areas after January 1, 1995, unless the discharge (s) have been authorized in an approved schedule for elimination or effluent limitation compliance. A variance through January, 1997 was granted (12/16/94) for permitted discharges located in open waters and at least 1 mile from any shoreline in Chandeleur Sound, Breton Sound, Barataria Bay, Caminada Bay, Timbalier Bay, Terrebonne Bay, East Cote Blanche Bay, West Cote Blanche Bay or Vermillion Bay.

The Louisiana Department of Environmental Quality (LDEQ) identified produced water discharges in open bay areas (Table B-1 in Appendix B) that may qualify for this variance.

In August, 1994, a telephone survey of these operators was conducted to determine if they would take advantage of an extension of the phase-out rule for coastal Louisiana produced water discharges. Most operators indicated that they would continue to discharge through 1997 if allowed. Discharges that planned re-injection or had been shut in were not included in the current assessment (Table B-1, Appendix B). Some operators could not say what company policy would be if an extension were granted, and these discharges were assumed to continue discharging, although they may have since been terminated. Therefore, the list of continuing open bay discharges used in the current assessment may include wells that are no longer active.

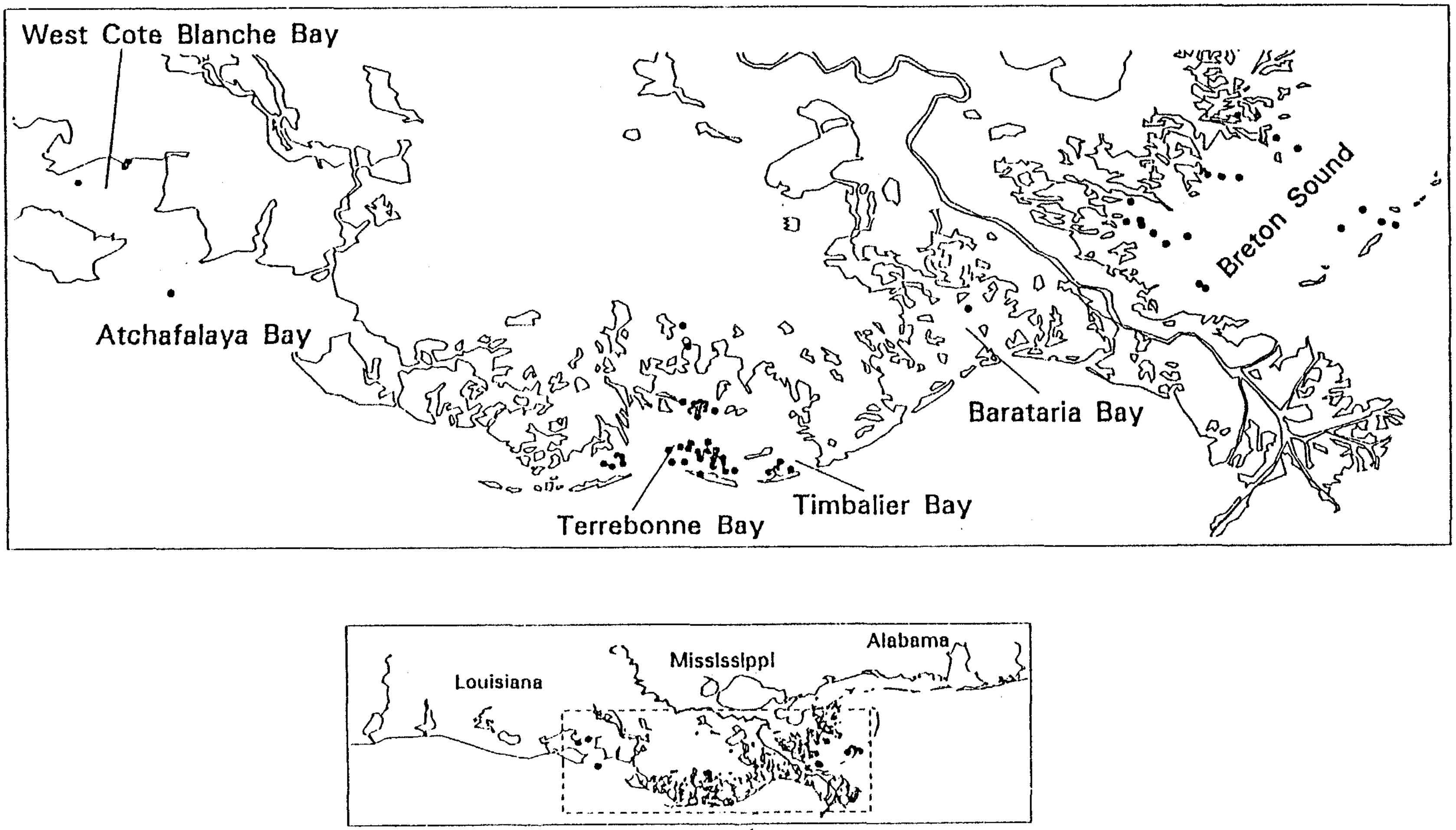
Figure 5-1 shows the locations of the assumed active discharges in open Louisiana bays. More detailed maps are given in Appendix B.

5.2 Characterization Of Discharges

5.2.1 Data Sources

Data describing the assumed continuing discharges listed in Table B-1 (Appendix B) and shown in Figure 5-1 were abstracted from LDEQ permit files. Table B-2 in Appendix B summarizes the data available for each discharge. A few permit files were not available.

Figure 5-1. Assumed active discharges in open Louisiana bays.



5.2.2 Depths and Discharge Rates

Information critical to an assessment of the environmental impact from a produced water discharge includes the depth of the platform and the rate of discharge. Higher rates of discharge in shallower waters can be expected to have more impact in terms of both human health and ecological effects than smaller discharges in deeper waters.

Table 5-1 summarizes the data for platform depths and discharge rates. Figure 5-2 shows the distribution of platform depths in the data set. Discharge rate distributions are given in Figure 5-3. The discharge rate data was described as a lognormal distribution with the mean, range and standard deviation given in Table 5-1. Table B-2 in Appendix B gives the depth and discharge rate for each discharge point included in the analysis.

Note that the two coastal sites in the USDOE study are reasonable representative of these discharges, falling on the high end of the distribution for discharge rates, and the low end of water depths (2,000 and 4,000 bbl/day; 5 and 7.5 feet).

Table 5-1. Platform depths and discharge rates.

	Depth (feet)	**Discharge (bbl/day)**
number	29	62
minimum	4	1
maximum	18	37,113.
mean	9.1	4526.7
standard deviation	2.3	7166.3

5.2.3 Contaminants in the Effluent

Chemical contaminants measured in open bay produced water discharges and reported in LDEQ permit files are summarized in Table 5-2. Data abstracted from LDEQ permit files for each discharge site are given in Appendix B, Table B-3. These data are for contaminants detected above the detection limit only, and over-estimate the mean concentration in the data set.

Radium concentrations measured in the discharges are given in Table B-4 in Appendix B, and are summarized in Table 5-3 below. This data set suggests no clear relationship between ^{226}Ra and ^{228}Ra concentrations in the effluent (Figure 5-4).

Figure 5-2. Depths of platforms, continuing open bay discharges.

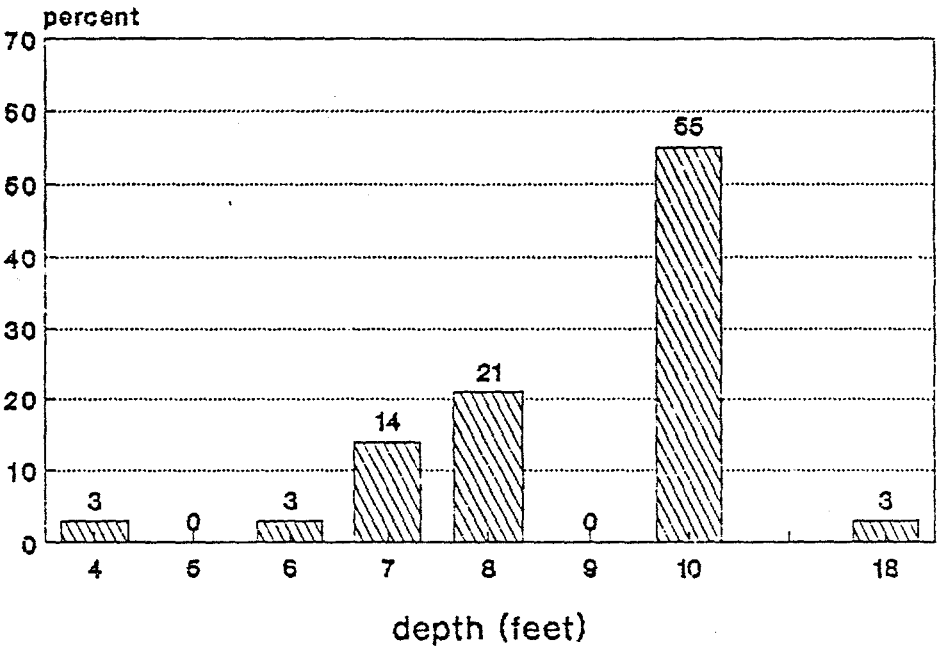


Figure 5-3. Discharge rates, continuing open bay discharges.

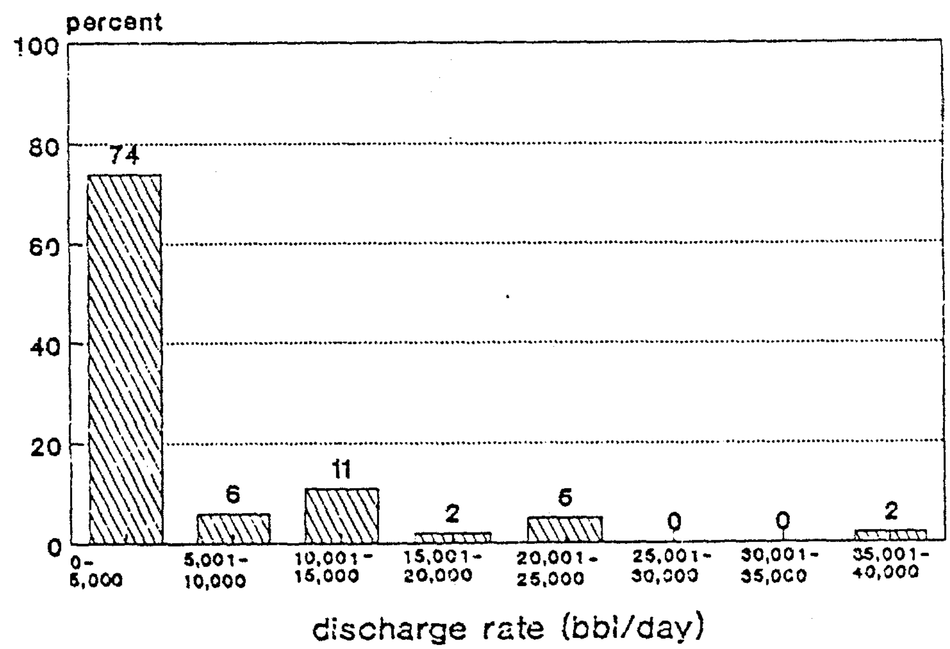


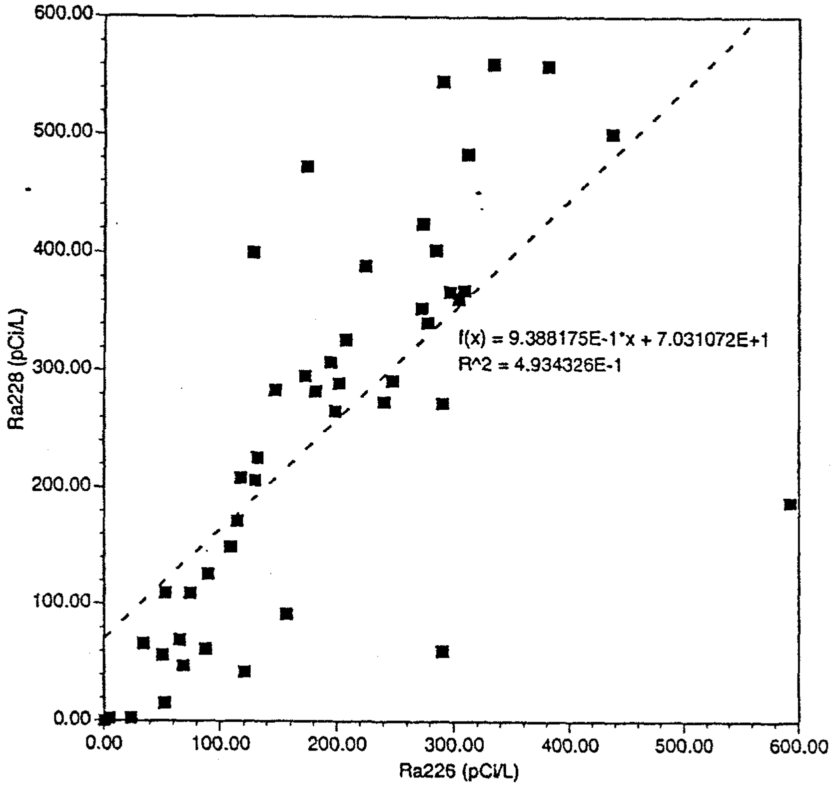
Table 5-2. Contaminant concentrations in open bay produced water discharges in Louisiana (for contaminants reported above detection limits).

	count	min	max	mean	std dev
METALS					
Antimony	7	11.85	20100	5595.91	8479.477
Arsenic	11	6.9	498.5	74.74	136.76
Cadmium	6	0.93	500	231.19	202.57
Chromium (IV)	6	9.5	200	83.49	70.09
Copper	11	10	710	288.37	197.93
Lead	7	35.36	829000	104263	292839
Mercury	4	0.007	27	7.08	11.26
Nickel	7	57.90	2840	1013.86	1062.08
Selenium	3	11.00	84	63.00	34.79
Silver	5	11.30	400	143.32	160.09
Thallium	4	248.39	3700	1904.74	1535.71
Zinc	12	31.09	6375	1217.10	2102.65
ORGANICS					
Benzene	12	10	9550	1813.23	2690.15
Bis (2-ethylhexyl) phthalate	6	45	80	59.67	12.40
Naphthalene	5	10	118	57.42	41.65
Phenol	13	24	12000	1557.86	3144.72
Toluene	12	16	2800	831.62	944.56
Xylenes	9	7	862	183.30	265.84

Table 5-3. Radium concentrations (pCi/l) in open bay discharges.

	^{226}Ra	^{228}Ra
number	47	47
minimum	0.0	0.0
maximum	592.0	560.0
mean	191.4	250.0
standard deviation	122.4	163.6

Figure 5-4. Relationship between ^{226}Ra and ^{228}Ra concentrations in effluents.



5.2.4 Effluent Toxicity

Toxicity tests are useful analytical tools because they can directly measure potential aquatic effects compared to chemical analyses which are difficult to extrapolate. This is particularly true in the case of complex effluents, such as produced water, where a broad range of toxicants can be present in low levels.

Toxicity data were available in LDEQ permit files for 58 assumed continuing discharge sites. Data were available for acute toxicity tests (96-hr LC_{50}) on *Mysidposis bahia* and *Cyprinodon variegatus* (sheepshead minnow); 7-day chronic growth and survival NOEL tests on the same two species; and fecundity studies on *Mysidposis bahia*. The acute LC_{50} data and NOEL growth and survival data are described in Tables 5-4 and 5-5. Distributions were derived from these data for use in probabilistic risk assessments.

Table 5-4. Results of acute toxicity (LC_{50}) tests, *Mysidopsis bahia* and *Cyprinodon variegatus* (percent effluent).

	Mysidopsis bahia	*Cyprinodon variegatus*
count	55	53
minimum	0.07	2.4
maximum	17.8	54.3
mean	7.4	18.3
median	4.8	15.7
standard deviation	4.9	9.2

Table 5-5. Results of chronic toxicity tests (NOEL, growth and survival, percent effluent).

	Mysidopsis bahia		*Cyprindon variegatus*	
	survival	growth	survival	growth
count	58	58	56	55
minimum	0.04	0.07	0.14	0.15
maximum	11.4	14.2	19.1	22.7
mean	2.9	3.7	6.0	7.0
median	1.4	1.9	3.4	4.2
standard deviation	3.1	3.6	5.6	5.9

5.3 Transport Modeling

The USEPA surface water transport model CORMIX 2.1 (Cornell Mixing Zone Expert System Model; Donckcr and Jirka, 1990) was used to estimate the dilution expected at 50 and 200 feet from open bay discharges. The CORMIX model may be used for the prediction of aqueous toxic or conventional pollutant discharges to surface water bodies. Its major emphasis is on prediction of plume geometry and dilution within an initial mixing zone, but the model also predicts plume behavior at larger distances (Bouchard *et al.*, 1995). The current version allows simulation of submerged or surface, single and multiport discharges. CORMIX has been used by USEPA in rulemaking for produced water discharges.

Table 5-6 summarizes the input parameters used in the analysis. A depth of 8 feet (2.44 m) was chosen to represent the assumed continuing open bay discharges in Louisiana (see Figure 5-2). A range of discharge rates was modeled (Table 5-7) to cover the range of discharge rates for the open bay discharges (see Figure 5-3).

Table 5-6. CORMIX input parameters.

AMBIENT PARAMETERS	
cross section	unbounded
average depth	2.44 m
depth at discharge	2.44 m
ambient velocity	0.05 m/s
Darcy-Weisbach friction factor	0.0524
Manning's friction factor	0.03
wind velocity	2 m/s
stratification type	unstratified
surface density	1005 kg/m^3
bottom density	1005 kg/m^3
DISCHARGE PARAMETERS	
discharge description	submerged single port
nearest bank	left
distance to bank	1609.76 m
port diameter	0.127m
port cross-section area	$0.0126m^2$
discharge flow rate	100 - 37,500 bbl/day
discharge port height	0.8 m
vertical discharge angle	90 degrees
horizontal discharge angle	0 degrees
discharge density	1020 kg/m^3
density difference	-15 kg/m^3
buoyant acceleration	-0.1464 m/s^2
discharge concentration	100 percent
surface heat exchange coeff.	0 m/s
coefficient of decay	0 m/s

Results are presented in terms of the expected dilution factor at 50 and 200 feet (Table 5-7) where :

DF (dilution factor) = Concentration Effluent / Concentration Water

Table 5-7. Estimates of dilution factors at 50 and 200 feet.

Discharge Rate	**Dilution Factor**		**Flow Class**
(bbl/day)	**50 feet**	**200 feet**	
37500	11.1	12.0	NV5
22500	15.4	17.3	NV5
15000	20.1	23.5	NV5
12500	22.7	27.1	NV5
1000	26.2	32.3	NV5
7500	31.8	41.0	NV5
5000	13.0	19.1	NV2
4000	11.2	17.9	NV2
3000	9.4	17.3	NV2
2000	11.4	24.4	NV2
1000	19.7	53.4	NV2
500	36.0	127.5	NV2
200	85.2	435.4	NV2
100	168.3	1135.5	NV2

CORMIX uses a 13 step procedure to determine the flow category of a discharge. CORMIX classified the flow as "NV5" for discharge rates between 37,500 bbl/day and 7,500 bbl/day, and as "NV2" for discharge rates between 5000 bbl/day and 1000 bbl/day. Both of these classifications show that the model treated the discharge as a negatively buoyant discharge in a uniform ambient layer. Class NV2 has an extremely strong negative buoyancy causing upstream spreading and does not have layer or surface interaction. Class NV5 has an interaction and unstable discharge configuration with vertical mixing and recirculation zones. After determining the flow classification CORMIX selects an algorithm that best represents the discharge scenario (Doneker and Jirka, 1990).

This change in flow classification (Table 5-7) explains the reduction in dilution predicted by the model between 7500 and 5000 bbl/day.

These data (Table 5-7) were used to derive an empirical relationship between discharge rate and dilution factor (Figure 5-5):

50 feet: $DF = 338.1 * (DISCHARGE)^{-0.3405}$ (R=0.88)

200 feet: $DF = 7315.6 * (DISCHARGE)^{-0.6473}$ (R=0.95)

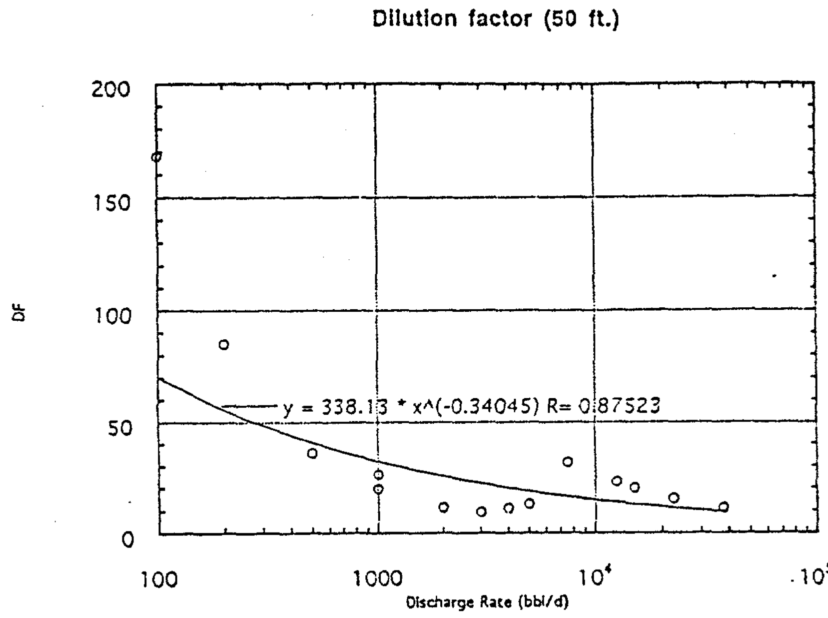
These empirical relationships fit well at high discharge rates, but tend to underestimate dilution at lower discharge rates (Figure 5-6).

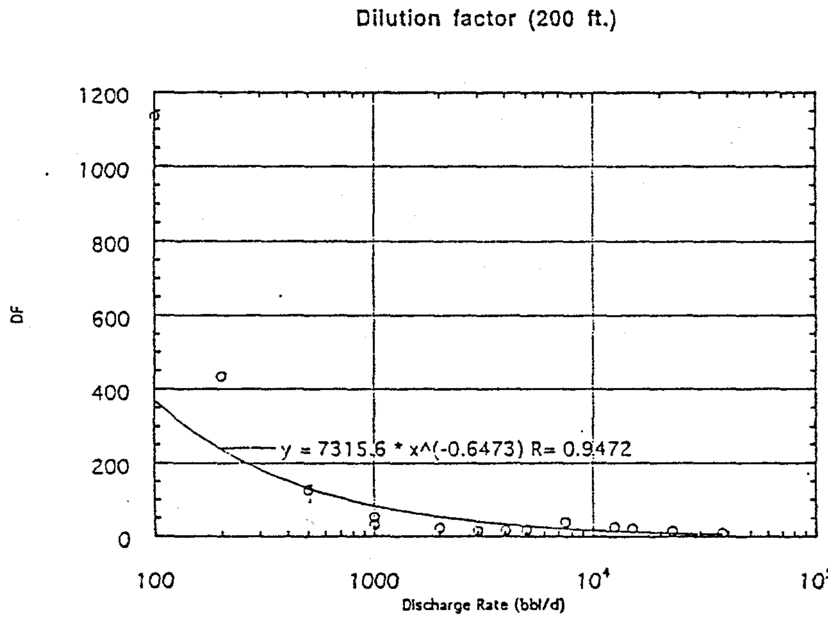
These empirical relationships were applied to the distribution of discharge rates for the open bay discharges (Table 5-1) to produce a distribution of dilution factors for 50 and 200 feet (Table 5-8). The dilution factor distributions were also used to develop a distribution of percent effluent expected in the water column at 50 and 200 feet (Table 5-8).

Table 5-8. Dilution factor and percent effluent distributions for open bay discharges, 50 and 200 feet.

	50 feet		200 feet	
	Dilution Factor	**Percent Effluent**	**Dilution Factor**	**Percent Effluent**
mean	25.8	4.5	61.9	2.7
median	23.9	4.2	47.6	2.1
standard dev.	10.1	1.7	51.7	2.0
minimum	9.4	1.0	8.1	0.1
maximum	102.0	10.6	749.8	12.4
95 th percentile	44.7	7.7	155.9	6.6

Figure 5-5. Relationship between discharge rate and modeled dilution factor at 50 and 200 feet from discharge.





6 HUMAN HEALTH RISK ASSESSMENT FOR RADIUM

6.1 Introduction and Approach

Radium may be accumulated by aquatic organisms, and there is a potential human health risk associated with the ingestion of radium in fish and shellfish caught near open bay produced water discharges. Screening and probabilistic human health risk assessments were done for open bay radium discharges in Louisiana.

The two data sets used in this risk assessment were:

USDOE Open Bay Study Sites

- measured concentrations of ^{226}Ra, and ^{228}Ra in finfish and crustaceans caught near the discharge at the Delacroix Island and Bay De Chene study sites (section 4).

Continuing Discharges

- measured concentrations of ^{226}Ra and ^{228}Ra in 47 open bay discharges (section 5)
- modeled dilution factors at 200 feet (Section 5)

6.2 Screening Assessment

Concentrations in Edible Fish

USDOE Open Bay Sites

Screening assessments were done for ^{226}Ra and ^{228}Ra in biota taken in the Spring of 1993 from the discharge site and two reference stations at both study sites. Multiple samples were taken for each species in the study at Bay De Chene. The highest concentrations of radium detected in each species at each site were used in the analysis (Table 6-1).

Only one concentration for each isotope was available for each species sampled from each site at Delacroix Island. For each isotope in each species, the value of the concentration at the discharge site and the higher of the two reference site values were used in the screening analysis.

Table 6-1. Maximum radium concentrations in biota measured at Delacroix Island and Bay De Chene Study Sites (pCi/g).

	Delacroix Island				Bay De Chene			
	Discharge		Reference		Discharge		Reference	
	^{226}Ra	^{228}Ra	^{226}Ra	^{228}Ra	^{226}Ra	^{228}Ra	^{226}Ra	^{228}Ra
croaker	0.005	0.112	0.063	0.021	0.024	0.094	0.032	0.05
spot	0.002	0.076	0.002	0.107	0.034	0.086	0.029	0.01
sea trout	NS	NS	NS	NS	0.021	0.159	0.016	0.042
blue crab	0.025	0.09	0.012	0.046	0.023	0.059	0.024	0.01
shrimp	NS	NS	NS	NS	0.011	0.01	0.027	0.124

NS = no sample

Continuing Discharges

Based on the modeling described in section 5, a conservative dilution factor of 20 was chosen to estimate worst-case water and fish radium concentrations 200 feet from the discharge.

Mean and maximum radium concentration in the data set for continuing open bay discharges (Table 6-2) were diluted by a factor of 20 to estimate water concentrations at 200 feet (Table 6-2). A conservative bioaccumulation factor of 500 (IAEA, 1985) was used to calculate concentrations of radium in edible fish:

$$C_{fish} = BAF \times C_{water} / 1000 \text{ (g/l)}$$

where:
C_{fish} = radium concentration in fish (pCi/l)
BAF = bioaccumulation factor (500)
C_{water} = radium concentration in water (pCi/l)

Estimated concentrations in edible fish for mean and maximum radium discharge concentrations are given in Table 6-2.

Table 6-2. Screening analysis for continuing discharges, water and fish concentrations 200 feet from discharge.

	Effluent (pCi/l)	Water (pCi/l)	Fish (pCi/g)
^{226}Ra			
mean	191.4	9.6	4.8
max	592	29.6	14.8
^{228}Ra			
mean	250	12.5	6.3
max	560	28	14

Exposure Period and Ingestion Rates

The screening analyses used the conservative value of 70 years as the exposure period. A conservative ingestion rate of 132 g/d was used (USEPA 1989a; 95th percentile value).

Risk Factor

USEPA (Federal Register, 1991) uses risk factors of 4.4×10^{-6} for ^{226}Ra and 3.8×10^{-6} for ^{228}Ra (per pCI/l of drinking water). This factor assumes a daily ingestion rate of 2 l/d of drinking water, and can be converted to unit risk values of 2.2×10^{-6} for ^{226}Ra and 1.9×10^{-6} for ^{228}Ra (per pCi/d). These unit risk factors were used in the screening analyses.

Exposure and Risk Characterization

Individual lifetime fatal cancer risks were calculated separately for ^{226}Ra and ^{228}Ra and then summed. Individual lifetime risk of cancer mortality (IR) was calculated as:

$$IR = [Ra] \times FI \times RF$$

where:
IR = individual incremental lifetime fatal cancer risk
[Ra] = concentrations of ^{226}Ra and ^{228}Ra in fish (pCi/g)
FI = seafood ingestion rate (g/d)
RF = risk factor (risk per pCi/d, 70 year exposure period)

Results

Results of the screening risk assessment for radium measured at the Delacroix Island and Bay De Chene study sites, and for the continuing open bay discharges are given in Table 6-3.

Table 6-3. Screening human health risk assessment for Delacroix Island and Bay De Chene study sites, and modeled continuing discharges, individual lifetime fatal cancer risk.

	Delacroix Island		Bay De Chene		Modeled Discharges	
Species	Discharge	Reference	Discharge	Reference	Mean	Max
croaker	1.7E-5	7.5E-5	3.1E-5	2.2E-5		
spot	8.2E-6	8.2E-6	3.1E-5	1.1E-5		
sea trout	NS	NS	4.6E-5	1.5E-5		
blue crab	1.2E-5	1.5E-5	2.2E-5	9.5E-6		
shrimp	NS	NS	5.7E-6	3.9E-5		
fish					3.0E-03	7.8E-03

NS=no sample

Estimated risks for the ingestion of radium in fishes exceed 1×10^{-6} in all cases. Note that the estimated cancer risks for fish sampled at reference stations at Delacroix Island and Bay De Chene are similar to those for ingestion of fish caught near the discharges.

Predicted screening-level risks are greater than 1×10^{-3} for the modeled continuing discharges. These results are from a conservative, screening level assessment, and do not represent best estimates of risk associated with radium discharged by open bay platforms. They do, however, suggest the need for a more detailed, probabilistic assessment.

6.3 Probabilistic Assessment

6.3.1 Exposure Assessment

Concentrations in Edible Fish

<u>USDOE Open Bay Sites</u>

Preliminary determinations of concentrations of radium in muscle from fishes sampled at the discharge sites were assumed to conservatively represent the concentrations in edible flesh of fishes caught by recreational fishermen.

Distributions for radium concentrations in finfish at Bay De Chene and Delacroix Island were derived for the probabilistic human health risk assessment. For the three species of finfish sampled (croaker, spot and seatrout) at the Bay de Chene discharge, the range of all values of ^{226}Ra in muscle could not be distinguished from a normal distribution, while those for ^{228}Ra fit a lognormal distribution. The combined values for ^{226}Ra concentrations were assumed to be a truncated normal distribution, averaging 0.017pCi/g (range,0.003 to 0.027).

For ^{228}Ra the combined values were assumed to be a lognormal distribution averaging 0.067 pCi/g (range, 0.009 to 0.096).

At Delacroix Island, only one fish of each of the same three species was sampled. Therefore the concentrations (pCi/g) of ^{226}Ra (0.02, 0.03,0.03) and the concentrations of ^{228}Ra (0.04, 0.04, 0.29) were assumed to be custom distributions with equal probabilities for the values from the three species.

Continuing Discharges

Radium concentrations in edible fish were estimated for the assumed continuing open bay discharges in Louisiana in two steps.

In the first step, the distribution of radium water concentrations was estimated by modifying the distribution of ^{226}Ra and ^{228}Ra concentrations reported for the open bay discharges (Table 5-3) by the distribution of dilution factors derived for 200 feet using the CORMIX model (section 5; Table 5-8).

Radium concentrations in fish were then derived using the bioaccumulation factor method:

$$C_{fish} = BAF \times C_{water} / 1000 \text{ (g/l)}$$

where:
C_{fish} = radium concentration in fish (pCi/l)
BAF = bioaccumulation factor
C_{water} = radium concentration in water (pCi/l)

A BAF distribution based on data collected in coastal Louisiana (Meinhold and Hamilton, 1992) was used to estimate concentrations in fish. This distribution is lognormal, has a range of 2 to 100, a mean of 30.4 and a standard deviation of 28. Table 6-4 gives the estimated distributions for radium concentrations in fish.

Table 6-4. Estimated radium concentrations in water and fish at 200 feet for modeled open bay discharges.

	Water Concentration (pCi/l)		Fish Concentration (pCi/g)	
	^{226}Ra	^{228}Ra	^{226}Ra	^{228}Ra
mean	5.5	6.9	0.2	0.2
median	3.9	4.9	0.08	0.1
std. dev	5.5	6.7	0.2	0.27
minimum	0	0	0	0
maximum	51.2	65.1	2.6	3.5
95th percentile	16.3	20.5	0.5	0.7

Ingestion Rates

Ingestion rates for recreational fishermen and their families were derived in section 4.3.2. The derived distribution of intake rates had a mean value of 10 g/d, a median value of 0.7, a standard deviation of 31.8 and a 95th percentile value of 51.8.

Exposure Period

Exposure periods (i.e. number of years fishermen catches and eats fish close to an offshore produced water discharge) may vary from several years to a large part of a lifetime. The probabilistic assessment assumed that the exposure period for recreational fishermen ranged from 5 to 65 years, and was described by a triangular distribution with the most frequent value set at 20 years.

Calculation of Radium Exposure

Daily ^{226}Ra and ^{228}Ra ingestion rates during the exposure period were calculated as:

$$RI = FI \times [Ra]_{fishes}$$

where:

RI = radium intake (pCi/d) during the exposure period
FI = intake of fish (g/d) as described in section 4.3.2.
$[Ra]_{fishes}$ = pCi/g

6.3.2 Dose Response Assessment

Current practice in radiation protection is to assume there is a cancer risk associated with even small doses of radiation. Risk factors are derived from epidemiological data and extrapolated down to low doses to describe the cancer risk associated with small exposures. Appendix C summarizes the basic concepts in radiation protection applicable to risk assessment, discusses in detail the USEPA risk factors for radium and derives the distribution for the risk factors used in the probabilistic assessment presented here (Table 6-5).

Table 6-5. Risk factor distribution for ^{226}Ra and ^{228}Ra (lognormal distributions; individual lifetime fatal cancer risk per pCi/day).

	^{226}Ra	^{228}Ra
Arithmetic Mean	1.5E-6	1.0E-6
Standard Deviation	9.0E-7	1.4E-6
Lower 90% Confidence Limit	9.4E-7	4.7E-7
Upper 90% Confidence Limit	2.2E-6	1.9E-6

6.3.3 Risk Characterization

This section presents the risk characterization analysis for the ingestion of radium in fishes harvested near offshore produced water outfalls in the Gulf of Mexico. The risk characterization step includes the calculation of individual lifetime fatal cancer risk.

In the probabilistic analysis, the risk factor for the exposure period (5 - 65 years for recreational fishermen) was modified as described in Appendix C:

$$RF(EP) = \frac{[EP + 10] \times URF(70)}{70 \text{ years}}$$

where:
RF(EP) = risk factor as a function of exposure period EP (lifetime risk per pCi/day)
EP = exposure period (years)
URF(70) = USEPA unit risk factor for lifetime exposure (lifetime risk per pCi/day)

Individual lifetime fatal cancer risks were calculated as:

$$ILR = RI \times RF(EP)$$

where:
ILR = individual lifetime fatal cancer risk
RI = average daily radium intake during the exposure period (pCi/day)
RF(EP) = risk factor modified by exposure period (lifetime risk per pCi/day)

Individual lifetime risks were calculated separately for ^{226}Ra and ^{228}Ra and then summed.

6.3.4 Results and Discussion

Results from the probabilistic risk assessment for radium in fishes at Delacroix Island and Bay De Chene are given in Table 6-6. Median individual lifetime fatal cancer risks for both study sites were less than 1×10^{-6}, and median and 95th percentile risks were less than 1×10^{-5}.

Results from the modeling analysis of continuing open bay discharges in Louisiana are also presented in Table 6-6. Median individual lifetime fatal cancer risks were 2.2×10^{-7}, and 95th percentile risks were 1.9×10^{-5}.

These results suggest that the ingestion of radium in fish near open bay produced water platforms does not present an important risk to human health. There are a number of uncertainties associated with this analysis, including:

- uncertainty due to limited data describing radium concentrations in animals at USDOE study sites;'
- uncertainty in modeling of radium dilution and bioaccumulation for continuing discharges;
- uncertainty in ingestion rate distribution; and
- uncertainty in radium dose-response function.

These uncertainties are included in the probabilistic risk assessment presented here by describing each of the relevant variables as a distribution in the Monte Carlo analysis. A more detailed uncertainty analysis will be done to describe the effect of major assumptions and distributions on the result.

Table 6-6. Probabilistic risk assessment for radium in fishes at Delacroix Island and Bay De Chene sampling sites: individual lifetime fatal cancer risk.

SITE	Individual Lifetime Fatal Cancer Risk				
	mean	median	std. deviation	5th percentile	95th percentile
DELACROIX ISLAND	1.7E-6	8.9E-8	6.8E-6	7.3E-10	7.7E-6
BAY DE CHENE	5.4E-7	3.3E-8	1.9E-6	3.0E-10	2.8E-6
CONTINUING DISCHARGES	4.2E-6	2.2E-7	1.8E-5	1.7E-9	1.9E-5

7 ECOLOGICAL RISK ASSESSMENT FOR RADIONUCLIDES

7.1 Background and Approach

An aquatic organism may be irradiated externally by radionuclides in water and sediment, and internally by radionuclides taken into the body by ingestion or direct absorption. Most incorporated radionuclides are differentially distributed among the organs and tissues of the organism. Radium, for example, tends to accumulate in bone, skin and exoskeleton.

Exposure to ionizing radiation can result in injury at the molecular, cellular and whole body levels. Most of the available studies of the effects of radiation on aquatic organisms are concerned with the induction of deterministic, somatic effects. These effects include increases in mortality and pathophysiological, developmental and reproductive effects. There is little information available concerning induction of cancer and genetic effects, although a few studies of stochastic genetic effects in organisms are available (Anderson and Harrison, 1986).

Appendix C reviews the terminology and units used in radiation protection, and summarizes the data available to describe the effects of radiation exposure on aquatic animals.

The National Council on Radiation Protection and Measurements recently reviewed the literature on the effects of ionizing radiation on aquatic organisms. NCRP (1991) suggested a reference dose rate to protect aquatic populations of 10 mGy/d (or 10 mSv/d; see Appendix C). NCRP also suggested a detailed assessment if an initial analysis results in estimated dose rate above 2.4 mGy/d (or 2.4 mSv/d).

IAEA (1988) developed dose-rate factors that relate the radiation exposure to an organism to a unit concentration of the radionuclide in the water in which the organism lives (Table 7-1). These dose rate factors are based on models using assumptions concerning the bioaccumulation factor, K_d, and the sizes and shapes of the animals (IAEA, 1988). These factors are useful for screening purposes.

In this assessment, the IAEA screening dose-rate factors were used in a conservative screening analysis to identify the potential for ecological effects from radium and other radionuclides discharged to Louisiana open bays in produced water.

Table 7-1. IAEA dose rate factors (mSv/hr per Bq/m^3).

ORGANISM	RADIONUCLIDE				
	^{226}Ra	^{228}Ra	^{210}Pb	^{210}Po	^{228}Th
FISH					
bathypelagic	1.38E-4	1.62E-7	4.96E-8	1.22E-4	2.21E-4
benthic	1.45E-4	3.83E-6	8.00E-6	1.22E-4	1.26E-3
MOLLUSKS	2.85E-4	4.41E-6	8.51E-5	6.10E-4	1.60E-3
CRUSTACEANS					
large, bathypelagic	2.77E-5	2.82E-8	2.46E-7	3.05E-4	3.68E-4
large, benthic	3.54E-5	4.03E-6	1.82E-5	3.05E-4	1.52E-3
small, bathypelagic	2.76E-5	1.86E-8	1.67E-7	1.83E-4	3.68E-3
small, benthic	3.70E-5	4.76E-6	6.14E-4	1.83E-4	5.12E-3

The data sets available for the analysis were:

USDOE Open Bay Study Sites

- measured concentrations of ^{226}Ra, ^{228}Ra$\cdot$ ^{210}Pb, ^{210}Po and ^{228}Th in the discharge at Delacroix Island and Bay De Chene Study Sites (section 4).

Ongoing Discharges

- measured concentrations of ^{226}Ra and ^{228}Ra in 47 open bay discharges (section 5)
- modeled dilution factors at 200 feet (section 5)

Dilution factors of 20 and 50 were applied to the concentrations of radionuclides measured in these effluents. The resulting water concentrations (at 200 feet from the discharge) were used to estimate the dose to aquatic animals using the IAEA dose conversion factors.

7.2 USDOE Open Bay Sites

Concentrations of radionuclides measured in the effluent at the Delacroix Island and Bay De Chene study sites are given in Table 7-2. Concentrations predicted at 200 feet using dilution factors of 20 and 50 are also given in Table 7-2. The IAEA dose conversion factors were applied to these estimated water concentrations, and a total dose to aquatic organisms calculated (Table 7-3). No estimated doses exceeded the NCRP reference limit of 10 mSv/day. Doses that exceed the NCRP suggested screening level for detailed assessment (2.4 mSv/d) are shown in Table 7-3 in bold.

Table 7-2. Concentrations of radionuclides predicted for 200 feet at the Delacroix Island and Bay De Chene study sites using dilution factors of 20 and 50.

Radionuclide	Delacroix Island			Bay De Chene		
	Discharge (pCi/l)	DF=20 (pCi/l)	DF=50 (pCi/l)	Discharge (pCi/l)	DF=20 (pCi/l)	DF=50 (pCi/l)
^{210}Pb	78.0	3.9	1.6	60.3	3.0	1.2
^{210}Po	<1.1	<0.06	0.02	<2.0[2]	<0.1	0.04
^{226}Ra	218.5	10.9	4.4	162.5	8.1	3.3
^{228}Ra	264.5	13.2	5.3	317.5	15.9	6.4
^{228}Th	154.5	7.7	0.3	15.0	0.8	0.3

Table 7-3. Screening level dose estimates for Delacroix Island and Bay De Chene study sites (mSv/d).

ORGANISM	Delacroix Island		Bay De Chene	
	DF=20	DF=50	DF=20	DF=50
FISH				
bathypelagic	1.5	0.6	1.3	0.5
benthic	**2.5**	1.0	2.0	0.8
MOLLUSKS	**4.3**	1.7	**3.5**	1.4
CRUSTACEANS	0.8			
large, bathypelagic	1.8	0.3	0.8	0.3
large, benthic	**3.0**	0.7	1.8	0.7
small, bathypelagic	**6.3**	1.2	**2.8**	1.1
small, benthic	**6.3**	**2.5**	**5.5**	2.2

7.3 Continuing Discharges

Radium concentrations measured in 47 open bay discharges are given in Appendix B, and summarized in Table 5-3. Mean and maximum concentrations are given in Table 7-4. Conservative dilution factors of 20 and 50 were applied to these concentrations to estimate worst-case radium concentrations 200 feet from open bay discharges (Table 7-4).

Mean and maximum doses calculated using the IAEA dose rate conversion factors (Table 7-1) are given in Table 7-5. No dose estimates exceeded the NCRP reference dose of 10 mSv/d. Dose estimates that exceed the NCRP screening value of 2.4 mSv/d are shown in bold in Table 7-5.

Table 7-4. Concentrations of radionuclides predicted for 200 feet from open bay discharges using conservative dilution factors of 20 and 50.

Radionuclide	Discharge		DF=20		DF=50	
	mean (pCi/l)	max (pCi/l)	mean (pCi/l)	max (pCi/l)	mean (pCi/l)	max (pCi/l)
^{226}Ra	191.4	592.0	9.6	29.6	3.8	11.8
^{228}Ra	250.0	560.0	12.5	28.0	3.8	11.8

Table 7-5. Screening level dose estimates for radium in continuing open bay discharges (mSv/d).

ORGANISM	DF=20		DF=50	
	mean	max	mean	max
FISH				
bathypelagic	1.3	**3.8**	0.5	1.5
benthic	1.3	**4.0**	0.5	1.6
MOLLUSKS	**2.5**	**7.5**	1.0	**3.0**
CRUSTACEANS				
large, bathypelagic	0.3	0.8	0.1	0.3
large, benthic	0.3	1.0	0.1	0.4
small, bathypelagic	0.3	0.8	0.1	0.3
small, benthic	0.3	1.0	0.1	0.4

7.4 Discussion

Based on a simple conservative screening analysis, no doses to aquatic animals are predicted from radionuclides in produced water discharges above the NCRP reference level of 10 mSv/d. Because of the conservative nature of this initial analysis, it can be concluded that no effects on aquatic animals from radionuclides discharged in produced water to open bays in Louisiana are expected. Additional quantitative assessments could be performed to assess the extent to which the NCRP screening level of 2.4 mSv/d is likely to be exceeded.

8 HUMAN HEALTH RISK ASSESSMENT FOR METALS AND ORGANICS

8.1 Introduction and Approach

A screening human health risk assessment was done for metals and organic compounds measured in continuing open bay discharges (section 5). This analysis followed the USEPA approach to estimating risks from toxic materials and carcinogens by applying RfD (reference dose) and slope factor values to estimates of chemical intake rates (USEPA, 1989a). Predicted water concentrations were also compared to USEPA and Louisiana human health surface water criteria.

8.2 Screening Assessment

Concentrations in Water and Fish

Concentrations in the effluent for continuing open bay discharges were described by the data abstracted from LDEQ permit files (Table 5-2). These data are only for contaminants detected in the effluent above the reported detection limit and so overestimate average concentrations.

Based on the modeling described in section 5, a conservative dilution factor of 20 was chosen to estimate worst-case water chemical concentrations 200 feet from the discharge. Most contaminants were assumed to remain in solution. Dissolved fractions of copper. lead and zinc were assumed to be 0.88, 0.38 and 0.59, respectively (USEPA, 1995).

In this preliminary assessment, contaminants were assessed only if : they were reported above detection limits in more than two of the LDEQ permit files; and toxicity data are available in IRIS or other USEPA literature. Mean and maximum chemical contaminant concentrations in effluents and in water at 200 feet are given in (Table 8-1).

Conservative, generic bioaccumulation factors (Strenge and Peterson, 1989; Table 8-1) were used to calculate concentrations of contaminants in edible fish:

$C_{fish} = BAF \times C_{water} / 1000$ (g/kg)

where:
C_{fish} = contaminant concentration in fish (μg/g)
BAF = bioaccumulation factor (l/kg)
C_{water} = contaminant concentration in water (μg/l)

Estimated concentrations in edible fish for mean and maximum contaminant discharge concentrations are given in Table 8-1.

Table 8-1. Contaminant concentrations in the effluent, in the water column 200 feet from the discharge, and in edible fish.

Contaminant	Effluent (μg/l)		Diss. Fract.	200 feet (μg/l)		BAF (l/kg)	Conc in fish (μg/g)	
	max	mean		max	mean		max	mean
Antimony	20100	5595.9	1	1005	279.8	1	1.0	0.3
Arsenic	498.5	74.8	1	24.925	3.7	1	0.02	0.004
Cadmium	500	231.2	1	25	11.6	200	5	2.3
Chromium (IV)	200	83.5	1	10	4.2	20	0.2	0.1
Copper	710	288.4	0.88	31.2	12.7	50	1.6	0.6
Lead	829000	104263	0.38	15751	1981	100	1575	198.1
Mercury	27	7.1	1	1.35	0.4	2.0E5	270	70.8
Nickel	2840	1013.9	1	142	50.7	100	14.2	5.1
Silver	400	143.3	1	20	7.2	2.3	0.05	0.02
Zinc	6375	1217.1	0.59	188.1	35.9	2.0E3	376.1	71.8
Benzene	9550	1813.2	1	477.5	90.7	24.1	11.5	2.2
Naphthalene	118	57.4	1	5.9	2.9	168	1.0	0.5
Phenol	12000	1557.9	1	600	77.9	7.57	4.5	0.6
Toluene	2800	831.6	1	140	41.6	69.9	9.8	2.9
Xylenes	862	183.3	1	43.1	9.2	177	7.6	1.6

Risk Factors

Risk factors (*slope factors for carcinogens and reference doses (RfD) for toxicants*) were obtained from the USEPA IRIS data base (April, 1995) and other sources. Table 8-2 summarizes these values.

<u>Reference Dose</u>

The RfD (chronic reference dose) is "an active estimate (with uncertainty spanning perhaps an order of magnitude or greater) of a daily exposure level for the human population, including sensitive subpopulations, that is likely to be without an appreciable risk of deleterious effects during a lifetime. Chronic RfDs are specifically developed to be protective ..." (USEPA 1989a).

Each RfD includes uncertainty factors (UFs). Depending on the derivation of the RfD, uncertainty factors can inflate the RfD by up to 10,000 times. Therefore, an estimated exposure that exceeds an RfD for a particular contaminant may or may not exceed a threshold for toxicity. Toxicity values of many of the chemicals commonly found in produced water discharges are highly uncertain, as shown in Table 8-2.

Tale 8-2. Rfds, uncertainty factors and slope factors.

Contaminant	RfD (mg/kg-day)	Confidence	UF	Weight of Evidence	Slope Factor per mg/kg-day	Human Health Criteria	
						USEPA (μg/l)	La (μg/l)
Antimony	4.00E-04	Low	1000			4.50E+04	
Arsenic	3.00E-04	Medium	3	A	5.00E-05	1.75E-02	
Cadmium	1.00E-03	High	10	B1[3]			
Chromium (IV)	5.00E-03	Low	500	A[3]			
Copper[1]	4.00E-02			D			
Lead[1]	3.60E-03			B2			
Mercury[2]	3.00E-04			D		1.46E-01	
Nickel	2.00E-02	Medium	300			1.00E+02	
Silver	5.00E-03	Low	3	D			
Zinc	3.00E-01	Medium	3	D			
Benzene	NA			A	2.90E-02	4.00E+01	12.5
Naphthalene	4.00E-03			D			
Phenol	6.00E-01	Low	100	D			50
Toluene	2.00E-01	Medium	1000	D		4.24E+05	6.93E+04
Xylenes	2.00E+00	Medium	100	D			

NA: not available
[1] no RfD available in IRIS, screening values derived in text
[2] no RfD available in IRIS, screening values from HEAST (1991)
[3] evidence is for inhalation carcinogenesis only

RfDs undergoing review at USEPA are not available in IRIS. At the time of this analysis, current RfD's were not available for copper, mercury, lead and naphthalene, all contaminants with the potential for toxic effects. Screening level estimates were available for mercury and naphthalene in HEAST (1991). These reference doses are interim values and have not been formally verified by USEPA.

No estimates are available for lead or copper. Screening level estimates were derived for these contaminants as described below.

Copper:

- current maximum contaminant level goal for drinking water is 1.3 mg/l
- assume based on 2 l/day water intake
- assume 70 kg adult
- Rfd = 0.04 mg/kg-day

Lead:

- current data suggest effects at a blood level concentration of 10 μg/dl (Carlisle and Wade, 1992)
- slope of 0.04 μg / Pb dL blood per μg /day in diet (Carlisle and Wade, 1992)
- assume 70 kg adult
- Rfd = 3.6E-3 mg/kg-day

Slope Factor

A slope factor is "a plausible upper-bound estimate of the probability of a response per unit intake of a chemical over a lifetime. The slope factor is used in risk assessments to estimate an *upper-bound* (italics added) lifetime probability of an individual developing cancer as a result of a lifetime exposure to a level of a particular carcinogen"(USEPA, 1989a) The upper bound is usually the upper 95th percent limit of the slope of a calculated dose-response curve. "In some cases slope factors based on human dose-response data are based on the "best" estimate instead of the upper 95 percent confidence limits" (USEPA, 1989a) Each USEPA slope factor is accompanied by a weight-of evidence classification, a "...system for characterizing the extent to which the available data indicate that an agent is a human carcinogen"(USEPA, 1989a). The weight of evidence classification used by USEPA is a follows:

A Human carcinogen
B1 Probable human carcinogen based on limited human data
B2 Probable human carcinogen based on sufficient evidence in animals only
C Possible human carcinogen
D Not classifiable as to human carcinogenicity
E Evidence of noncarcinogenicity in human beings

Note that cadmium and chromium, classified as B1 and A carcinogens, respectively, have evidence only for cancer associated with inhalation.

Exposure Assumptions

The screening analyses used the conservative value of 70 years as the duration of exposure to reflect the assumption of a lifetime exposure. A conservative ingestion rate of 132 g/d was used (USEPA 1989a; 95th percentile value), along with an exposure frequency of 365 d/year. An assumed body weight of 70 kg for adults was used in the analysis (USEPA, 1990). Intakes were averaged over a 70 year lifetime.

Exposure Assessment and Risk Characterization

Intake rates for contaminants in finfish caught near coastal open bay platforms were calculated following USEPA methods developed for the assessment of CERCLA sites (USEPA, 1989a).

$$I = \frac{[C] \times FI \times ED \times EF}{BW \times AT}$$

where:

I = intake (mg/kg-d)
[C] = concentration in finfish (mg/kg)
FI = ingestion rate (0.132 kg/d)
ED = exposure duration (70 years)
EF = exposure frequency (365 d/year)
AT = averaging time (70 years)
BW = body weight (70 kg)

The risks associated with the ingestion of contaminants in finfish caught near coastal open bay platforms were calculated following EPA methods developed for assessments at CERCLA sites (USEPA, 1989a):

Toxics

$$HI = \frac{I}{RfD}$$

where:
HI = hazard index
I = intake rate (mg/kg-d)
Rfd = reference dose (mg/kg-d)

Hazard quotients greater than one suggest a potential for chronic toxic effects.

Carcinogens

$$IR = I \times RF$$

where:
IR = individual incremental lifetime fatal cancer risk
I = intake rate (mg/kg-d)
RF = risk factor (risk per mg/kg-d, 70 year exposure period)

Water Quality Criteria

Predicted water concentrations at 200 feet from the discharge were compared to USEPA and Louisiana water quality criteria for human health (for fish ingestion). A ratio [predicted water concentration/water quality criteria] was calculated. Where ratios are greater than one, the human health water quality criteria are predicted to be exceeded.

8.3 Results

Results of the screening risk assessment for the continuing open bay discharges in Louisiana are given in Tables 8-3 and 8-4.

Contaminants with hazard quotients greater than were antimony, cadmium, lead, nickel, mercury and zinc. Screening cancer risk estimates for benzene exceed 1 x 10^{-4}.

Contaminants predicted to exceed water quality standards for human health include mercury, nickel, benzene and phenol.

Table 8-3. Hazard quotients and cancer risk estimates.

Contaminant	Hazard Quotient		Individual Lifetime Fatal Cancer Risk	
	maximum	mean	maximum	mean
Antimony	**4.7**	**1.3**		
Arsenic	0.2	0.02	2.4E-9	3.5E-10
Cadmium	**9.4**	**4.4**		
Chromium (IV)	0.07	0.03		
Copper	0.07	0.03		
Lead	**825**	**104**		
Mercury	**1697.1**	**445.1**		
Nickel	**1.3**	0.5		
Silver	0.02	0.006		
Zinc	**2.4**	0.5		
Benzene			6.3E-4	1.2E-4
Naphthalene	0.5	0.2		
Phenol	0.01	0.002		
Toluene	0.1	0.03		
Xylenes	0.01	0.002		

Table 8-4. Ratio: Predicted concentration at 200 feet / water quality criteria for human health.

Contaminant	Louisiana Criteria		USEPA Criteria	
	maximum	mean	maximum	mean
Antimony			0.02	0.006
Arsenic				
Cadmium				
Chromium (IV)				
Copper				
Lead				
Mercury			9.3	2.4
Nickel			1.4	0.5
Silver				
Zinc				
Benzene	38.2	7.3	1.2	2.3
Naphthalene				
Phenol	12	1.6		
Toluene	0.002	0.0006	3.3E-4	9.1E-5
Xylenes				

1 Ratio: predicted concentration at 200 feet / water quality criteria for human health

8.4 Discussion

Contaminants eliminated from further consideration were arsenic, chromium, copper, silver, naphthalene, toluene and xylenes. Contaminants of potential concern identified in this screening step included benzene, antimony, cadmium, lead, mercury, nickel, zinc and phenol. These contaminants will be analyzed in a more quantitative assessment. Because of the conservative nature of this screening analysis, no important effect on human health can be assumed. The analysis serves to eliminate contaminants that do not warrant further time and attention.

Major uncertainties and conservative assumptions in this screening assessment included:

1. use of worst-case water concentrations;

2. use of average chemical concentrations that exclude zero values;

3. use of conservative ingestion rates and exposure periods;

4. use of generic bioaccumulation factors; and

5. use of uncertain reference doses that include large safety factors or are not verified by USEPA (lead, mercury, antimony, nickel).

Hazard quotients for antimony, cadmium, nickel and zinc and water quality ratios for mercury, nickel and naphthalene exceeded 1 by less than an order of magnitude. The cancer risk estimate for benzene slightly exceeded 1×10^{-4}. Phenol exceeded the Louisiana water quality criteria only for the maximum effluent concentration. A more realistic and quantitative assessment using predicted dilutions for the entire range of discharges and effluent concentration distributions is expected to predict few exceedances. This analysis is being done.

Contaminants that exceeded hazard quotients by more than an order of magnitude were lead and mercury. These contaminants are being assessed in a quantitative, probabilistic risk assessment that includes best estimates of distributions for: dilution factors, effluent concentrations, bioaccumulation factors, ingestion rates, and dose-response relationships. Other contaminants that exceed hazard quotients or water quality ratios of 1 after a more quantitative assessment using dilution factor and effluent concentrations distributions will also be assessed using this more quantitative approach.

The major uncertainties and conservatisms in the screening assessment will be addressed in the analysis:

1. dilution factor distributions, rather than a single conservative value will be used;

2. chemical concentration distributions in the effluent will reflect values reported below the detection limit (essentially zero);

3. intake rate distributions derived from the field survey conducted in the USDOE field survey will replace the conservative assumption used in the screening analysis;

4. the conservative lifetime exposure period used in the screening analysis will be replaced by a more reasonable distribution of exposure periods;

5. literature on bioaccumulation of these contaminants will be reviewed and values relevant to fish living in the Gulf of Mexico derived;

6. more up-to-date dose-response relationships will be used in the assessment:

- dose-response functions are available for lead and mercury that take into account its pharmacokinetic behavior (Carlisle and Wade, 1992; Lipfert *et al.*, 1993; 1994)
- available toxicity data will be reviewed for antimony and cadmium to reduce the uncertainty and conservatisms inherent in the USEPA Rfds;

9 ECOLOGICAL RISK ASSESSMENT FOR METALS , ORGANICS AND TOTAL EFFLUENT

9.1 Introduction and Approach

Three screening analysis were performed to identify potential ecological effects and important receptors.

1. Screening assessment of sediment toxicity.

Sediment metal and PAH concentrations measured at the Delacroix Island and Bay De Chene USDOE study sites were compared to proposed sediment quality criteria.

2. Screening assessment of potential toxicity of individual contaminants in the water column.

Worst-case predicted water column concentrations of contaminants measured in continuing open bay effluents (LDEQ permit files) were compared to USEPA and Louisiana water quality criteria.

3. Screening assessment of effluent toxicity.

Predicted water column concentrations of effluent were compared to results of acute and chronic toxicity tests performed in the laboratory with standard test organisms.

9.2 Sediment Toxicity -- USDOE Open Bay Sites

Sediment Quality Criteria

Marine environments containing high levels of (multiple) contaminants may be associated with adverse effects on biota. However, no direct causal relationship has been established between a contaminant and a biological effect in a marine environment. Therefore, development of sediment quality criteria relies on prudent use of the best information available and empirical data (E.V.S. Consultants, 1990).

Toxicity determination of sediment contamination has the same problems as assessment of any complex mixture. Currently the sediment equilibrium partitioning (SEP) approach for individual contaminants is the most widely available procedure for evaluating toxicity of sediments. SEP combines a theoretical combination of equilibrium partitioning, with a correction for the effects of organic carbon and, in some cases, acid volatile sulfides. Sediment criteria (Table 9-3), based on specific levels of probability of toxicological effects that could be related to compilations of a biological effects database (BEDS) for contaminant concentrations in marine and estuarine sediments, were recently updated, but remain generally consistent with those previously reported (Long *et al.*, 1990; 1995).

BEDS includes a wide variety of adverse biological effects and information derived from all the types of measurements described above. Concentrations in each study included in BEDS were assigned an effects/no effects descriptor, and ascending orders of concentration were assigned percentile values to describe the distributions. The lower tenth percentile level was identified as the Effects Range Low (ERL) value, the fiftieth percentile was identified the Effects Range Median (ERM) value. Measured sediment values below the ERL value of a contaminant represent a minimal effects range, where effects "would rarely be observed". Concentrations at and above the ERL value, but less than the ERM value, "represent a possible-effects range within which effects would occasionally occur". Concentrations at or above the ERM value "represent a probable effects range within which effects would frequently occur" (Long *et al.*, 1995).

Screening Ecological Risk Assessment for Sediment

A screening ecological risk assessment was performed, using preliminary data that describe concentrations of heavy metals and PAHs in sediment cores taken at sampling stations at the Bay De Chene and Delacroix Island USDOE study sites (Appendix A). These data were compared to sediment quality criteria (Table 9-1) developed for contaminants in marine and estuarine sediments (Long *et al.*, 1995).

Table 9-2 shows the results of the screening assessment for metals in sediment, and Tables 9-3, 4 and 5 show the results of the PAH analyses.

Table 9-1 Proposed sediment quality criteria (from Long *et al.*, 1995).

Contaminant	Criteria ERL[1]	ERM[2]
Metals	ppm[3]	ppm[3]
Arsenic	8.2	70
Cadmium	1.2	9.6
Chromium	81	370
Copper	34	270
Lead	46.7	218
Mercury	0.15	0.71
Nickel	20.9	51.6
Silver	1.0	3.7
Zinc	150	410
Organics	ppb[3]	ppb[3]
Total PCBs	22.7	180
Total PAH	4022	44792
Acenapthene	16	500
Acenaphthylene	44	640
Anthracene	85.3	1100
Fluorene	19	540
2-Methylnaphthalene	70	670
Naphthalene	160	2100
Phenanthrene	240	1500
Low Molec. Weight-PAH	552	3160
Benzo(a)anthracene	261	1600
Benzo(a)pyrene	430	1600
Chrysene	384	2800
Dibenzo(a,h)anthracene	63.4	260
Fluoranthene	600	5100
Pyrene	665	2600
High Molec. Weight-PAH	1700	9600

1 ERL: effects range low
2 ERM: effects range median
3 dry weight

Table 9-2. Measured metal concentrations that exceed sediment ERL: criteria (Long *et al.*, 1995) at sampling sites around two production platforms near the coast of Louisiana.(*mean value)

	As (ppm)	Ni (ppm)
ERL	8.2	20.9
Site/Sample		
Delacroix Island		
R1	4.73*	25.10*
R2	3.58*	20.00*
Discharge	10.70*	22.70*
100NW		23.73*
300NW		24.72*
500NW		21.16*
100NE		21.7
300NE		21.6
500NE		22.6
Bay de Chene		
R1	8.67*	20.60*
R2	7.47*	21.53*
Discharge	11.00*	24.18*
100NW	10.43*	28.17*
300NW	13.90	25.70
500NW	8.70	23.90
100SW		25.30
300SW		22.80
1000SW		22.90
100NE		28.83
300NE		25.10*
500NE		28.33*
1000NE		28.07*

Table 9-3. Sediment samples from the Delacroix Island area that exceeded ERL values (Long *et al.*, 1995) for total and individual PAH concentrations.

Contaminant	ERL (ppb)	Measured (ppb)	Location	Sediment Depth (cm)
Total PAH	4,022	9,406	Discharge	0 to 5
		8,143	Discharge	20 to 25
		20,065	Discharge	0 to 5
		6,913	Discharge	35 to 40
		9,142	Discharge	0 to 5
		16,401	Discharge	20 to 25
		6,056	100 ft NW	0 to 5
Acenaphthene	16	22	Discharge	0 to 5
		130	Discharge	20 to 25
		41	Discharge	35 to 40
		50	Discharge	0 to 5
		64	Discharge	20 to 25
		190	Discharge	35 to 40
		24	Discharge	0 to 5
		280	Discharge	20 to 25
		19	Discharge	35 to 40
		99	100 ft NW	0 to 5
		180	300 ft NW	0 to 5
		69	500 ft NW	0 to 5
		210	100 ft NE	0 to 5
		71	300 ft NE	0 to 5
		140	500 ft NE	0 to 5
Acenaphthylene	44	-	-	-
Anthracene	85	150	Discharge	20 to 25
		200	100 ft NW	0 to 5
Fluorene	19	53	Discharge	0 to 5
		83	Discharge	20 to 25
		100	Discharge	0 to 5
		48	Discharge	20 to 25
		58	Discharge	35 to 40
		50	Discharge	0 to 5
		76	Discharge	20 to 25
Naphthalene	160	160	Discharge	0 to 5
		200	Discharge	0 to 5
		160	Discharge	0 to 5
		260	Reference 1	35 to 40
Benzo(a)anthracene	261	320	Discharge	20 to 25
		350	Discharge	35 to 40
		1,000	Discharge	20 to 25
		350	100 ft NW	0 to 5
Benzo(a)pyrene	430	470	Discharge	20 to 25
Chrysene	384	470	Discharge	20 to 25
		1,200	Discharge	20 to 25
Dibenzo(a,h) anthracene	63	67	Discharge	20 to 25
Fluoranthene	600	1,000	Discharge	20 to 25
		620	Discharge	35 to 40
		1,400	Discharge	35 to 40
		3,500	Discharge	20 to 25
		900	100 ft NW	0 to 5
Pyrene	665	2,200	Discharge	20 to 25
		880	Discharge	35 to 40

Table 9-4. Sediment samples from the Bay de Chene area that exceeded ERL values (Long *et al.*, 1995) for total and individual PAH concentrations.

Contaminant	ERL (ppb)	Measured (ppb)	Location	Depth (cm)
Total PAH	4022	23723	Discharge	0 to 5
		18003	Discharge	20 to 25
		35369	Discharge	35 to 40
		162152	Discharge	0 to 5
		28980	Discharge	20 to 25
		49963	Discharge	35 to 40
		32179	Discharge	0 to 5
		31482	Discharge	20 to 25
		43359	Discharge	35 to 40
		6336	300 ft NE	0 to 5
		5370	100 ft NW	0 to 5
		4075	300 ft NW	0 to 5
		11577	100 ft NE	0 to 5
Acenaphthene	16	180	Discharge	0 to 5
		69	Discharge	20 to 25
		99	Discharge	35 to 40
		210	Discharge	0 to 5
		71	Discharge	20 to 25
		140	Discharge	35 to 40
		250	Discharge	0 to 5
		110	Discharge	20 to 25
		140	Discharge	35 to 40
		48	100 ft NE	0 to 5
		20	300 ft NE	0 to 5
Acenaphthylene	44	-	-	-
Anthracene	85.3	250	Discharge	0 to 5
		150	Discharge	20 to 25
		160	Discharge	35 to 40
		1000	Discharge	0 to 5
		300	Discharge	20 to 25
		220	Discharge	35 to 40
		470	Discharge	0 to 5
		210	Discharge	20 to 25
		180	Discharge	35 to 40
		86	100 ft NE	0 to 5
Fluorene	19	230	Discharge	0 to 5
		130	Discharge	20 to 25
		240	Discharge	35 to 40
		390	Discharge	0 to 5
		150	Discharge	20 to 25
		350	Discharge	35 to 40
		340	Discharge	0 to 5
		210	Discharge	20 to 25
		320	Discharge	35 to 40
		22	100 ft NW	0 to 5
		33	300 ft NW	0 to 5
		67	100 ft NE	0 to 5
Naphthalene	160	160	Discharge	0 to 5

Table 9-4 continued

Contaminant	ERL (ppb)	Measured (ppb)	Location	Depth (cm)
Phenanthrene	240	890	Discharge	0 to 5
		300	Discharge	20 to 25
		600	Discharge	35 to 40
		1800	Discharge	0 to 5
		370	Discharge	20 to 25
		890	Discharge	35 to 40
		1400	Discharge	0 to 5
		490	Discharge	20 to 25
		680	Discharge	35 to 40
		250	100 ft NE	0 to 5
		260	300 ft NE	0 to 5
Benzo(a)anthracene	261	960	Discharge	0 to 5
		470	Discharge	20 to 25
		330	Discharge	35 to 40
		12000	Discharge	0 to 5
		780	Discharge	20 to 25
		490	Discharge	35 to 40
		1400	Discharge	0 to 5
		760	Discharge	20 to 25
		340	100 ft NE	0 to 5
		350	300 ft NE	0 to 5
Benzo(a)pyrene	430	850	Discharge	0 to 5
		9000	Discharge	0 to 5
		530	Discharge	20 to 25
		1200	Discharge	0 to 5
		650	Discharge	20 to 25
Chrysene	384	1000	Discharge	0 to 5
		600	Discharge	20 to 25
		470	Discharge	35 to 40
		11000	Discharge	0 to 5
		790	Discharge	20 to 25
		600	Discharge	35 to 40
		1300	Discharge	0 to 5
		820	Discharge	20 to 25
		470	100 ft NE	0 to 5
Dibenzo(a,h) anthracene	63.4	150	Discharge	0 to 5
		78	Discharge	20 to 25
		1700	Discharge	0 to 5
		95	Discharge	20 to 25
		83	Discharge	35 to 40
		210	Discharge	0 to 5
		130	Discharge	20 to 25
		70	100 ft NE	0 to 5
Fluoranthene	600	2100	Discharge	0 to 5
		1000	Discharge	20 to 25
		780	Discharge	35 to 40
		8100	Discharge	0 to 5
		1300	Discharge	20 to 25
		1200	Discharge	35 to 40
		2700	Discharge	0 to 5
		1700	Discharge	20 to 25
		800	Discharge	35 to 40
		910	100 ft NE	0 to 5
		650	300 ft NE	0 to 5
Pyrene	665	1500	Discharge	0 to 5
		810	Discharge	20 to 25
		6100	Discharge	0 to 5
		940	Discharge	20 to 25
		960	Discharge	35 to 40
		1900	Discharge	0 to 5
		1300	Discharge	20 to 25
		730	100 ft NE	0 to 5

Table 9-5. PAH concentrations in marine sediments at Bay de Chene that exceed ERM concentrations.

Contaminant	ERM (ppb)	Measured (ppb)	Location	Sediment Depth (cm)
Total PAH	44,792	162,152	Discharge	0 to 5
		49,963	Discharge	35 to 40
Benzo(a)anthracene	1,600	12,000	Discharge	0 to 5
Benzo(a)pyrene	1,600	9,000	Discharge	0 to 5
Chrysene	2,800	11,000	Discharge	0 to 5
Dibenzo(a,h)anthracene	260	1,700	Discharge	0 to 5
Fluoranthene	5,100	8,100	Discharge	0 to 5
Pyrene	2,600	6,100	Discharge	0 to 5
High Molecular Weight PAH	9,600	47,900	Discharge	0 to 5

None of the measured concentration of metals in sediment samples exceeded their respective ERM value. In general, measured sediment concentrations were below the ERL (minimal effects range), with the exception of arsenic and nickel. Each of these metals exceeded its ERL value in samples from at least one reference site, and each discharge site. Excess arsenic was detected up to 500 ft from the Bay de Chene discharge (Table 9-2). Excess nickel was detected up to 500 ft from the Delacroix Island discharge, and up to 1,000 ft from the Bay de Chene Discharge. There was no clear pattern of concentration with distance from a discharge.

With the exception of acenaphthene, individual and total PAH concentrations exceeded ERL criteria at, and 100 ft from the discharge site (Table 9-3). Acenaphthene concentrations exceeded the ERL values at the discharge, 100, 300 and 500 ft sample sites. Neither individual nor total PAH concentrations in sediment samples from Delacroix Island exceeded ERM criteria.

Individual and total PAH concentrations exceeded ERL criteria at the discharge site, and 100 ft and 300 ft from the discharge (Table 9-4). For Bay de Chene, individual and total PAH concentrations in samples from the discharge site exceeded ERM criteria (Table 9-5).

Depressed numbers of individuals and numbers of species were found only at the discharge stations in preliminary results of the benthos sampling performed at the two platforms (Mulino et al., 1995). For Bay de Chene, the comparisons of PAH concentrations to ERM criteria were consistent with the results of benthos observations. Further work will be done to analyze the relationships of PAH concentrations to distance and depth, and to search for relationships to the benthos sampling results at the two stations.

These results are preliminary, and cannot be applied to all other open bay discharge sites with much confidence, but the discharge rates and depths of the Bay De Chene and Delacroix Island study sites are comparable (discharge rates are on high end of distribution) to those that are continuing to discharge (see section 5).

9.3 Toxicity of Individual Produced Water Components - Continuing Open Bay Discharges

A screening analysis was performed for potential toxic effects from individual contaminants in continuing open bay discharges. Worst-case predicted water column concentrations of contaminants measured in continuing open bay effluents (LDEQ permit files) were compared to USEPA and Louisiana water quality criteria.

Concentrations in the effluent for continuing open bay discharges were described by the data abstracted from LDEQ permit files (section 5). These data are only for contaminants detected in the effluent above the reported detection limit and so overestimate average concentrations.

Based on the modeling described in section 5, a conservative dilution factor of 20 was chosen to estimate worst-case water chemical concentrations both 50 and 200 feet from the discharge. Most contaminants were assumed to remain in solution. Dissolved fractions of copper. lead and zinc were assumed to be 0.88, 0.38 and 0.59, respectively (USEPA, 1995).

In this preliminary assessment, contaminants were assessed only if : they were reported above detection limits in more than two of the LDEQ permit files; and water quality criteria were available. Mean and maximum chemical contaminant concentrations in the data set for continuing open bay discharges were diluted by a factor of 20 to estimate water concentrations at 200 feet (Table 9-6).

Louisiana and USEPA water quality criteria (Table 9-6) were compared to the predicted water concentrations at 200 feet. A ratio was calculated by dividing the concentration predicted in water by the acute and chronic water quality criteria. Ratios greater than 1 suggest a potential for toxic effects. Results are given in Tables 9-7 and 9-8.

Table 9-6. Worst-case concentrations predicted at 50 and 200 feet and water quality criteria.

Contaminant	Predicted Concentration (μg/l)		Acute Water Quality Criteria (μg/l)		Chronic Water Quality Criteria (μg/l)	
	mean	maximum	La	USEPA	La	USEPA
Antimony	279.8	1005		1500		500
Arsenic	3.7	24.9	69	69	36	36
Cadmium	11.6	25.0	45.6	43	10	9.3
Chromium (VI)	4.2	10.0	1100	1100	50	50
Copper	12.7	31.2	4.37	2.9	4.37	
Lead	1981.0	15751	220	140	8.5	5.6
Mercury	0.4	1.4	2.1	2.1	0.025	0.025
Nickel	50.7	142	75	75	8.3	8.3
Silver	7.2	20.0		7.2		0.92
Zinc	35.9	188.1	95	95	86	86
Benzene	90.7	477.5	2700	5100	1350	700
Naphthalene	3.0	5.9		2300		
Phenol	77.9	600	580	5800	290	
Toluene	41.6	140	950	6300	475	5000

Table 9-7. Ratios: predicted concentrations at 50 feet/ acute water quality criteria.

Contaminant	La Acute Water Quality Criteria Ratio		USEPA Acute Water Quality Criteria Ratio	
	mean	maximum	mean	maximum
Antimony			0.2	0.7
Arsenic	0.1	0.4	0.1	0.4
Cadmium	0.3	0.6	0.3	0.6
Chromium (VI)	0.004	0.01	0.004	0.01
Copper	2.9	7.1	4.4	10.7
Lead	9.0	71.6	14.1	112.5
Mercury	0.2	0.6	0.2	0.6
Nickel	0.7	1.9	0.7	1.9
Silver			1.0	2.8
Zinc	0.4	2.0	0.4	2.0
Benzene	0.03	0.2	0.02	0.1
Naphthalene			0.001	0.002
Phenol	0.1	1.0	0.01	0.1
Toluene	0.04	0.2	0.01	0.02

Table 9-8. Ratios: predicted concentrations at 200 feet/ chronic water quality criteria.

Contaminant	La Chronic Water Quality Criteria Ratio		USEPA Chronic Quality Criteria Ratio	
	mean	maximum	mean	maximum
Antimony			0.6	2.0
Arsenic	0.1	0.7	0.1	0.7
Cadmium	1.2	2.5	1.2	2.7
Chromium (VI)	0.1	0.20	0.1	0.2
Copper	2.9	7.1		
Lead	233.0	1853.0	353.7	2812.7
Mercury	14.2	54.0	14.2	54.0
Nickel	6.1	17.1	6.1	17.1
Silver			7.8	21.7
Zinc	0.4	2.2	0.4	2.2
Benzene	0.1	0.4	0.1	0.7
Naphthalene				
Phenol	0.3	2.1		
Toluene	0.1	0.3	0.01	0.03

Worst-case predicted water concentrations exceeded acute water quality standards for copper, lead, nickel, silver and zinc. Chronic water quality criteria were exceeded for antimony, cadmium, copper, lead, mercury, nickel, silver, zinc and phenol. Contaminants eliminated from further consideration included arsenic, chromium, benzene, naphthalene and toluene.

Because of the conservative nature of this screening analysis, no important effect on aquatic biota can be assumed. The analysis serves to eliminate contaminants that do not warrant further time and attention.

Major uncertainties and conservative assumptions in this screening assessment include:

1. use of worst-case water concentrations;

2. use of average chemical concentrations that exclude zero values;

3. simple comparison to water quality criteria with no reference to specific receptors or end-points of concern in open Louisiana bays.

Water quality ratios of one were exceeded by less than an order of magnitude for cadmium, silver, zinc, and phenol. Contaminants eliminated from further consideration included arsenic, chromium, benzene, naphthalene and toluene.

A more realistic and quantitative assessment using predicted dilutions for the entire range of discharges and effluent concentration distributions is expected to predict few exceedances. This analysis is being done.

Water quality ratios exceeded one by more than an order of magnitude for copper, lead, mercury, and nickel. These contaminants are being assessed in a quantitative risk assessment that includes best estimates of distributions for: dilution factors, effluent concentrations, and dose-response relationships and follows the USEPA suggested framework for ecological risk assessment (USEPA< 1992). Other contaminants that exceed hazard quotients or water quality ratios of 1 after a more quantitative assessment using dilution factor and effluent concentrations distributions will also be assessed using this more quantitative approach.

The major uncertainties and conservatisms in the screening assessment will be addressed in the analysis:

1. Dilution factor distributions, rather than a single conservative value will be used;

2. Chemical concentration distributions in the effluent will reflect values reported below the detection limit (essentially zero);

3. Statistical methods will be used to estimate toxic effects in species important in the Gulf of Mexico from measured effects in *Mysidposis bahia* and *Cyprinodon variegatus*.

9.4 Toxicity of Effluent -- Continuing Open Bay Discharges
Toxicity of Produced Water

Predicted water column concentrations of effluent were compared to results of acute and chronic toxicity tests performed in the laboratory with standard test organisms.

Toxicity tests are useful analytical tools because they can directly measure potential aquatic effects compared to chemical analyses which are difficult to extrapolate. This is particularly true in the case of complex effluents, such as produced water, where a broad range of toxicants can be present in low levels. Produced water test procedures usually use mortality as the measured response with results of acute tests expressed as an effluent median lethal concentration for an exposure duration of 96 hrs (96-hr LC_{50}) or the effluent concentration which results in the mortality of 50% of the test organisms in a 96-hr exposure period.

Toxicity test data available in LDEQ permit files for assumed continuing discharge sites are summarized in section 5. The estimated distribution of percent effluent expected at 50 and 200 feet for the continuing discharges in open bays is given in Table 5-8.

Acute and chronic toxicity ratios were calculated based on mean, maximum and minimum percent effluent and mean and minimum (i.e. most toxic) LC50 and chronic NOEL for survival values (*Mysidopsis bahia; Cyprinodon variegatus*). Results of this simple ratio test are shown in Table 9-9 and 9-10. Ratios greater than one suggest a potential for toxic effects.

These results suggest a potential for toxic effects for some discharges at 50 feet (acute) and at 200 feet (chronic). A more quantitative assessment will be performed to estimate the number of discharges where toxicity is expected for fish and crustaceans important in the Gulf of Mexico.

Table 9-9. Acute toxicity ratio: percent effluent at 50 feet / LC_{50}.

	ACUTE TOXICITY RATIO			
Percent	*Mysidposis bahia*		*Cyprinodon variegatus*	
Effluent	mean	minimum	mean	minimum
mean	0.6	**63.7**	0.2	**1.9**
maximum	**1.4**	**151.4**	0.6	**4.4**
minimum	0.1	**14.0**	0.1	0.4

Table 9-10. Chronic survival toxicity ratio: percent effluent at 200 feet / NOEL.

	CHRONIC SURVIVAL TOXICITY RATIO			
Percent	*Mysidposis bahia*		*Cyprinodon variegatus*	
Effluent	mean	minimum	mean	minimum
mean	0.7	37.9	0.4	17.7
maximum	3.3	176.4	1.8	82.3
minimum	0.04	1.9	0.02	0.9

This quantitative assessment will:

1. Use distributions of percent effluent at 50 and 200 feet rather than maximum or average values;

2. Use statistical methods to estimate toxic effects in species important in the Gulf of Mexico from measured effects in *Mysidposis bahia* and *Cyprinodon variegatus*. Models are available to incorporate taxonomic differences, difference in life stage and size, mode of exposure, severity and proportion responding (Suter, 1993b).

3. Quantify risk by the degree of overlap between the distribution of percent effluent and the derived effect distributions for important ecological receptors. The use of distributions recognizes the variability in exposure in space and time and the natural variability in response of individuals and populations.

10 SUMMARY AND CONCLUSIONS

The risk assessment presented in this report is an interim, preliminary analysis. Screening-level assessments were performed to identify potentially important contaminants and ecological receptors, and to eliminate others from further consideration. Based on the results of this preliminary analysis, additional probabilistic risk assessments are being done for specific contaminants and ecological receptors. A probabilistic analysis was completed for radium ingestion by recreational fishermen and their families and is presented in this report.

Human Health Risk Assessment for Radium

Screening and probabilistic human health risk assessments were done for open bay radium discharges in Louisiana.

A screening assessment was performed using worst-case estimates of concentrations in fish, ingestion rates and dose-response factors to determine the need for a more quantitative analysis.

Predicted screening-level risks were greater than 1×10^{-3} for the modeled continuing discharges. These results are from a conservative, screening level assessment, and do not represent best estimates of risk associated with radium discharged by open bay platforms. They do, however, suggest the need for a more detailed, probabilistic assessment.

A probabilistic risk assessment was done using distributions of: radium concentrations in fish based (from field sampling and modeling); fish ingestion rates (from USDOE fishermen survey); and risk factors (Meinhold et al., 1995).

Median individual lifetime fatal cancer risks for both USDOE study sites (Delacroix Island and Bay De Chene) were less than 1×10^{-6}, and median and 95th percentile risks were less than 1×10^{-5}. Median individual lifetime fatal cancer risks for continuing open bay discharges were 2.2×10^{-7}, and 95th percentile risks were 1.9×10^{-5}.

These results suggest that the ingestion of radium in fish near open bay produced water platforms does not present an important risk to human health.

Ecological Risk Assessment for Radionuclides

This assessment used concentrations of radionuclides measured in the effluent at the two USDOE study sites, and radium concentrations reported in permit files for continuing open bay discharges to assess potential ecological effects from radionuclides discharged in produced water. Worst-case water concentrations were predicted using a dilution factor derived from the modeling analyses presented in section 5. Predicted water concentrations were compared to screening dose-rate factors developed by IAEA (1988) that relate the radiation exposure to an organism to a unit concentration of the radionuclide in the water in which the organism lives. Estimated doses were compared to reference dose rates suggested by the National Council on Radiation Protection (NCRP, 1991).

Based on a simple conservative screening analysis, no doses to aquatic animals are predicted from radionuclides in produced water discharges above the NCRP reference level of 10 mSv/d. Because of the conservative nature of this initial analysis, it can be concluded that no effects on aquatic animals from radionuclides discharged in produced water to open bays in Louisiana are expected. Additional quantitative assessments could be performed to assess the extent to which the NCRP screening level of 2.4 mSv/d are likely to be exceeded.

Human Health Risk Assessment for Chemical Contaminants

A screening human health risk assessment was done for metals and organic compounds measured in continuing open bay discharges. This analysis followed the USEPA approach to estimating risks from toxic materials and carcinogens by applying RfD (reference dose) and slope factor values to estimates of chemical intake rates (USEPA, 1989b). Predicted water concentrations were also compared to USEPA and Louisiana human health water quality criteria.

Contaminants eliminated from further consideration were arsenic, chromium, copper, silver, naphthalene, toluene and xylenes. Contaminants of potential concern identified in this screening step included benzene, antimony, cadmium, lead, mercury, nickel, zinc and phenol. These contaminants will be analyzed in a more quantitative assessment. Because of the conservative nature of this screening analysis, no important effect on human health can be assumed. The analysis serves to eliminate contaminants that do not warrant further time and attention.

Major uncertainties and conservative assumptions in this screening assessment included:

1. use of worst-case water concentrations;

2. use of average chemical concentrations that exclude zero values;

3. use of conservative ingestion rates and exposure periods;

4. use of generic bioaccumulation factors; and

5. use of uncertain reference doses that include large safety factors or are not verified by USEPA (lead, mercury, antimony, nickel).

Hazard quotients for antimony, cadmium, nickel and zinc and water quality ratios for mercury, nickel and naphthalene exceeded one by less than an order of magnitude. The cancer risk estimate for benzene slightly exceeded 1×10^{-4}. Phenol exceeded the Louisiana water quality criteria only for the maximum effluent concentration. A more realistic and quantitative assessment using predicted dilutions for the entire range of discharges and effluent concentration distributions is expected to predict few exceedances for these contaminants. This analysis is being done.

Contaminants that exceeded hazard quotients by more than an order of magnitude were lead and mercury. These contaminants are being assessed in a quantitative, probabilistic risk assessment that includes best estimates of distributions for: dilution factors, effluent concentrations, bioaccumulation factors, ingestion rates, and dose-response relationships. Other contaminants that exceed hazard quotients or water quality ratios of one after a more quantitative assessment using dilution factor and effluent concentrations distributions will also be assessed using this approach.

The major uncertainties and conservatisms in the screening assessment will be addressed in the analysis:

1. dilution factor distributions, rather than a single conservative value will be used;

2. chemical concentration distributions in the effluent will reflect values reported below the detection limit;

3. intake rate distributions derived from the field survey conducted in the USDOE field survey will replace the conservative assumption used in the screening analysis;

4. the conservative lifetime exposure period used in the screening analysis will be replaced by a more reasonable distribution of exposure periods;

5. literature on bioaccumulation of these contaminants will be reviewed and values relevant to fish living in the Gulf of Mexico derived; and

6. more up-to-date dose-response relationships will be used in the assessment:

- dose-response functions are available for lead and mercury that take into account its pharmacokinetic behavior (Carlisle and Wade, 1992; Lipfert *et al.*, 1993; 1994)
- available toxicity data will be reviewed for antimony and cadmium to reduce the uncertainty and conservatisms inherent in the USEPA Rfds.

Ecological Risk Assessment for Chemical Contaminants and Effluent

Three screening assessments were performed:

1. Screening assessment of sediment toxicity.

Sediment metal and PAH concentrations measured at the USDOE study sites were compared to proposed sediment quality criteria.

None of the measured concentration of metals in sediment samples exceeded their respective ERM value. In general, measured sediment concentrations were below the ERL (minimal effects range), with the exception of arsenic and nickel. Each of these metals exceeded its ERL value in samples from at least one reference site, and each discharge site. There was no clear pattern of concentration with distance from a discharge.

With the exception of acenaphthene, individual and total PAH concentrations exceeded ERL criteria at, and 100 ft from the discharge site. Acenaphthene concentrations exceeded the ERL values at the discharge, 100, 300 and 500 ft sample sites. Neither individual nor total PAH concentrations in sediment samples from Delacroix Island exceeded ERM criteria.

Individual and total PAH concentrations exceeded ERL criteria at the discharge site, and 100 ft and 300 ft from the discharge. For Bay de Chene, individual and total PAH concentrations in samples from the discharge site exceeded ERM criteria.

Depressed numbers of individuals and numbers of species were found only at the discharge stations in preliminary results of the benthos sampling performed at the two platforms (Mulino et al., 1995). For Bay de Chene, the comparisons of PAH concentrations to ERM criteria were consistent with the results of benthos observations. Further work will be done to analyze the relationships of PAH concentrations to distance and depth, and to search for relationships to the benthos sampling results at the two stations.

These results are preliminary, and cannot be applied to all other open bay discharge sites with much confidence, but the discharge rates and depths of the Bay De Chene and Delacroix Island study sites are comparable (discharge rates are on high end of distribution) to those that are continuing to discharge.

<u>2. Screening assessment of potential toxicity of individual contaminants in the water column.</u>

Worst-case predicted water column concentrations of contaminants measured in continuing open bay effluents (LDEQ permit files) were compared to USEPA and Louisiana water quality criteria.

Worst-case predicted water concentrations exceeded acute water quality standards for copper, lead, nickel, silver and zinc. Chronic water quality criteria were exceeded for antimony, cadmium, copper, lead, mercury, nickel, silver, zinc and phenol. Contaminants eliminated from further consideration included arsenic, chromium, benzene, naphthalene and toluene.

Because of the conservative nature of this screening analysis, no important effect on aquatic biota can be assumed. The analysis serves to eliminate contaminants that do not warrant further time and attention.

Major uncertainties and conservative assumptions in this screening assessment include:

1. use of worst-case water concentrations;

2. use of average chemical concentrations that exclude zero values;

3. simple comparison to water quality criteria with no reference to specific receptors or end-points of concern in open Louisiana bays.

Water quality ratios of one were exceeded by less than an order of magnitude for cadmium, silver, zinc, and phenol. A more realistic and quantitative assessment using predicted dilutions for the entire range of discharges and effluent concentration distributions is expected to predict few exceedances. This analysis is being done.

Water quality ratios exceeded one by more than an order of magnitude for copper, lead, mercury, and nickel. These contaminants are being assessed in a quantitative risk assessment that includes best estimates of distributions for: dilution factors, effluent concentrations, and dose-response relationships. Other contaminants that exceed hazard quotients or water quality ratios of one after a more quantitative assessment using dilution factor and effluent concentrations distributions will also be assessed using this more quantitative approach.

The major uncertainties and conservatisms in the screening assessment will be addressed in the analysis:

1. dilution factor distributions, rather than a single conservative value will be used;

2. chemical concentration distributions in the effluent will reflect values reported below the detection limit;

3. literature on dose-response functions for these contaminants will be reviewed and values relevant to fish living in the Gulf of Mexico derived.

3. Screening assessment of effluent toxicity.

Predicted water column concentrations of effluent were compared to results of acute and chronic toxicity test performed in the laboratory with standard test organisms.

These results suggest a potential for toxic effects for some discharges at 50 feet (acute) and at 200 feet (chronic). A more quantitative assessment will be performed to estimate the number of discharges where toxicity is expected for fish and crustaceans important in the Gulf of Mexico. This quantitative assessment will:

1. Use distributions of percent effluent at 50 and 200 feet rather than maximum or average values;

2. Use statistical methods to estimate toxic effects in species important in the Gulf of Mexico from measured effects in *Mysidposis bahia* and *Cyprinodon variegatus.*

3. Quantify risk by the degree of overlap between the distribution of percent effluent and the derived effect distributions for important ecological receptors.

Conclusions

The tiered approach to risk assessment is a cost-effective way to provide risk managers with information needed to make risk management decisions. This screening assessment for human health and ecological risks eliminated a number of contaminants from further consideration. More quantitative assessments are being performed on contaminants of potential concern.

Human health risks from radium in produced water appear to be small. Ecological risks from radium and other radionuclides in produced water also appear to be small.

Many of the chemical contaminants discharged to open Louisiana bays appear to ppresent little human health or ecological risk and will not be analyzed further.

A conservative screening analysis suggested potential risks to human health from mercury and lead. Conservative screening analyses suggested a potential for risks to ecological receptors from total effluent, antimony, cadmium, copper, lead, nickel, silver, zinc and phenol in the water column and PAHs in sediment.

Quantitative risk assessments are being done for these contaminants.

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APPENDIX A
USDOE OPEN BAY SITES: PRELIMINARY DATA

Table A-1. Preliminary radium data in tissue collected at Delacroix Island and Bay De Chene.

Tissue analysis results.

Site	Survey	Station	Organism	Tissue Type*	Number of Specimens in Composite	^{226}Ra [LLD**] (pCi/g)	^{228}Ra [LLD] (pCi/g)
Bay de Chene	Spring 1993	Discharge	Croaker	Whole	11	0.021 [0.004]	0.038 [0.012]
					11	0.014 [0.004]	0.094 [0.013]
					11	0.024 [0.004]	0.067 [0.012]
					11	0.008 [0.004]	0.040 [0.012]
					11	0.004 [0.004]	0.029 [0.012]
Bay de Chene	Spring 1993	Discharge	Spot	Whole	15	0.034 [0.007]	0.073 [0.014]
					15	0.023 [0.003]	0.086 [0.009]
					15	0.024 [0.003]	0.018 [0.007]
					15	0.026 [0.003]	0.048 [0.009]
					15	0.019 [0.003]	0.026 [0.009]
Bay de Chene	Spring 1993	Discharge	Seatrout	Whole	8	0.021 [0.004]	0.057 [0.012]
					8	0.016 [0.004]	0.159 [0.011]
					8	0.016 [0.006]	0.121 [0.014]
					8	0.004 [0.003]	0.037 [0.009]
					8	0.004 [0.003]	0.105 [0.009]
Bay de Chene	Spring 1993	Discharge	Blue Crab	Edible	2	0.023 [0.003]	0.056 [0.009]
					2	0.009 [0.003]	0.058 [0.009]
					2	0.020 [0.003]	0.041 [0.008]
					2	0.017 [0.003]	0.059 [0.008]
Bay de Chene	Spring 1993	Discharge	Shrimp	Edible	73	0.007 [0.004]	0.026 [0.010]
					73	0.006 [0.004]	BDL† [0.010]
					73	0.006 [0.004]	BDL [0.010]
					73	0.007 [0.004]	BDL [0.010]
					73	0.011 [0.004]	BDL [0.016]
Bay de Chene	Spring 1993	Reference 1	Croaker	Whole	14	0.027 [0.003]	BDL [0.015]
					14	0.009 [0.003]	BDL [0.015]
					14	0.011 [0.003]	BDL [0.015]
					14	0.010 [0.004]	0.046 [0.019]
					14	0.024 [0.003]	BDL [0.018]

Site	Survey	Station	Organism	Tissue Type*	Number of Specimens in Composite	^{226}Ra [LLD**] (pCi/g)	^{228}Ra [LLD] (pCi/g)
Bay de Chene	Spring 1993	Reference 1	Spot	Whole	8	0.029 [0.003]	BDL [0.018]
					8	0.020 [0.003]	BDL [0.019]
					8	0.024 [0.003]	BDL [0.018]
					8	0.022 [0.003]	BDL [0.018]
					8	0.024 [0.003]	BDL [0.019]
Bay de Chene	Spring 1993	Reference 1	Seatrout	Whole	4	0.016 [0.004]	0.020 [0.007]
Bay de Chene	Spring 1993	Reference 1	Shrimp	Edible	28	0.027 [0.004]	BDL [0.021]
					28	0.013 [0.004]	BDL [0.021]
					28	0.005 [0.003]	BDL [0.018]
					28	0.014 [0.003]	BDL [0.019]
Bay de Chene	Spring 1993	Reference 1	Blue Crab	Edible	20	0.012 [0.003]	BDL [0.019]
Bay de Chene	Spring 1993	Reference 2	Croaker	Whole	13	0.031 [0.004]	BDL [0.010]
					13	0.032 [0.004]	BDL [0.011]
					13	0.024 [0.004]	BDL [0.011]
					13	0.014 [0.004]	BDL [0.010]
					13	0.032 [0.004]	BDL [0.012]
Bay de Chene	Spring 1993	Reference 2	Spot	Whole	10	0.021 [0.004]	BDL [0.013]
					10	0.023 [0.004]	BDL [0.012]
					10	0.008 [0.004]	BDL [0.013]
					10	0.022 [0.004]	BDL [0.012]
					10	BDL [0.004]	0.042 [0.010]
Bay de Chene	Spring 1993	Reference 2	Seatrout	Whole	9	BDL [0.004]	0.036 [0.010]
					9	0.007 [0.004]	0.032 [0.010]
					9	0.012 [0.004]	BDL [0.010]
Bay de Chene	Spring 1993	Reference 2	Shrimp	Edible	111	0.021 [0.003]	BDL [0.017]
					111	0.013 [0.003]	BDL [0.018]
					111	0.006 [0.003]	BDL [0.018]
					111	0.010 [0.003]	BDL [0.018]
					111	0.010 [0.004]	0.124 [0.01]

Site	Survey	Station	Organism	Tissue Type*	Number of Specimens in Composite	^{226}Ra [LLD**] (pCi/g)	^{228}Ra [LLD] (pCi/g)
Bay de Chene	Spring 1993	Reference 2	Blue Crab	Edible	4	0.007 [0.004]	BDL [0.010]
					4	0.024 [0.003]	BDL [0.018]
					4	0.023 [0.003]	BDL [0.018]
					4	0.024 [0.003]	BDL [0.018]
Delacroix Island	Spring 1993	Discharge	Croaker	Edible	16	0.025 [0.004]	0.037 [0.007]
			Spot	Edible	8	0.005 [0.003]	0.027 [0.006]
			Blue Crab	Edible	12	0.013 [0.003]	0.032 [0.006]
Delacroix Island	Spring 1993	Reference 1	Croaker	Edible	16	0.005 [0.004]	0.112 [0.007]
			Spot	Edible	4	BDL [0.004]	0.076 [0.007]
			Blue Crab	Edible	19	0.025 [0.004]	0.090 [0.006]
Delacroix Island	Spring 1993	Reference 2	Croaker	Edible	29	0.018 [0.003]	0.039 [0.007]
			Spot	Edible	6	BDL [0.003]	0.017 [0.006]
			Blue Crab	Edible	13	0.023 [0.004]	0.013 [0.008]
Delacroix Island	Spring 1994	Discharge	Croaker	Edible	56	0.019 [0.003]	0.0159 [0.007]
			Spot	Edible	11	BDL [0.004]	0.036 [0.008]
			Blue Crab	Edible	23	0.007 [0.004]	0.046 [0.008]
Delacroix Island	Spring 1994	Reference 1	Croaker	Edible	16	0.028 [0.022]	0.266 [0.045]
			Spot	Edible	4	BDL [0.004]	0.025 [0.008]
			Blue Crab	Edible	22	0.007 [0.003]	BDL [0.008]
Delacroix Island	Spring 1994	Reference 2	Croaker	Edible	14	0.063 [0.018]	BDL [0.042]
			Spot	Edible	5	BDL [0.003]	0.107 [0.008]
			Blue Crab	Edible	20	0.012 [0.003]	0.041 [0.008]

* Whole = whole specimen analyzed; edible = edible tissue analyzed.
** LLD = Lower limit of detection
† BDL = Below detection limit

Table A-2 Codes used to identify organic compounds in sediment.

Analyte	Code
Naphthalene	CON
C_1-Naphthalene	C1N
C_2-Naphthalene	C2N
C_3-Naphthalene	C3N
C_4-Naphthalene	C4N
Acenaphthylene	ACEY
Acenaphthene	ACE
Biphenyl	BIP
Fluorene	COF
C_1-Fluorene	C1F
C_2-Fluorene	C2F
C_3-Fluorene	C3F
Dibenzothiophene	COD
C_1-Dibenzothiophene	C1D
C_2-Dibenzothiophene	C2D
C_3-Dibenzothiophene	C3D
Phenanthrene	COP
Anthracene	COA
C_1-Phenanthrene/Anthracene	C_1P/A
C_2-Phenanthrene/Anthracene	C_2P/A
C_3-Phenanthrene/Anthracene	C_3P/A
C_4-Phenanthrene/Anthracene	C_4P/A
Fluoranthene	Flant
Pyrene	Pyr
C1-Fluoranthene/Pyrene	C_1F/P
C_2-Fluoranthene/Pyrene	C_2F/P
C_3-Fluoranthenec/Pyrene	C_3F/P
Chrysene	COC
C_1-Chrysene	C1C
C_2-Chrysene	C2C
C_3-Ghrysene	C3C
C_4-Chrysene	C4C
Benzo[a]anthracene	BAA
Benzo[b]fluoranthene	BBF
Benzo[k]fluoranthene	BKE
Benzo[a]pyrene	BAP
Benzo[e]pyrene	BEP
Perylene	PER
Indeno[1,2,3c,d]pyrene	IND
Dibenzo[a,h]anthracene	DAH
Benzo[g,h,i]perylene	BGP

Table A-3. PAHs in sediment collected at Delacroix Island and Bay De Chene.

Delacroix Island Sediment PAH

Site	Depth (cm)	C0N ng/g	2-C1N ng/g	1-C1N ng/g	2,6-C2N ng/g	2,3,5-C3N ng/g	C1N ng/g	C2N ng/g	C3N ng/g	C4N ng/g
Discharge	0 to 5	160	290	170	260	160	350	960	1300	1200
Discharge	20 to 25	17	32	25	85	45	41	210	370	320
Discharge	35 to 40	4.1	0	0	0	1.2	0	0	14	13
Discharge	0 to 5	200	530	310	530	200	640	2200	3300	2600
Discharge	20 to 25	12	6.3	2.9	9.5	11	7.5	53	95	110
Discharge	35 to 40	9.8	5.9	2.6	6.9	7	7	57	100	96
Discharge	0 to 5	160	290	180	210	140	350	960	1300	1100
Discharge	20 to 25	16	8.5	8.8	0	5.3	14	34	87	92
Discharge	35 to 40	0	0	0	0	0	0	0	0	0
Reference 1	0 to 5	3.2	0	0	0	0	0	0	0	0
Reference 1	20 to 25	11	0	0	0	0	0	0	0	0
Reference 1	35 to 40	260	6.4	5.5	7.5	1.3	8.6	17	22	21
Reference 1	0 to 5	6.2	0	0	0	0	0	0	0	0
Reference 1	20 to 25	2.1	0	0	0	0	0	0	0	0
Reference 1	35 to 40	0	0	0	0	0	0	0	0	0
Reference 1	0 to 5	4.9	0	0	0	0	0	0	0	0
Reference 1	20 to 25	4.7	0	0	0	0	0	0	0	0
Reference 1	35 to 40	12	0	0	0	0	0	0	0	0
Reference 2	0 to 5	3.6	2	2	0	0	3.1	0	0	0
Reference 2	20 to 25	8	0	0	0	0	0	0	0	0
Reference 2	35 to 40	7.2	3	1.8	0.8	0	3.6	7.5	8	11
Reference 2	0 to 5	3.2	2.9	2	1.7	0.84	4	8.9	7.4	12
Reference 2	20 to 25	10	0	0	0	0	0	0	0	0
Reference 2	35 to 40	7.4	5	3.6	4.4	1.7	7.2	17	26	35
Reference 2	0 to 5	2.9	1.7	1.1	1.8	0	2.1	5.2	6.7	0
Reference 2	20 to 25	4.9	1.6	1.4	1.1	0	2.5	4.3	4.2	9.1
Reference 2	35 to 40	27	7.8	4.7	2.3	0	8.7	10	11	12
1000 South	0 to 5	1.9	1.8	0.95	1.9	0.55	2.5	4.3	4.8	6.7
500 South	0 to 5	8.6	2.8	1.7	0.99	0	3.8	6.6	5.7	6.6
300 South	0 to 5	2	1.8	1.5	1.4	0.64	2.7	6.3	7.7	13
100 South	0 to 5	3.7	2.6	1.9	1	0.7	3.7	6.3	6.5	8.6
100 NW	0 to 5	8.6	9.5	6.9	14	6.5	11	41	54	53
300 NW	0 to 5	3.5	2.6	2.1	1.5	0.71	3.8	7.1	7.2	11
500NW	0 to 5	2	1.6	1.2	1.3	0.35	2.3	5.1	6.7	7.5
1000 NW	0 to 5	2.2	1.8	1.4	1.6	0.59	2.8	6.6	7.3	9.3
100 NE	0 to 5	8.5	11	6.4	8.3	2.4	12	26	32	49
300 NE	0 to 5	4.8	4	2.1	3.8	2.7	4.2	12	31	63
500 NE	0 to 5	3.8	3.9	2.8	6.3	1.3	4.4	11	16	21

Site	Depth (cm)	ACEY ng/g	ACE ng/g	BIP ng/g	COF ng/g	C1F ng/g	C2F ng/g	C3F ng/g	C0A ng/g	C0P ng/g
Discharge	0 to 5	0	22	38	53	150	420	520	22	110
Discharge	20 to 25	0	130	8.1	83	64	140	170	94	160
Discharge	35 to 40	0	41	0	11	12	17	24	12	12
Discharge	0 to 5	0	50	67	100	320	910	1100	46	220
Discharge	20 to 25	0	64	5.2	48	25	49	64	23	82
Discharge	35 to 40	4.4	190	5.2	58	54	64	74	73	110
Discharge	0 to 5	0	24	37	50	150	390	460	21	97
Discharge	20 to 25	11	280	7.6	76	89	110	130	150	130
Discharge	35 to 40	0	19	0	0	0	0	0	6.4	1.8
Reference 1	0 to 5	0	0	0	2.7	0	13	14	0	6.8
Reference 1	20 to 25	0	0	0	1.9	0	0	0	2.2	5.9
Reference 1	35 to 40	0	0	9.4	7.9	30	77	63	7.4	15
Reference 1	0 to 5	0	0	0	0	0	0	0	2	4.7
Reference 1	20 to 25	0	0	0	2.9	0	0	0	0	8
Reference 1	35 to 40	0	0	0	0	0	0	0	0	3.9
Reference 1	0 to 5	0	0	0	0	0	0	0	0	4.3
Reference 1	20 to 25	0	0	0	3	4.4	0	0	0	6.7
Reference 1	35 to 40	0	0	0	4.6	0	0	0	0	12
Reference 2	0 to 5	0	0	0	0	0	0	0	0	4.2
Reference 2	20 to 25	0	0	0	3.1	0	0	0	3.1	14
Reference 2	35 to 40	2.1	2	4.7	6.4	5	6.3	5.1	7.2	27
Reference 2	0 to 5	0	0	0	2	3.4	7.9	11	2.3	5.7
Reference 2	20 to 25	2.1	2	3.8	7.9	9	21	25	8	24
Reference 2	35 to 40	0	3.9	3.9	9.1	11	36	33	11	36
Reference 2	0 to 5	0	0	1.1	2.1	2.6	6.2	11	1.8	4.4
Reference 2	20 to 25	9.1	0	2.3	4.2	4.2	10	12	3.9	15
Reference 2	35 to 40	12	6	10	10	17	8.7	13	13	62
1000 South	0 to 5	6.7	0	1.4	1.4	1.6	3.1	8.2	1.5	3.9
500 South	0 to 5	2.5	2.5	4.2	6.6	4.4	5	11	6.3	26
300 South	0 to 5	0	2.6	1.2	3.4	4.3	10	14	5.6	11
100 South	0 to 5	0	6.9	1.5	8.5	4.1	5.5	7.5	19	50
100 NW	0 to 5	17	13	4.1	78	48	53	47	200	410
300 NW	0 to 5	0	0	1.3	1.8	2.4	5.8	7.4	1.4	5.4
500NW	0 to 5	0	0	0	1.6	2.3	6.3	8.3	1.8	4.7
1000 NW	0 to 5	0	0	0	2.7	3.9	7	8.3	6.3	14
100 NE	0 to 5	0	0	5	7.4	12	31	55	9.7	21
300 NE	0 to 5	0.42	2.9	2.3	4.6	13	37	73	4	12
500 NE	0 to 5	0.42	0.92	2.3	3.4	5	12	24	3.6	11

Delacroix Island Sediment PAH

Site	Depth (cm)	1C1P ng/g	C1P/A ng/g	C2P/A ng/g	C3P/A ng/g	C4P/A ng/g	FLANT ng/g	PYR ng/g	C1F/P ng/g	C2F/P ng/g
Discharge	0 to 5	88	400	670	470	230	110	81	120	110
Discharge	20 to 25	41	190	270	180	340	1000	650	580	170
Discharge	35 to 40	7.2	22	49	33	99	620	380	230	56
Discharge	0 to 5	170	810	1400	950	510	240	170	270	240
Discharge	20 to 25	18	69	96	68	68	270	170	110	38
Discharge	35 to 40	45	130	190	99	260	1400	880	580	170
Discharge	0 to 5	86	370	630	450	250	150	100	130	98
Discharge	20 to 25	72	260	340	190	690	3500	2200	1700	440
Discharge	35 to 40	2	7.7	6.3	6.6	6	47	23	9.7	4.4
Reference 1	0 to 5	4.4	15	25	.23	13	23	18	13	8.3
Reference 1	20 to 25	2	6.3	9.6	18	20	20	17	12	8
Reference 1	35 to 40	6.7	30	50	42	74	32	17	26	0
Reference 1	0 to 5	3.6	12	14	17	9.9	19	14	11	9.4
Reference 1	20 to 25	3.7	11	13	17	15	26	17	13	8.3
Reference 1	35 to 40	0	0	0	0	0	5.2	5.1	0	0
Reference 1	0 to 5	2.9	9.8	15	21	17	19	14	9.7	7.7
Reference 1	20 to 25	3	7	5.6	11	9.8	23	16	12	6
Reference 1	35 to 40	5.4	13	5.8	0	0	24	18	13	0
Reference 2	0 to 5	1.5	6.9	12	16	12	13	9.7	8.3	6.8
Reference 2	20 to 25	5.1	12	16	16	14	45	33	24	13
Reference 2	35 to 40	4.5	16	13	7	6.1	62	46	32	8.5
Reference 2	0 to 5	2.4	9.4	15	13	9.6	25	20	12	7.2
Reference 2	20 to 25	4.3	21	20	12	14	69	57	33	11
Reference 2	35 to 40	8.9	36	53	35	42	160	120	67	25
Reference 2	0 to 5	2	9.2	14	12	7.9	19	15	9.2	6.2
Reference 2	20 to 25	2.9	10	14	8.5	6.2	42	34	21	6.4
Reference 2	35 to 40	7.1	25	15	9.4	7.3	94	74	47	12
1000 South	0 to 5	1.7	7	12	10	10	22	19	12	8.8
500 South	0 to 5	3.4	13	8.3	6.1	6.4	56	43	24	8.9
300 South	0 to 5	3.5	15	22	17	25	64	50	38	24
100 South	0 to 5	5.5	22	18	11	27	110	88	51	18
100 NW	0 to 5	50	250	150	70	190	900	570	460	130
300 NW	0 to 5	2.2	7.3	11	7.9	9.7	15	12	12	7
500NW	0 to 5	1.9	7.6	14	11	8.6	23	18	11	7.7
1000 NW	0 to 5	4.5	19	19	11	17	53	35	31	13
100 NE	0 to 5	8.7	32	65	62	58	110	99	67	36
300 NE	0 to 5	7.7	24	64	64	47	47	40	38	21
500 NE	0 to 5	5.6	18	33	25	19	43	36	24	12

Delacroix Island Sediment PAH

Site	Depth (cm)	C3F/P ng/g	C0D ng/g	C1D ng/g	C2D ng/g	C3D ng/g	BAA ng/g	C0C ng/g	C1C ng/g	C2C ng/g
Discharge	0 to 5	98	15	76	170	180	21	34	38	52
Discharge	20 to 25	69	29	41	73	74	320	470	160	67
Discharge	35 to 40	19	6.2	9.3	16	7.9	130	130	52	16
Discharge	0 to 5	210	29	150	350	370	36	75	110	110
Discharge	20 to 25	26	15	16	25	31	33	44	23	13
Discharge	35 to 40	64	26	37	48	33	350	350	150	50
Discharge	0 to 5	91	14	76	160	180	33	41	45	51
Discharge	20 to 25	150	35	52	83	44	1000	1200	380	120
Discharge	35 to 40	0	0.94	2.1	0	0	2.4	4.2	0	0
Reference 1	0 to 5	5.6	1.5	6	13	13	3.4	6.9	7.2	5.8
Reference 1	20 to 25	6.3	1.6	0	0	0	2.7	5.3	3.4	1.5
Reference 1	35 to 40	0	3.1	27	50	47	2.5	4.2	0	0
Reference 1	0 to 5	3.8	1.3	3.4	7	5.7	2.7	5.5	6	3.9
Reference 1	20 to 25	0	1.6	0	0	0	3.1	4.9	0	0
Reference 1	35 to 40	0	0	0	0	0	0	3.6	0	0
Reference 1	0 to 5	7.2	0.82	3.6	8	9	2.9	5.4	6.1	4.1
Reference 1	20 to 25	0	1	0	0	0	2.9	4.7	4.5	2.8
Reference 1	35 to 40	0	0	0	0	0	0	5.7	0	0
Reference 2	0 to 5	0	0	0	0	0	2.8	6.8	5	3.3
Reference 2	20 to 25	8.9	2.6	0	0	0	0	10	0	0
Reference 2	35 to 40	3	1.9	0	0	0	7.3	15	3.5	2.7
Reference 2	0 to 5	5.6	1.3	3.5	7.9	9.6	4.8	7.6	6.1	4.1
Reference 2	20 to 25	0	3	3.5	7.2	8.7	8.9	14	9.8	5.7
Reference 2	35 to 40	15	4.7	12	27	25	40	82	28	15
Reference 2	0 to 5	2.6	1.2	3.3	7.6	7.3	3.8	5.3	5.5	4.6
Reference 2	20 to 25	1.8	1.6	2.1	3.4	3.3	6.5	11	8.5	4.3
Reference 2	35 to 40	6.3	2.9	2.5	0	0	12	21	12	4.4
1000 South	0 to 5	5	0.93	2.5	6.3	7.2	5.2	7.9	7.4	5.3
500 South	0 to 5	2.9	1.8	1.9	3.8	3.3	8.9	19	7.6	2.2
300 South	0 to 5	11	1.7	3.9	9.8	11	29	43	20	11
100 South	0 to 5	8.8	3.9	4.1	6.8	6.3	60	57	30	10
100 NW	0 to 5	33	27	21	33	28	350	340	140	49
300 NW	0 to 5	2.7	0.99	2.5	4.9	4.7	4	6.2	5.4	4.1
500NW	0 to 5	4.1	0.89	2.8	6.5	7	6	7.9	7.4	5
1000 NW	0 to 5	5.5	1.7	4	6.9	5.9	24	23	13	5.9
100 NE	0 to 5	28	4.9	13	30	37	31	61	30	19
300 NE	0 to 5	19	2.7	10	27	32	12	14	21	12
500 NE	0 to 5	9.9	2.3	6	14	15	12	15	14	7.9

Delacroix Island Sediment PAH

Site	Depth (cm)	C3C ng/g	C4C ng/g	BBF ng/g	BKF ng/g	BEP ng/g	BAP ng/g	PER ng/g	IND ng/g	DAH ng/g
Discharge	0 to 5	58	20	25	6	12	9	110	7.7	0
Discharge	20 to 25	55	25	390	140	160	210	190	120	35
Discharge	35 to 40	10	3.8	100	36	40	48	120	24	8.4
Discharge	0 to 5	110	95	48	17	24	23	190	15	4.1
Discharge	20 to 25	8.5	0	41	13	20	16	140	14	2.3
Discharge	35 to 40	37	7.8	320	92	120	170	180	91	27
Discharge	0 to 5	55	24	32	9	15	13	100	9	0
Discharge	20 to 25	48	81	800	270	320	470	220	230	67
Discharge	35 to 40	0	0	4.7	1.2	1.8	1.3	110	1.3	0
Reference 1	0 to 5	5.4	0	11	2.1	5.4	2.6	52	3.5	0
Reference 1	20 to 25	0	0	7.9	2.4	3.9	2.7	55	3.2	0
Reference 1	35 to 40	0	0	0	0	2.2	0	75	2.1	0
Reference 1	0 to 5	3.2	0	8.1	2.1	4.3	1.6	54	3.2	0
Reference 1	20 to 25	0	0	7.3	2	3.9	2.5	89	3.1	0
Reference 1	35 to 40	0	0	3.3	0.76	1.9	0	140	0	0
Reference 1	0 to 5	0	0	8.5	2.4	4.2	2.7	52	2.9	0
Reference 1	20 to 25	0	0	7.2	2.2	3.7	2.3	60	3.4	0
Reference 1	35 to 40	0	0	5.7	1.7	2.7	1.2	130	0	0
Reference 2	0 to 5	0	0	6.3	1.9	3.3	1.7	41	2.8	0
Reference 2	20 to 25	0	0	9.2	2	4.2	2	45	3.2	0
Reference 2	35 to 40	0	0	15	3.7	7.9	3.9	84	5.3	0
Reference 2	0 to 5	1.8	4.4	12	2.7	6	3.3	63	4	0
Reference 2	20 to 25	0	0	18	4.4	8.6	4.6	60	5.7	1.1
Reference 2	35 to 40	9.8	5.1	60	19	28	30	110	22	5.1
Reference 2	0 to 5	2.9	0	8.4	2.3	4.1	2.4	52	32	0.65
Reference 2	20 to 25	0	0	15	3.1	7.9	4.1	61	5.2	1.5
Reference 2	35 to 40	0	0	24	4.7	11	5.7	71	6.1	0
1000 South	0 to 5	4.9	5.1	14	3.5	7.1	4.1	80	4.6	1
500 South	0 to 5	1.4	2.9	17	5	9	5.9	40	5.3	1.3
300 South	0 to 5	9.8	8.4	52	16	25	25	85	16	4.3
100 South	0 to 5	7	6	77	25	39	55	70	32	8.3
100 NW	0 to 5	40	43	280	110	130	210	140	110	36
300 NW	0 to 5	3.8	3.1	11	2.1	5.3	3	200	3.5	0
500NW	0 to 5	4.4	4.1	14	4	6.7	4.4	78	4.5	1
1000 NW	0 to 5	4.8	2.8	27	9.1	13	15	58	8.1	2.9
100 NE	0 to 5	20	13	52	17	27	22	140	16	4.5
300 NE	0 to 5	11	7.2	23	6.2	11	8.6	190	8.3	1.9
500 NE	0 to 5	5.7	6	24	6.3	13	8.7	140	9.2	2

Site	Depth (cm)	BGP ng/g	Total PAH ng/g
Discharge	0 to 5	10	9405.7
Discharge	20 to 25	100	8143.1
Discharge	35 to 40	22	2456.1
Discharge	0 to 5	16	20065.1
Discharge	20 to 25	16	2071.2
Discharge	35 to 40	81	6912.6
Discharge	0 to 5	11	9142
Discharge	20 to 25	190	16401.2
Discharge	35 to 40	2.3	272.14
Reference 1	0 to 5	5	331.8
Reference 1	20 to 25	5.6	235.4
Reference 1	35 to 40	2.4	1052.2
Reference 1	0 to 5	5.4	244
Reference 1	20 to 25	4.6	259
Reference 1	35 to 40	1.8	165.56
Reference 1	0 to 5	5.9	251.02
Reference 1	20 to 25	5.6	212.5
Reference 1	35 to 40	5.7	260.5
Reference 2	0 to 5	5.4	181.4
Reference 2	20 to 25	7	300.4
Reference 2	35 to 40	6.5	463.5
Reference 2	0 to 5	5.7	342.24
Reference 2	20 to 25	8	525.3
Reference 2	35 to 40	23	1358.8
Reference 2	0 to 5	3.8	294.95
Reference 2	20 to 25	9.2	384.3
Reference 2	35 to 40	10	719.6
1000 South	0 to 5	6.3	334.03
500 South	0 to 5	7.3	420.89
300 South	0 to 5	17	746.54
100 South	0 to 5	33	1027.7
100 NW	0 to 5	91	6055.6
300 NW	0 to 5	5.5	421.9
500NW	0 to 5	5.8	330.34
1000 NW	0 to 5	8.6	517.49
100 NE	0 to 5	21	1420.8
300 NE	0 to 5	12	1058.42
500 NE	0 to 5	12	671.74

Bay de Chene Sediment PAH

Site	Depth (cm)	C0N ng/g	2-C1N ng/g	1-C1N ng/g	2,6-C2N ng/g	2,3,5-C3N ng/g	C1N ng/g	C2N ng/g	C3N ng/g	C4N ng/g
Discharge	0 to 5	56	61	40	77	83	74	340	820	1000
Discharge	20 to 25	46	82	47	75	52	92	360	980	1200
Discharge	35 to 40	61	510	480	670	320	680	2600	3800	3400
Discharge	0 to 5	110	110	68	320	320	130	1400	3600	4200
Discharge	20 to 25	46	92	51	160	110	99	600	1700	2100
Discharge	35 to 40	56	890	810	950	540	1200	4200	5500	4600
Discharge	0 to 5	160	140	120	110	110	180	520	1100	1400
Discharge	20 to 25	57	120	74	160	100	140	740	2000	2400
Discharge	35 to 40	70	670	670	940	490	920	3800	5100	4300
Reference 1	0 to 5	3.5	0	0	0	0	0	0	0	0
Reference 1	20 to 25	6.8	2.6	1.7	0	0	3.1	8.2	6.3	0
Reference 1	35 to 40	2.5	1.5	0	0	0	1.6	5	0	0
Reference 1	0 to 5	6.6	2.6	2.2	0	0	4	7.2	4.4	5.7
Reference 1	20 to 25	6.4	3.1	2	0	0	3.8	7.5	0	0
Reference 1	35 to 40	3.1	0	0	0	0	0	0	0	0
Reference 1	0 to 5	2.8	0	0	0	0	0	0	0	0
Reference 1	20 to 25	6.7	2.1	0	0	0	3.5	8.6	0	0
Reference 1	35 to 40	4	2.6	1.3	0	0	3.2	0	0	0
Reference 2	0 to 5	5	4	0	2.2	0	5.1	9.1	8.1	10
Reference 2	20 to 25	4.7	1.9	0.95	1.4	1.2	2.9	4.8	5.3	5
Reference 2	35 to 40	3.7	2.1	1.5	0	0	2	6.1	6.7	7.2
Reference 2	0 to 5	3.4	2.8	1.5	1.2	0.53	4.4	9.1	9.9	12
Reference 2	20 to 25	3.6	1.4	1	0.52	0.54	1.4	4	4.2	3.2
Reference 2	35 to 40	3.8	1.4	0.97	0.63	0	1.7	4.5	3.2	3.6
Reference 2	0 to 5	5	3.4	1.9	1.04	0.95	3.5	8	7.7	9.6
Reference 2	20 to 25	5	2.7	1.3	1.4	1.1	2.3	6.2	9.3	11
Reference 2	35 to 40	3.7	1.5	0.93	5.9	0.59	1.6	3.3	2.9	1.9
300 ft NE	0 to 5	11	12	6.6	5.6	2.9	12	23	25	34
500 ft NE	0 to 5	5.2	4.9	2.1	2.6	1.3	4.4	9.9	12	19
1000 ft NE	0 to 5	2.7	2.1	0.96	0.59	0.45	1.8	3.9	4.3	4.6
1000 ft SE	0 to 5	2.9	2.5	1.4	1.4	0.76	2.5	5.3	6.2	7.9
500 ft SE	0 to 5	1.6	1.4	1.2	0.79	0.59	1.5	3.9	4.1	0.53
100 ft SW	0 to 5	14	16	6.7	6.8	3.9	14	27	43	58
300 ft SW	0 to 5	3.8	2.6	1.2	1.3	0.57	2.4	6.5	7.4	9.4
500 ft SW	0 to 5	2.2	1.7	1.2	0.74	0.58	1.7	4.3	4.5	5.3
1000 ft SW	0 to 5	4.3	2.9	1.6	2	0.79	3.5	7.9	9.3	13
100 ft NW	0 to 5	32	38	16	23	13	38	74	130	240
300 ft NW	0 to 5	21	20	9.1	16	9	20	56	100	120
500 ft NW	0 to 5	5.8	5	2.2	3.3	1.8	4.9	11	16	25
1000 ft NW	0 to 5	3.6	3.6	1.9	2.1	1.4	4.2	7.9	11	16
100 ft NE	0 to 5	38	32	17	30	43	35	130	400	520

Bay de Chene Sediment PAH

Site	Depth (cm)	ACEY ng/g	ACE ng/g	BIP ng/g	COF ng/g	C1F ng/g	C2F ng/g	C3F ng/g	C0A ng/g	C0P ng/g
Discharge	0 to 5	6.1	180	37	230	280	530	730	250	890
Discharge	20 to 25	6.4	69	20	130	320	650	870	150	300
Discharge	35 to 40	5.5	99	21	240	780	1600	2000	160	600
Discharge	0 to 5	47	210	47	390	960	2000	3100	1000	1800
Discharge	20 to 25	5.2	71	20	150	480	1000	1400	300	370
Discharge	35 to 40	0	140	28	350	1100	2000	2700	220	890
Discharge	0 to 5	40	250	59	340	380	680	900	470	1400
Discharge	20 to 25	8.1	110	25	210	580	1200	1700	210	490
Discharge	35 to 40	5.7	140	24	320	1000	1900	2500	180	680
Reference 1	0 to 5	0	0	0	1.3	1.3	4.3	5	1.3	3.7
Reference 1	20 to 25	0	0	0	0	0	0	0	0	7.7
Reference 1	35 to 40	0	0	0.98	1.3	2.1	0	0	1.3	3.6
Reference 1	0 to 5	5.7	0	2.6	3.3	1.8	7.4	9.8	2.7	11
Reference 1	20 to 25	0	2.1	2	2.8	0	0	0	1.5	7.4
Reference 1	35 to 40	0	0	1.4	1.1	0	0	0	1.2	3.8
Reference 1	0 to 5	0	0	1.2	1.8	3.7	14	19	2.4	6.7
Reference 1	20 to 25	0	0	2	2.5	0	0	0	1.4	8
Reference 1	35 to 40	0	0	1.5	1.6	0	0	0	1.8	5.9
Reference 2	0 to 5	0	0	2.6	5.6	6.7	17	21	5.6	15
Reference 2	20 to 25	0	1.4	2	4.3	5	6.3	4.4	3.8	14
Reference 2	35 to 40	0	1.9	1.9	6	5	5.5	0	4	13
Reference 2	0 to 5	0	0	2	3.5	5.5	14	13	4.3	12
Reference 2	20 to 25	0.68	0.92	2	3.5	3.4	4.9	4.8	2.3	8.4
Reference 2	35 to 40	0.56	1.7	1.8	5.3	3.4	2.9	2.8	2.3	11
Reference 2	0 to 5	0.68	0.83	2.1	4.5	6.3	16	18	4.1	12
Reference 2	20 to 25	0.59	1	2.3	4.5	7.4	13	14	3.7	11
Reference 2	35 to 40	0.48	1.4	1.6	4.6	3.1	3.2	0	2.3	10
300 ft NE	0 to 5	2.8	20	5.2	28	25	33	62	78	260
500 ft NE	0 to 5	0.97	3.4	3	8.2	9.1	20	31	9.6	20
1000 ft NE	0 to 5	0.43	0.65	1.2	1.8	2.3	5.2	8.3	1.7	6
1000 ft SE	0 to 5	0.46	0.63	1.6	2.8	4.2	10	15	2.7	8.8
500 ft SE	0 to 5	0.21	0.46	0.89	1.3	2.1	4.5	8	1.2	4.2
100 ft SW	0 to 5	0.99	6.6	6.6	13	38	88	130	13	32
300 ft SW	0 to 5	0.99	1.6	1.6	3	4.4	10	16	3	9
500 ft SW	0 to 5	0.44	0.99	0.99	1.9	2.4	5.8	9.2	2.1	7.4
1000 ft SW	0 to 5	0.86	2.1	2.1	3.7	6.4	19	25	3.8	12
100 ft NW	0 to 5	2.1	6.2	14	22	150	340	470	30	49
300 ft NW	0 to 5	11	16	10	33	45	88	120	26	150
500 ft NW	0 to 5	0.89	1.8	3	6.7	11	25	37	6.2	17
1000 ft NW	0 to 5	0.63	5.5	1.5	8.4	8.3	16	23	32	56
100 ft NE	0 to 5	5.7	48	18	67	120	260	340	86	250

Bay de Chene Sediment PAH

Site	Depth (cm)	1C1P ng/g	C1P/A ng/g	C2P/A ng/g	C3P/A ng/g	C4P/A ng/g	FLANT ng/g	PYR ng/g	C1F/P ng/g	C2F/P ng/g
Discharge	0 to 5	160	570	1000	810	760	2100	1500	930	480
Discharge	20 to 25	140	460	1100	980	790	1000	810	640	440
Discharge	35 to 40	410	1400	2600	2000	1300	780	650	670	650
Discharge	0 to 5	600	2500	5100	3800	8300	8100	6100	11000	5800
Discharge	20 to 25	240	770	1800	1700	1400	1300	940	1000	980
Discharge	35 to 40	550	2000	3500	2700	1600	1200	960	910	850
Discharge	0 to 5	250	880	1300	1000	1100	2700	1900	1300	690
Discharge	20 to 25	290	920	2100	1700	1400	1700	1300	1000	730
Discharge	35 to 40	510	1700	3200	2500	1500	800	660	680	790
Reference 1	0 to 5	1.9	6.1	9.9	12	8.7	9.3	9.5	6.7	5.7
Reference 1	20 to 25	1.3	4.2	3.1	0	0	7.5	8.7	7	3
Reference 1	35 to 40	0.96	4.3	4.7	0	0	5.9	6.2	8.4	3.8
Reference 1	0 to 5	3.3	9.8	14	12	10	17	19	14	7.5
Reference 1	20 to 25	1.8	5.5	7.1	0	0	7.9	8.9	11	3.3
Reference 1	35 to 40	1.3	3.5	0	0	0	6.5	7.2	7.9	5.9
Reference 1	0 to 5	2.6	9.8	19	18	15	16	21	16	11
Reference 1	20 to 25	1.7	5.9	3.7	2.2	1.7	7.1	7.9	8.3	0
Reference 1	35 to 40	1.4	5.1	5.2	0	0	7	7.2	7.5	5.4
Reference 2	0 to 5	4.6	18	29	24	18	41	35	19	12
Reference 2	20 to 25	4.1	11	15	7	7.8	29	21	12	8.1
Reference 2	35 to 40	4.5	11	9.1	5.3	9.8	23	16	9.1	4.4
Reference 2	0 to 5	3.7	15	26	23	21	36	31	18	13
Reference 2	20 to 25	3	6.3	6.7	4.5	5.8	17	12	6.9	4.1
Reference 2	35 to 40	4	7.4	5.1	2.7	5	14	9.8	7.1	3.5
Reference 2	0 to 5	4.4	16	26	21	16	35	31	17	12
Reference 2	20 to 25	5.3	17	21	15	11	32	25	14	7.7
Reference 2	35 to 40	3.6	6.6	4.5	3.2	4.9	12	9.2	6.4	3.8
300 ft NE	0 to 5	26	100	92	55	160	650	630	360	250
500 ft NE	0 to 5	8.9	29	52	51	38	140	100	48	29
1000 ft NE	0 to 5	2	6.6	11	11	8.1	13	16	9.7	8.4
1000 ft SE	0 to 5	3.5	13	23	24	15	27	26	16	13
500 ft SE	0 to 5	1.8	6	11	12	11	12	14	12	21
100 ft SW	0 to 5	18	52	130	160	110	130	110	86	87
300 ft SW	0 to 5	3.8	13	25	28	18	30	34	21	16
500 ft SW	0 to 5	1.8	7.1	11	12	9.8	18	22	13	9.3
1000 ft SW	0 to 5	4.7	18	36	39	21	42	37	21	18
100 ft NW	0 to 5	33	99	340	470	320	210	190	170	150
300 ft NW	0 to 5	34	120	180	170	140	440	330	190	83
500 ft NW	0 to 5	8.4	28	55	56	39	62	53	34	26
1000 ft NW	0 to 5	15	52	55	40	72	460	360	150	57
100 ft NE	0 to 5	81	280	500	450	350	910	730	500	440

Bay de Chene Sediment PAH

Site	Depth	C3F/P	C0D	C1D	C2D	C3D	BAA	C0C	C1C	C2C
	(cm)	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g
Discharge	0 to 5	380	99	180	370	380	960	1000	430	320
Discharge	20 to 25	400	66	200	430	460	470	600	300	290
Discharge	35 to 40	660	69	500	950	960	330	470	290	370
Discharge	0 to 5	3000	210	690	1500	1400	12000	11000	6400	2800
Discharge	20 to 25	970	71	310	660	790	780	790	700	800
Discharge	35 to 40	750	96	670	1300	1200	490	600	430	560
Discharge	0 to 5	510	150	250	460	470	1400	1300	610	450
Discharge	20 to 25	500	88	390	800	800	760	820	530	480
Discharge	35 to 40	790	87	630	1200	1200	250	300	310	460
Reference 1	0 to 5	6.8	0.91	1.8	5.3	6.8	2.5	3.7	3.5	2.7
Reference 1	20 to 25	0	0	0	0	0	1.7	3.4	0	0
Reference 1	35 to 40	4.4	0	0	0	0	1.9	3.4	5.9	3.4
Reference 1	0 to 5	4.9	1.1	4	7.2	9.7	4	6	5.1	5.3
Reference 1	20 to 25	0	0	0	0	0	1.8	3.8	0	0
Reference 1	35 to 40	0	0	0	0	0	1.7	3.3	0	0
Reference 1	0 to 5	11	1.5	3.7	10	15	3.9	5.8	6	7.1
Reference 1	20 to 25	0	0	0	0	0	1.7	3.1	0	0
Reference 1	35 to 40	0	0	0	0	0	1.3	2.9	0	0
Reference 2	0 to 5	7	2.6	8.5	19	17	5.6	11	7.8	8.1
Reference 2	20 to 25	3.7	2.3	4.3	5.1	5.2	3.3	6.1	4	3
Reference 2	35 to 40	3.5	1.7	2.4	1.5	0	3.8	6	4.4	2.6
Reference 2	0 to 5	8.4	2.1	5.5	14	15	8.1	12	9.1	7.3
Reference 2	20 to 25	2.1	1.2	1.8	2.5	2.4	1.9	4	3.1	2.7
Reference 2	35 to 40	2	1	0	0	0	1.6	3.4	2.8	2.2
Reference 2	0 to 5	9.2	2.3	5.6	12	13	5	9	9	8.3
Reference 2	20 to 25	6.1	3	5.3	8.9	7.9	4.3	7.5	5.8	5.6
Reference 2	35 to 40	1.8	0.87	0	1.1	0	1.7	2.9	1.9	1.5
300 ft NE	0 to 5	170	16	16	30	45	350	310	200	130
500 ft NE	0 to 5	24	4.5	10	24	28	23	26	23	20
1000 ft NE	0 to 5	6.5	1.1	2.5	5.3	6.4	3.2	4.9	5.6	5
1000 ft SE	0 to 5	11	1.6	4.4	10	13	5.4	8.6	7.9	9.1
500 ft SE	0 to 5	27	1	2.1	5.1	6.3	3.7	5.2	9	16
100 ft SW	0 to 5	68	9.1	26	68	78	40	55	42	48
300 ft SW	0 to 5	14	1.8	4.8	12	14	8.6	10	9.1	11
500 ft SW	0 to 5	8.2	1	2.1	5.3	6.2	6.6	7.3	6.1	6.1
1000 ft SW	0 to 5	16	2.3	6.2	17	19	1.4	12	11	13
100 ft NW	0 to 5	140	24	83	210	230	58	110	79	110
300 ft NW	0 to 5	72	19	34	72	76	100	190	84	57
500 ft NW	0 to 5	25	4.1	10	24	28	13	23	17	20
1000 ft NW	0 to 5	33	7.2	9.8	18	19	190	150	66	31
100 ft NE	0 to 5	370	39	87	180	190	340	470	290	260

Bay de Chene Sediment PAH

Site	Depth (cm)	C3C ng/g	C4C ng/g	BBF ng/g	BKF ng/g	BEP ng/g	BAP ng/g	PER ng/g	IND ng/g	DAH ng/g
Discharge	0 to 5	220	130	1400	420	640	850	440	730	150
Discharge	20 to 25	230	140	670	220	290	390	370	320	78
Discharge	35 to 40	360	190	400	120	170	210	480	170	43
Discharge	0 to 5	2100	640	14000	5200	6000	9000	2900	6100	1700
Discharge	20 to 25	600	330	880	290	390	530	460	360	95
Discharge	35 to 40	380	200	670	240	300	360	600	320	83
Discharge	0 to 5	280	160	1700	580	750	1200	580	900	210
Discharge	20 to 25	430	180	1100	320	490	650	560	550	130
Discharge	35 to 40	410	190	310	100	140	150	520	120	32
Reference 1	0 to 5	4.8	4.6	5.4	1.6	2.8	1.6	36	2.4	0
Reference 1	20 to 25	0	0	6.7	0	3.1	0	480	0	0
Reference 1	35 to 40	0	0	6.6	1	3.1	1.1	510	2.7	0
Reference 1	0 to 5	0	0	7.9	2.5	4.2	2.7	140	3.5	1
Reference 1	20 to 25	0	0	5.2	1.2	2.5	1.1	580	1.9	0
Reference 1	35 to 40	0	0	4.8	1.3	2.6	1.2	430	1.7	0
Reference 1	0 to 5	7.2	4.3	7.8	2.6	4.5	2.7	56	3.2	0.94
Reference 1	20 to 25	0	0	4.5	0	2.2	1.1	390	1.7	0
Reference 1	35 to 40	0	0	4.3	1.6	2.1	0.99	510	1.6	0
Reference 2	0 to 5	2.1	0	12	4.7	6.3	4.7	86	3.5	0.94
Reference 2	20 to 25	0	0	6.2	2.2	3.6	2.4	130	2.4	0
Reference 2	35 to 40	0	0	7.6	2.3	3.8	2.6	160	3.3	0
Reference 2	0 to 5	4.5	0	16	4.9	7.4	5.1	95	6.6	1.3
Reference 2	20 to 25	1.6	1	4.4	0.95	2.3	1.2	83	1.3	0.25
Reference 2	35 to 40	0	0	4	0.88	2.1	0.82	150	0.89	0.16
Reference 2	0 to 5	6.7	3.5	10	2.7	5.6	3.2	60	2.7	0.58
Reference 2	20 to 25	3.9	2.2	9	2.4	4.7	2.7	88	3	0.46
Reference 2	35 to 40	0	0	3.5	0.84	1.7	0.69	110	0.77	0
300 ft NE	0 to 5	110	56	470	170	260	340	170	220	54
500 ft NE	0 to 5	15	7.8	27	8.2	15	11	77	7.2	1.9
1000 ft NE	0 to 5	5.2	3.4	7.9	1.9	4.3	2	52	2.5	0.55
1000 ft SE	0 to 5	8.1	4.8	10	3	6	4.2	41	3.1	0.68
500 ft SE	0 to 5	17	7.3	8.5	2.2	7.4	5.2	44	3.8	1
100 ft SW	0 to 5	41	25	51	17	27	24	100	15	3.7
300 ft SW	0 to 5	6.7	5.1	13	4.2	7.4	5.1	44	3.7	1
500 ft SW	0 to 5	4.5	2.9	10	3	6	5.6	27	4.6	0.89
1000 ft SW	0 to 5	9	5.1	13	3.5	7.4	4.6	57	4.2	1.1
100 ft NW	0 to 5	110	59	93	30	50	44	190	33	8.2
300 ft NW	0 to 5	59	22	190	67	98	89	130	65	16
500 ft NW	0 to 5	16	7.1	22	5.8	12	9.1	76	8.1	1.9
1000 ft NW	0 to 5	19	10	160	58	75	110	75	53	12
100 ft NE	0 to 5	220	100	540	170	350	360	220	260	70

Bay de Chene Sediment PAH

Site	Depth (cm)	BGP ng/g	Total PAH ng/g
Discharge	0 to 5	630	23723.1
Discharge	20 to 25	270	18003.4
Discharge	35 to 40	140	35368.5
Discharge	0 to 5	4400	162152
Discharge	20 to 25	290	28980.2
Discharge	35 to 40	270	49963
Discharge	0 to 5	740	32179
Discharge	20 to 25	440	31482.1
Discharge	35 to 40	110	43358.7
Reference 1	0 to 5	4.7	188.11
Reference 1	20 to 25	4.6	570.7
Reference 1	35 to 40	4.3	601.94
Reference 1	0 to 5	5.2	397.9
Reference 1	20 to 25	3.3	684.9
Reference 1	35 to 40	3.1	492.6
Reference 1	0 to 5	4.3	337.54
Reference 1	20 to 25	2.7	480.3
Reference 1	35 to 40	2.4	587.89
Reference 2	0 to 5	5.5	529.94
Reference 2	20 to 25	3.2	371.35
Reference 2	35 to 40	4.1	368.4
Reference 2	0 to 5	7.7	515.83
Reference 2	20 to 25	1.9	236.66
Reference 2	35 to 40	1.5	283.51
Reference 2	0 to 5	4.1	456.48
Reference 2	20 to 25	7.1	423.65
Reference 2	35 to 40	1.9	234.37
300 ft NE	0 to 5	250	6336.1
500 ft NE	0 to 5	10	1025.17
1000 ft NE	0 to 5	3.7	258.73
1000 ft SE	0 to 5	5.2	394.63
500 ft SE	0 to 5	8	319.07
100 ft SW	0 to 5	19	2157.39
300 ft SW	0 to 5	5.5	454.56
500 ft SW	0 to 5	6	276.83
1000 ft SW	0 to 5	5.5	565.25
100 ft NW	0 to 5	39	5369.5
300 ft NW	0 to 5	78	4075.1
500 ft NW	0 to 5	10	877.09
1000 ft NW	0 to 5	56	2616.03
100 ft NE	0 to 5	380	11576.7

Table A-4. Metals in sediment collected at Delacroix Island and Bay De Chene.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	Site/Sample		Al	As	Ba	Ca	Cd	Cr	Cu	Fe	Hg	Mn	Mo	Ni	Pb	V	Zn
2	Bay de Chene		(%)	(ppm)	(ppm)	(%)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
3	Discharge A		5.81	11.0	1370	0.83	0.43	55.30	21.8	2.98	0.172	534	1.2	24.6	35.6	91.0	112.0
4	B		5.24	10.6	466	0.97	0.34	50.60	21.3	2.82	0.423	474	1.2	22.3	19.5	91.7	102.0
5	B		5.05	9.9	1790	0.78	0.29	49.80	19.5	2.73	-	454	1.1	21.9	22.8	75.9	101.0
6	B		5.00	9.7	162	0.82	0.36	42.00	19.0	2.66	-	457	1.1	21.6	12.1	76.8	99.3
7		average B	5.10	10.07	806.00	0.86	0.33	47.47	19.93	2.74	0.42	461.67	1.13	21.93	18.13	81.47	100.77
8	C		5.77	11.9	673	0.90	0.46	56.80	27.5	3.13	0.187	561	1.3	26.0	29.8	93.7	152.0
9	Discharge	Mean (3 #s)	5.56	10.99	949.67	0.86	0.41	53.19	23.08	2.95	0.26	518.89	1.21	24.18	27.84	88.72	121.59
10		SD	0.40	0.92	370.04	0.04	0.07	5.01	3.94	0.20	0.14	51.36	0.08	2.07	8.90	6.43	26.93
11	Reference 1A		4.09	8.6	1090	15.30	0.25	40.30	13.6	2.04	0.047	354	1.8	16.0	16.7	66.8	56.4
12	R1B		5.97	9.1	934	5.39	0.33	56.40	19.1	2.84	0.041	313	2.3	23.6	19.9	100.0	84.0
13	R1C		5.58	8.3	1100	1.95	0.35	52.30	18.3	2.78	0.052	370	2.0	22.2	23.7	85.1	74.5
14	R1	Mean	5.21	8.67	1041.33	7.55	0.31	49.67	17.00	2.55	0.05	345.67	2.03	20.60	20.10	83.97	71.63
15		SD	0.99	0.40	93.09	6.93	0.05	8.37	2.97	0.45	0.01	29.40	0.25	4.04	3.50	16.63	14.02
16	Reference 2A		4.95	5.7	753	1.13	0.23	42.70	15.3	2.29	0.049	454	1.1	19.6	18.9	75.4	68.3
17	R2B		5.47	7.7	850	1.13	0.32	49.90	16.1	2.51	0.046	421	1.6	20.7	21.5	73.1	76.5
18	R2C		6.07	9.0	621	1.03	0.36	53.10	19.9	2.91	0.047	479	1.7	24.3	22.4	95.6	87.0
19	R2	Mean	5.50	7.47	741.33	1.10	0.30	48.57	17.10	2.57	0.05	451.33	1.47	21.53	20.93	81.37	77.27
20		SD	0.56	1.66	114.94	0.06	0.07	5.33	2.46	0.31	0.00	29.09	0.32	2.46	1.82	12.38	9.37
21	100NW		6.35	10.3	1370	0.70	0.40	58.70	23.9	3.25	0.072	427	1.2	27.7	27.2	99.9	109.0
22	100NW		6.38	11.3	990	0.75	0.41	62.70	24.9	3.36	-	440	1.2	28.7	27.3	115.0	115.0
23	100NW		6.44	9.7	570	0.67	0.41	59.50	24.2	3.30	-	433	1.2	28.1	25.6	109.0	109.0
24	100NW	Mean	6.39	10.43	976.67	0.71	0.41	60.30	24.33	3.30	0.07	433.33	1.20	28.17	26.70	107.97	111.00
25		SD	0.05	0.81	400.17	0.04	0.01	2.12	0.51	0.06		6.51	0.00	0.50	0.95	7.60	3.46
26	300NW		5.22	13.9	691	0.66	0.46	48.50	23.5	2.98	0.083	505	1.3	25.7	24.9	86.5	93.0
27	500NW		6.21	8.7	1330	0.99	0.34	54.10	18.6	2.77	0.052	357	1.4	23.9	23.1	86.4	88.4
28	1000NW		5.64	7.7	771	1.22	0.27	48.00	15.3	2.24	0.042	312	1.4	18.6	26.3	77.9	70.8
29	100SW		6.45	7.3	1320	0.76	0.39	58.90	20.9	2.96	1.400	380	1.1	25.3	24.6	101.0	102.0
30	300SW		5.82	8.0	1310	1.80	0.29	53.70	18.5	2.79	0.098	386	2.0	22.8	22.2	84.0	82.3
31	500SW		5.38	6.8	1350	1.24	0.28	45.30	13.2	2.16	0.088	291	1.6	19.9	19.6	68.6	93.7
32	1000SW		6.06	5.9	1100	1.08	0.33	53.30	17.2	2.74	0.040	344	1.7	22.9	22.1	93.2	84.3
33	100NE		5.89	11.4	1090	0.87	0.55	53.40	26.6	3.10	0.065	524	1.4	26.0	35.3	89.3	158.0
34	100NE		5.84	5.3	1460	1.05	0.42	63.80	28.8	3.08	0.096	519	1.2	31.7	28.3	89.5	121.0
35	100NE		5.48	5.8	1360	1.05	0.52	54.60	30.1	3.13	0.133	518	1.6	28.8	32.4	86.8	159.0
36	100NE	Mean	5.74	7.50	1303.33	0.99	0.50	57.27	28.50	3.10	0.10	520.33	1.40	28.83	32.00	88.53	146.00
37		SD	0.22368	3.38674	191.3984	0.10392	0.06807	5.68976	1.76918	0.02517	0.03404	3.21455	0.2	2.85015	3.5171	1.50444	21.6564
38	300NE		5.74	7.3	1560	1.68	0.46	55.50	21.5	2.96	0.500	460	2.2	22.2	33.3	83.2	105.0
39	300NE		5.56	4.6	1670	2.59	0.32	59.20	21.2	2.57	0.072	372	4.0	24.7	25.4	89.3	77.0
40	300NE		5.51	6.2	65.1	1.53	0.32	54.90	20.8	3.07	0.064	376	3.7	28.4	19.4	91.7	81.9
41	300NE	Mean	5.60	6.03	1098.37	1.93	0.37	56.53	21.17	2.87	0.21	402.67	3.30	25.10	26.03	88.07	87.97
42		SD	0.12	1.36	896.52	0.57	0.08	2.33	0.35	0.26	0.25	49.69	0.96	3.12	6.97	4.38	14.95
43																	
44																	

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
45	Site/Sample		Al	As	Ba	Ca	Cd	Cr	Cu	Fe	Hg	Mn	Mo	Ni	Pb	V	Zn
46	Bay de Chene		(%)	(ppm)	(ppm)	(%)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
47	500NE		5.42	6.9	947	0.54	0.26	49.70	17.4	2.55	0.034	285	1.1	21.1	20.1	87.3	84.4
48	500NE		6.73	5.6	1260	0.86	0.35	66.60	23.5	3.28	0.061	448	1.2	31.8	23.2	102.0	98.6
49	500NE		6.83	6.6	1120	0.63	0.34	64.20	23.5	3.37	0.058	591	1.0	32.1	24.3	103.0	103.0
50	500NE	Mean	6.33	6.37	1109.00	0.68	0.32	60.17	21.47	3.07	0.05	441.33	1.10	28.33	22.53	97.43	95.33
51		SD	0.79	0.68	156.79	0.17	0.05	9.14	3.52	0.45	0.01	153.11	0.10	6.27	2.18	8.79	9.72
52	1000NE		6.55	8.0	979	1.17	0.34	59.00	20.6	3.09	0.045	329	1.7	26.1	22.4	105.0	90.3
53	1000NE	b	5.94	6.4	1140	1.47	0.25	56.10	20.0	2.87	0.044	321	1.4	31.0	18.9	85.6	73.2
54	1000NE	b	5.94	4.7	325	2.14	0.21	55.60	18.2	2.69	0.042	317	1.3	27.1	16.7	82.2	68.7
55	1000NE	b	5.61	4.7	1060	2.36	0.23	54.20	17.9	2.59	0.042	309	1.2	25.6	18.5	82.1	67.8
56		Average b	5.83	5.27	841.67	1.99	0.23	55.30	18.70	2.72	0.04	315.67	1.30	27.90	18.03	83.30	69.90
57	1000NE		6.77	6.4	1000	1.15	0.23	66.70	22.3	3.12	0.047	283	1.3	30.2	20.1	104.0	86.7
58	1000NE	Mean (3 #s)	6.38	6.56	940.22	1.44	0.27	60.33	20.53	2.98	0.04	309.22	1.43	28.07	20.18	97.43	82.30
59		SD	0.49	1.37	86.00	0.48	0.06	5.82	1.80	0.22	0.00	23.67	0.23	2.06	2.18	12.25	10.89
60	500SE		3.97	6.1	832	12.30	0.20	32.20	10.8	1.73	0.029	387	0.9	14.0	14.0	53.4	51.8
61	1000SE		5.55	7.8	1120	1.50	0.39	49.00	15.5	2.43	0.400	440	1.1	20.3	20.5	77.4	77.5
62	Site/Sample		Al	As	Ba	Ca	Cd	Cr	Cu	Fe	Hg	Mn	Mo	Ni	Pb	V	Zn
63	DELACROIX I.		(%)	(ppm)	(ppm)	(%)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
64	Discharge A		6.04	11.2	350	0.88	0.25	56.10	23.4	3.49	0.063	1160	1.4	34.4	24.6	101.0	101.0
65	B		5.80	10.7	1380	0.83	0.24	54.10	22.3	3.26	0.067	948	1.4	32.4	27.4	94.2	98.9
66	C		5.86	10.2	358	0.82	0.26	56.00	22.7	3.30	0.075	1196	1.3	1.3	21.2	101.0	97.2
67	Discharge	Mean	5.90	10.70	696.00	0.84	0.25	55.40	22.80	3.35	0.07	1101.33	1.37	22.70	24.40	98.73	99.03
68		SD	0.12	0.50	592.37	0.03	0.01	1.13	0.56	0.12	0.01	134.00	0.06	18.56	3.10	3.93	1.90
69	Reference 1A		5.62	4.7	994	1.09	0.20	54.00	17.3	2.66	0.045	535	1.3	25.8	23.8	85.2	83.4
70	R1A		-	-	-	-	-	-	-	-	0.048	-	-	-	-	-	-
71	R1A		-	-	-	-	-	-	-	-	0.047	-	-	-	-	-	-
72		R1A mean									0.047						
73	R1B		5.50	5.0	1071	1.09	0.17	47.30	14.6	2.33	0.041	606	0.9	23.9	22.1	71.6	73.6
74	R1C		5.56	4.5	1010	0.90	0.19	50.60	17.1	2.57	0.046	653	1.0	25.6	23.9	76.7	75.1
75	R1	Mean	5.56	4.73	1025.00	1.03	0.19	50.63	16.33	2.52	0.045	598.00	1.07	25.10	23.27	77.83	77.37
76		SD	0.06	0.25	40.63	0.11	0.02	3.35	1.50	0.17	0.003	59.41	0.21	1.04	1.01	6.87	5.28
77	Site/Sample		Al	As	Ba	Ca	Cd	Cr	Cu	Fe	Hg	Mn	Mo	Ni	Pb	V	Zn
78	DELACROIX I.		(%)	(ppm)	(ppm)	(%)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
79	R2A		4.70	3.2	1340	1.10	0.04	36.20	9.9	1.84	0.030	515	0.7	19.0	18.2	58.7	55.8
80	R2B		4.85	4.2	1430	1.05	0.11	45.70	11.6	1.95	0.033	443	0.9	20.8	19.3	59.4	57.4
81	R2B		4.93	4.6	1410	1.02	0.11	41.00	12.4	1.94	-	441	1.0	21.1	18.6	57.6	58.4
82	R2B		4.92	4.2	1290	1.01	0.19	42.30	11.7	1.92	-	447	1.0	21.1	19.3	55.4	59.2
83	R2B	average	4.90	4.33	1376.67	1.03	0.14	43.00	11.90	1.94	0.033	443.67	0.97	21.00	19.07	57.47	58.33
84	R2C		4.79	3.2	1330	1.03	0.08	38.40	9.7	1.77	0.030	416	0.9	20.0	18.0	51.6	55.0
85	R2	Mean (3#s)	4.80	3.58	1348.89	1.05	0.09	39.20	10.50	1.85	0.031	458.22	0.86	20.00	18.42	55.92	56.38
86		SD	0.10	0.65	24.57	0.04	0.05	3.47	1.22	0.08	0.002	51.08	0.14	1.00	0.57	3.79	1.74
87	100OS		4.79	3.2	283	3.96	0.17	41.20	11.0	1.80	0.028	430	0.8	17.7	12.7	56.6	57.9
88																	

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
89	Site/Sample		Al	As	Ba	Ca	Cd	Cr	Cu	Fe	Hg	Mn	Mo	Ni	Pb	V	Zn
90	DELACROIX I.		(%)	(ppm)	(ppm)	(%)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
91	500S		4.84	4.0	1220	1.04	0.07	36.00	9.8	1.70	0.032	340	0.7	17.6	16.1	55.9	51.8
92	500S		-	-	-	-	-	-	-	-	0.030	-	-	-	-	-	-
93	500S		-	-	-	-	-	-	-	-	0.031	-	-	-	-	-	-
94	300S		4.73	3.5	933	1.13	0.07	36.50	9.2	1.54	0.029	274	0.7	15.3	13.8	42.4	52.4
95	100S		4.46	3.7	1170	1.18	0.07	35.60	8.7	1.46	0.024	378	0.6	15.6	14.8	35.6	47.5
96	100ONW		3.90	3.8	2850	6.79	0.05	29.50	8.8	1.43	0.230	406	1.0	14.6	13.7	42.3	46.5
97	100ONW		2.79	5.1	73.7	3.84	0.17	28.90	12.7	2.59	0.038	396	2.2	16.7	4.1	44.3	45.2
98	100ONW		3.23	5.4	299	3.20	0.10	29.90	10.7	1.09	0.027	295	1.6	14.1	6.1	46.3	30.0
99	100ONW	Mean	3.31	4.77	1074.23	4.61	0.11	29.43	10.73	1.70	0.10	365.67	1.60	15.13	7.97	44.30	40.57
100		SD	0.56	0.85	1541.98	1.91	0.06	0.50	1.95	0.79	0.11	61.40	0.60	1.38	5.06	2.00	9.17
101	500NW		5.00	3.1	1330	1.05	0.07	40.30	10.5	1.78	0.028	325	0.8	19.5	16.9	50.5	57.4
102	500NW		4.97	4.1	482	1.03	0.11	35.90	11.2	1.78	-	316	0.8	18.8	13.4	41.7	55.2
103	500NW		5.02	3.8	349	1.06	0.15	40.90	10.9	1.80	-	329	0.7	18.6	11.7	45.5	57.6
104	500NW		5.55	5.2	686	1.03	0.30	47.90	13.9	2.29	0.043	489	0.9	26.3	16.1	73.5	65.0
105	500NW		5.14	3.9	1760	1.10	0.24	44.10	11.5	1.84	0.032	382	0.8	22.6	16.0	60.5	54.9
106	500NW	Mean	5.14	4.02	921.40	1.05	0.17	41.82	11.60	1.90	0.03	368.20	0.80	21.16	14.82	54.34	58.02
107		SD	0.24	0.76	601.32	0.03	0.09	4.48	1.34	0.22	0.01	72.30	0.07	3.29	2.19	12.82	4.09
108	300NW		5.66	5.6	834	4.39	0.25	51.90	17.3	2.19	0.030	370	0.9	22.6	17.1	81.5	72.0
109	300NW	b	5.55	5.3	1270	1.45	0.33	49.40	15.7	2.13	0.032	378	0.9	26.5	18.1	74.1	61.0
110	300NW	b	5.63	5.2	1130	1.46	0.27	50.60	15.5	2.15	0.031	375	0.8	24.4	15.7	72.9	65.9
111	300NW	b	5.72	7.2	1160	1.37	0.31	52.10	15.1	2.20	0.030	379	0.9	27.0	16.3	75.7	64.4
112		Average b	5.63	5.90	1186.67	1.43	0.30	50.70	15.43	2.16	0.03	377.33	0.87	25.97	16.70	74.23	63.77
113	300NW		5.19	7.5	1220	1.34	0.30	47.00	12.4	2.10	0.035	620	0.8	25.6	16.1	65.9	57.5
114	300NW	Mean	5.49	6.33	1080.22	2.39	0.28	49.87	15.04	2.15	0.03	455.78	0.86	24.72	16.63	73.88	64.42
115		SD	0.26	1.02	213.89	1.74	0.03	2.55	2.47	0.05	0.00	142.27	0.05	1.85	0.50	7.81	7.27
116	100NW		5.24	6.4	1180	0.97	0.20	43.70	15.6	2.34	0.048	956	0.8	23.0	21.0	61.0	69.3
117	100NW		5.43	7.7	1420	1.04	0.29	48.50	14.0	2.21	0.040	704	0.7	27.0	17.4	68.8	62.5
118	100NW		5.33	4.6	1290	1.24	0.92	41.80	10.9	1.90	0.045	588	0.5	21.2	15.1	54.0	53.5
119	100NW	Mean	5.33	6.23	1296.67	1.08	0.47	44.67	13.50	2.15	0.04	749.33	0.67	23.73	17.83	61.27	61.77
120		SD	0.10	1.56	120.14	0.14	0.39	3.45	2.39	0.23	0.00	188.14	0.15	2.97	2.97	7.40	7.93
121	500NE		5.47	4.7	1050	0.96	0.10	47.00	14.7	2.32	0.037	549	0.8	22.6	20.8	75.1	73.8
122	300NE		5.52	3.9	615	0.93	0.17	44.70	16.3	2.30	0.038	470	1.0	21.6	13.3	68.5	70.8
123	100NE		5.70	4.6	278	0.91	0.23	50.30	17.2	2.44	0.043	380	1.1	21.7	14.2	75.2	77.2

APPENDIX B
CHARACTERIZATION OF CONTINUING OPEN BAY DISCHARGES

Table B-1. Open Bay Discharge Permits Identified by LDEQ (ordered alphabetically by operator, permits may be for more than one discharge, permits in bold removed from further consideration).

Permit Number	Company	Field	Comment[1]
2901	Aviva	Breton Sound 31	I, C
2134	Callon Offshore Pet.	Chandeleur Sound 25	I, C
1934	Callon Offshore Pet.	Main Pass 35	I, C
2860	Callon Offshore Pet.	Black Bay	I, C
2859	Callon Offshore Pet.	East Black Bay	I, C
2142	Callon Offshore Pet.	North Black Bay	I, C
2672	Callon Offshore Pet.	Southeast Black Bay	I, C
1901	Callon Offshore Pet.	West Black Bay	I, C
3023	Clovelly (LL&E)	Chandeleur Sound 51	I, C
2952	Columbia Materials	Breton Sound 20	I, C
4206	Devon	Breton Sound 30	NI
3014	Energy Dev. Corp.	Main Pass 49	I, C
2827	Energy Dev. Corp.	Breton Sound 1	I, C?
2747	**Exxon**	**Lake Raccourci**	**I, N**
2732	**Exxon**	**Lake Sand**	**I, N**
3320	Greenhill Petroleum	Timbalier Bay	I, C
2072	Gulfland (Grasso)	Main Pass 35	I, C
2995	Hubco Exploration	Saturday Island	I, C
3002	Hubco Expolration	SE Saturday Island	I, C
2704	Hunt Petroleum	Caillou Island	I, C
2809	**Kerr-McGee**	**Breton Sound 36**	**I, N**
2810	Kerr-McGee	Breton Sound 32	I, C
2618	Kerr-McGee	Breton Sound 20	I, C

3063	Laurel Operating	West Black Bay	I, C
3072	LL&E (Nerco)	East Lake Sand	I, C
1856	Pennzoil	Quarantine Bay	I, C
1902	**Pennzoil (Amoco)**	**Redfish Point**	**I, N**
2856	Pogo	Breton Sound 2	I, C
2857	Pogo	Breton Sound 23	I, C
2479	Qunitana	Timbalier Bay	I, C
1898	**Samedan**	**Breton Sound 17**	**I, N**
1870	Scana	Chandeleur Sound 51	I, C
2072	Slam Resources	Main Pass 35	NI
2915	Snyder Oil	Chandeuler Sound 71	NI
2084	Texaco	Caillou Island	I, C?
2816	Texaco	Lake Barre	I, C?
2881	Texaco	Lake Pelto	I, C?
2504	Texaco	West Cote Blanche Bay	I, C?
2523	Texaco	Cote Blanche Island	I, C?
3030.	Texaco	Queen Bess Island	I, C?
2825	Texaco	Rabbit Island	I, C?
1866	Texoil	Main Pass 4	NI
3032	Texoil	Chandeleur Sound 71	I, C
2273	Torch Operating	Chandeleur Sound 52	I, C
2915	Torch Operating	Chandeleur Sound 71	I, C
2898	Unocal	Caillou Island	I, C

[1] Results of interview, I = interviewed, NI = not interviewed, C= will continue to discharge if allowed, C?= not sure about continuing to discharge, N= plan to reinject or P&A and will not continue to discharge.
(previous owner]

Table B-2. Location, receiving water body, depth, discharge rates and other data available for assumed continuing open bay discharges in Louisiana (ordered by receiving water body).

Permit No.	Latitude	Longitude	Receiving Water Body	Average Depth (ft)	Discharge Rate (bbl/day)	Data [1]	Comments
2825	29 26' 53"	91 36' 12"	Atchafalaya Bay		2910	T x N	
3002	29 24' 35.061	89 54' 21.470"	Barataria Bay	8	2017	x C x	
1901	29 35' 51"	89 32' 25"	Black Bay	7	10123	T C N	
1901	29 35' 12"	89 32' 13"	Black Bay	7	20,077	T C N	
1901	29 35' 40"	89 34' 10"	Black Bay	8	11,500	T C N	
2672	29 32' 48.918"	89 29' 10.609"	Black Bay	7	8366	T x N	
2860	29 34' 9.7"	89 30' 45"	Black Bay		6800	T C N	
3063	29 35' 40"	89 34' 10	Black Bay	8	11,500	T x x	
2072	29 27' 3.403"	89 24' 11.464	Breton Sound	8	17,500	x C N	
2618	29 34' 41.4"	89 07' 00"	Breton Sound		22500	x x N	
2856			Breton Sound		3	T C x	
2857	29 35' 31.251"	89 01' 53.993"	Breton Sound		10	T x x	
2857	29 35' 6.121"	89 00' 4.795"	Breton Sound		10	T x x	
2901			Breton Sound		200	x x x	Permit not Available
2901			Breton Sound		876	x x x	Permit Not Available
2952	29 37' 4.813"	89 4' 12.891"	Breton Sound	18	223	x x N	
1870	29 46' 32"	89 15' 09"	Chandeleur Sound		49	T C N	
2273	29 45' 08.65"	89 12' 29.31"	Chandeleur Sound			x C x	
2915	29 42' 16"	89 24' 23"	Chandeleur Sound	6	130	T C N	
3023	29 46' 21"	89 16' 52"	Chandeleur sound	10	3.4	T C x	
3032	29 42' 15.824"	89 24' 23.062"	Chandeleur sound	10	25	T C N	
3032	29 41' 46.466"	89 23' 48.018"	Chandeleur sound	10	25	T C N	
2859	29 33' 45.179"	89 26' 27.147"	E. Black Bay		10807	T C x	
2816	29 12' 50"	90 29" 20"	Jacko Bay		600	T x x	
2816	29 12' 10"	90 28' 10"	Jacko Bay		220	T x x	
2816	29 12' 50"	90 28' 00"	Jacko Bay		614	T x x	
2816	29 12' 00"	90 28' 50"	Jacko Bay		117	T x x	
2816	29 13" 00"	90 30" 50"	Jacko Bay		int.	T x x	
2816	29 19' 50"	90 30' 10"	Jacko Bay		30	T x x	
2816	29 12' 00"	90 29' 50"	Jacko Bay		int	T x x	
2816	29-13' 00"	90-28' 40"	Lake Barre		510	T x x	
2881	29 06' 20"	90 39' 10"	Lake Pelto		729	T x x	
2881	29 05' 20"	90 38' 30"	Lake Pelto		1103	T x x	

2881	29 06' 10"	90 38' 40"	Lake Pelto		489	T x x	
2881	29 05' 00"	90 39' 50"	Lake Pelto		2485	T x x	
1866	29-41' 31.2"	89-22' 0.2"	Main Pass			T x N	
2072			Main Pass		20250	x C N	
2134	29 46' 26"	89 17' 27"	Main Pass			x x x	Permit not available
2134	29 49' 35"	89 19' 58"	Main Pass			x x x	Permit not available
3014			Main Pass		0	x x x	Permit not available
2142	29 38' 12.03"	89 33' 33.64"	North Black Bay		12076	T C N	
1856	29 25' 09"	89 30' 49"	Quarantine Bay	10	15000	T C x	
2995	29 10' 43.943"	90 46' 30.170"	Salt Bay	8		x x x	
2881	29 05' 20"	90 40' 50"	Terrebonne Bay		204	T x N	
2084	29 06' 50"	90 29' 00"	Terrebonne Bay	10	2,484	T x N	
2084	29 05' 30"	90 30' 40"	Terrebonne Bay	10	3,017	T x N	
2084	29 07' 10"	90 30' 10"	Terrebonne Bay	10	3,720	T x N	
2084	29 07' 20"	29 31' 10"	Terrebonne Bay			T x N	
2084	29 06' 00"	90 25' 50"	Terrebonne Bay	10	41	T x N	
2084	29 04' 00"	90 28' 40"	Terrebonne Bay	10	701	T x N	
2704	29 05' 28.293	90 32' 17.027"	Terrebonne Bay	8	524	x x N	
2816	29 11' 20"	90 29' 00"	Terrebonne Bay		30	T x x	
2816	29 22' 30"	90 30' 50"	Terrebonne Bay		140	T x x	
2898	29 04' 25"	90 24' 20"	Terrebonne Bay	4	3000	T C N	
2898	29 07' 50"	90 29' 50"	Terrebonne Bay			T C N	
2898	29 06' 00"	90 28' 40"	Terrebonne Bay	10	617	T C N	
2479			Timbailier Bay		10	T C N	
2816	29 12' 00"	90 26" 50"	Timbailier Bay		10	T x x	
2898	29 04" 20"	90 25' 30"	Timbailier Bay			T C N	
3320	29 05' 29"	90 18' 30"	Timbailier Bay		4744	x x N	
3320	29 04' 12"	90 18' 30"	Timbailier Bay		3873	T C N	
3320	29 04' 33"	90 17' 10"	Timbailier Bay		4914	x x N	
3320	29 04' 37'	90 19' 2"	Timbailier Bay		7368	x x N	
3320	29 04' 17'	90 19' 25"	Timbailier Bay		1680	x x N	
2084	29 06' 20"	90 27' 30"	Timbalier Bay	10	1,201	T x N	
2084	29 07' 00"	90 26' 40"	Timbalier Bay			T x N	
2084	29 06' 10"	90 26 50"	Timbalier Bay			T x N	
2084	29 05' 20"	90 27' 00"	Timbalier Bay			T x N	
2084	29 05' 22"	90 25' 56"	Timbalier Bay			T x N	
2084	29 07' 00"	90 32' 40"	Timbalier Bay	10	802	T x N	
2084	29 05' 20"	90 27' 00"	Timbalier Bay	10	2,126	T x N	
2084	29 08' 00"	90 27' 40"	Timbalier Bay	10	2,065	T x N	
2084	29 06' 50"	90 27' 50"	Timbalier Bay	10	586	T x N	
2084	29 06' 19"	90 27' 58"	Timbalier Bay			T x N	
2504	29 41' 04"	91 47' 59"	West Cote Blance Bay	10	37113	T x N	
2523	29 43' 10"	91 42' 00"	West Cote Blanche Bay	7	5,364	T C N	
2523	29 43' 48"	91 41' 35"	West Cote	Blanch e Bay		T C N	

1934						14443	x x x	Permit not available
2827						1	x x x	
2915							x x x	Permit not available
3072							x x x	No Data in Permit File
4206							x x x	Permit Not Available

[1] Available Data" T= toxicity data; C= chemical data; N= NORM data

Figure C-1. Assumed active discharges in open Louisiana bays.

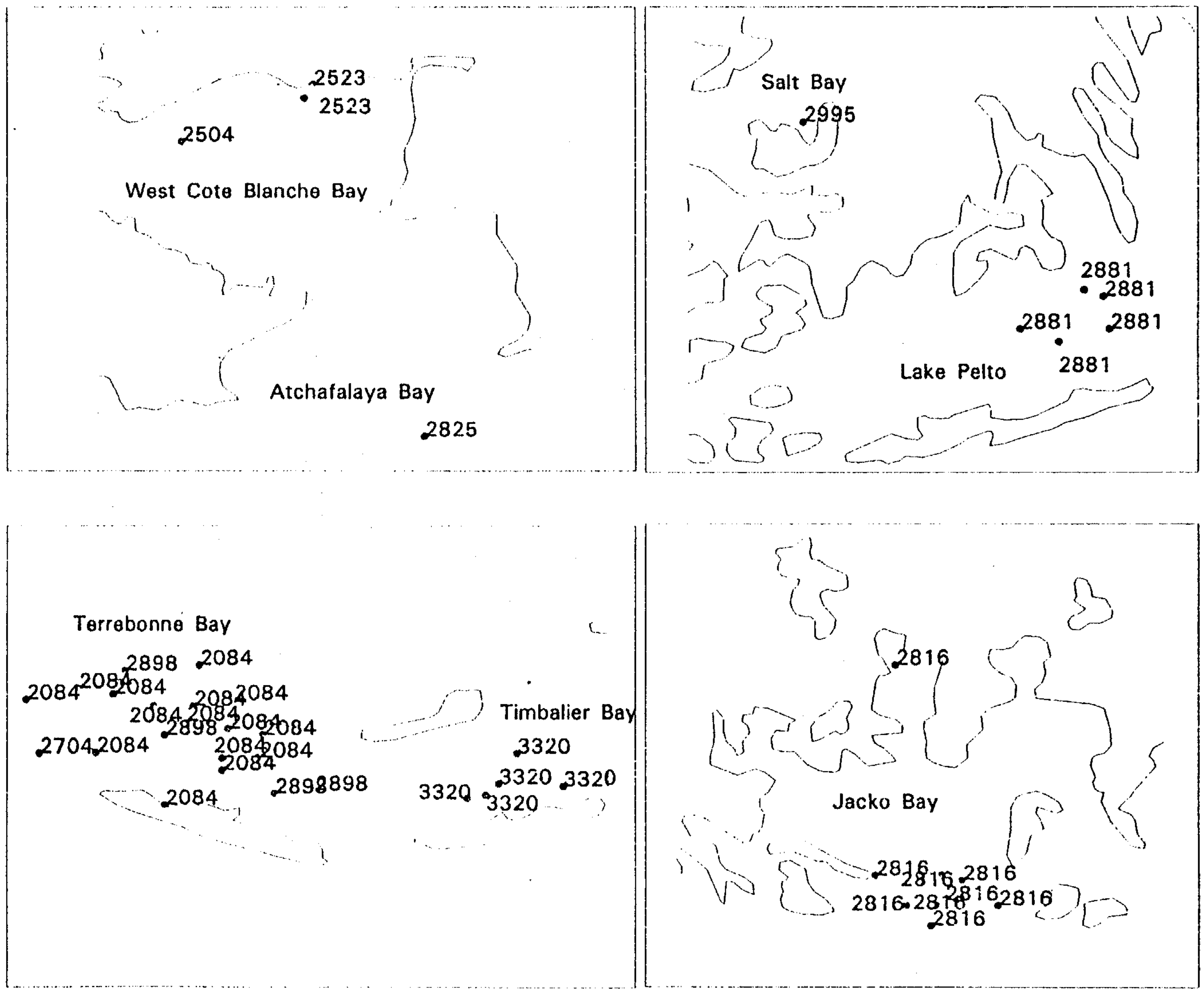

Figure C-1.(cont.) Assumed active discharges in open Louisiana bays.

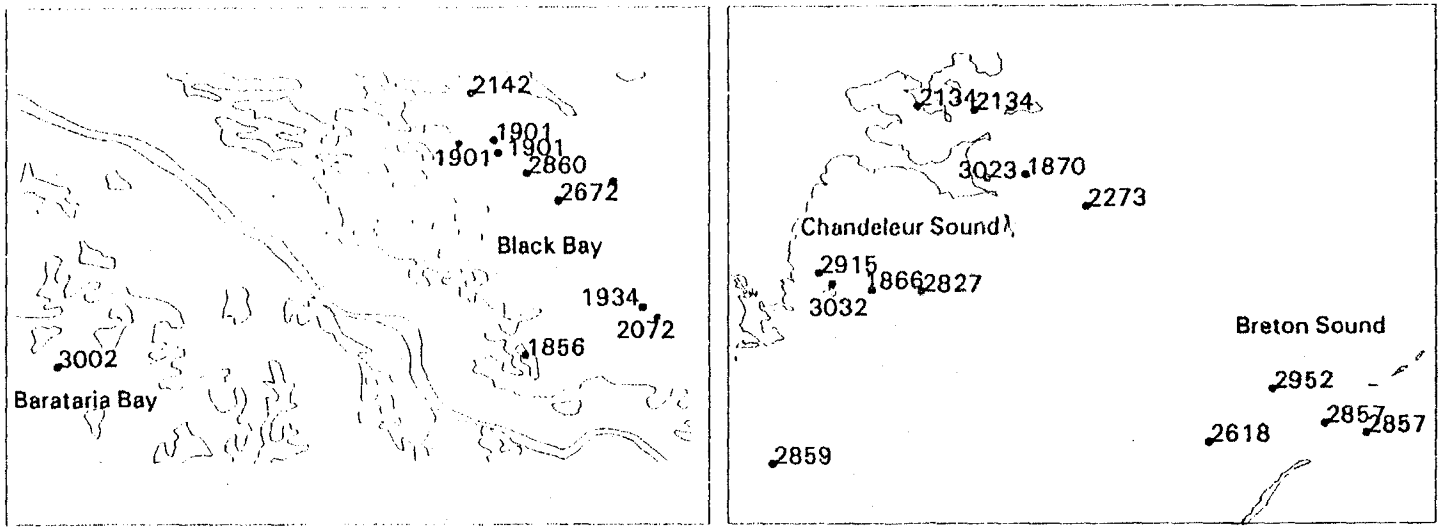

Table B-3. Chemical contaminant concentrations in open bay produced water discharges in Louisiana (ordered by receiving water body

Permit No.	1856	1856	1856	1856	1856	1870	1901	1901	1901	2072	2142	2523	2523	2618	2856	2859	2860	2898	2915	3002	3023	3032
	sample #1	sample #2	sample #	sample #	average																	
ANTIMONY													134		0.3			20.1		12.5	15.43	11.852
ARSENIC	0.013				0.013	0.011	6.9				10		117	30		44	79	0.011		88.489		27.055
BARIUM														62000								
BENZENE	19600	7270	4910	6420	9550		1400	150	770	950	19600	4910	1760	96		396	10	4400		410		85
CADMIUM													1.8		0.01		0.11	0.5		<.003	0.46	301.515
CHROMIUM (IV)							140						26.9					0.2		17.626	0.05	53.864
COPPER	0.39				0.39		130				710		350	10	0.02		0.16	0.38		244.643	0.27	460.8
LEAD													56		829		1.1	0.3		83.788	2.28	35.355
MERCURY															0.004	0.0034				0.0068	0.001	<0.001
NAPHTHALENE	1180				1180				41	82		51	100				0.01					
NICKEL											310		261				2.1	1.5		57.895	2.84	113.043
PHENANTHRENE	20				20																	
PHENOL	631				631	70	360	180	340	350	91	2200	1530		12000		0.15	3200		1400	24	
SELENIUM																0.077				80		10.986
SILVER													125					0.4		11.304	0.24	14.291
TOLUENE	3890	1660	2280	2980	2702.5		2800	180	580	830	3890	799	759	110		223	0.035	1500	16			
XYLENES	1090	621	737	1000	862		110	10		95	1090	390				67	0.028	220	44		7	
ZINC	0.17				0.17	0.1	110				120		1950	50	0.38		0.26	4.1		31.094	0.24	76.173
Bis (2-ethylhexyl) phth	66				66	60	80				57					45	0.05					
Flourene	11				11																	
2,4-Dimethylphenol	106				106				14	48		8040			990			510		77		
Acetone										390					2200							
2-Methylnaphthalene										53							0.01					
2-Methylphenol							20	10		66							0.02	1500				
4-Methylphenol							150			300							0.14	1700			60	
Benzoic acid										420												
Iron														16000								
2-Butanone															2100			930			230	
Beryllium																		0.05		<.1		0.635
Thallium																		2.5		248.387	2.73	345.313
Methylene Chloride																	0.008			36		
Acetone																	0.039				98	
1,2 Dichloropropane																						55
Carcon Tetrachloride																						45
2-Hexanone																					30	55
2-Chlorophenol																						18
1,4-Dichlorobenzene																						11
1,2-Dichlorobenzene																						12
N-Nitroso-di-n-propylamine																						11
1,2,4-Trichlorobenzene																						13
Acenapthene																						17
Fluorene																						11
4-Methyl-2-Pentanone																					17	
Diethylphthalate															580							
4-Nitrophenol												49										

Table B-4. Radium concentrations in open bay produced water discharges in Louisiana (ordered by receiving water body).

Permit No.		^{226}Ra (pCi/l)	^{228}Ra (pCi/l)
1866		23	2
1870		73.8	109.0
1901		296	367
1902		178	245
2072		240	273
2084	Tank Bat 2	181	282
2084	Tank Bat 4	65.2	69.2
2084	Tank Bat 6	308	368
2084	Tank Bat 7	87.1	61.4
2084	Tank Bat 8	156	91.4
2084	Tank Bat 9	273	424
2084	Tank Bat 10	172	295
2084	Tank Bat 11	114	171
2084	Tank Bat 14	117	208
2084	Tank Bat 15	247	291
2084	Tank Bat 17	146	283
2084	Tank Bat 18	50.2	56.3
2084	Tank Bat 19	272	353
2084	Tank Bat 20	380	558
2084	Tank Bat 21	311	483
2084	Tank Bat 22	89.2	125
2084	Tank Bat 23	68	47.1
2084	Tank Bat 24	131	225.0
2142		277.0	341.0
2479		3.9	2
2504		108	149
2523	TB#3	207	326
2523	TB#1	129	206
2618		201	289
2672		277.0	341.01

2704		127	400
2825		436	501
2860		120	41.9
2881	TB#2	52.7	109
2881	TB#3	194.0	307
2881	TB#4	173	472
2881	TB#5	290	545.0
2881	TB#1	224	389
2898		0.0	0
2915		290	60
2915		34	66
2952		52	15
3032		592	188
3320		198	265
3320		290	272
3320		284	402
3320		303	361
3320		333	560

APPENDIX C
RADIONUCLIDE EFFECTS

C.1 Quantities and Units

Traditional units in radiation dose measurements (i.e. Ci, rad, rem) are being replaced by the International System (SI) of units (Bq, Gy, Sv). The names and units (traditional and SI) for activity, absorbed dose and dose equivalent are given in Table C-1. Prefixes commonly applied to these units are given in Table C-2.

Table C-1. Radiological names and units.

Quantity	Traditional		SI		Conversion
	Name	Unit	Name	Unit	
activity	curie (Ci)	3.7×10^{10} dis/sec	becquerel (Bq)	1 dis/sec	1 Bq = 2.7×10^{-11} Ci
absorbed dose	rad (rad)	100 erg/gm	gray (Gy)	1 J/kg	1 Gy = 100 rad
equivalent dose	rem (rem)	100 erg/gm	sievert (Sv)	1 J/kg	1 Sv = 100 rem

Table C-2. Prefixes used in radiation protection.

pico (p)	10^{-12}
nano (n)	10^{-9}
micro (μ)	10^{-6}
milli (m)	10^{-3}
kilo (k)	10^{3}
mega (M)	10^{6}
giga (G)	10^{9}
tera (T)	10^{12}

Radioactivity is quantified in terms of the number of spontaneous energy emitting transformations per unit time -- a quantity known as activity. An example of a transformation is the decay of a radium 226 nucleus into a radon 222 nucleus, an alpha particle and gamma rays. The unit of activity has historically been the curie (Ci). One curie is equal to 3.7×10^{10} disintegrations per second. In the SI system, the basic unit of activity has been redefined as one disintegration per second, known as the becquerel (Bq). One curie is equal to 3.7×10^{10} Bq.

The biological effects of exposure to a radionuclide are related to the absorbed dose and dose rate. The absorbed dose is a measure of the energy imparted to matter. An absorbed dose of 100 erg/gram is called 1 rad. In the SI system of units, the unit of absorbed dose is the Gray (Gy, 1 Joule/kilogram). An absorbed dose of 1 rad is equal to 0.01 Gy (1 Gy = 100 rads).

The probability of stochastic effects (i.e. cancer and genetic effects) depends not only on the absorbed dose, but also on the type and energy of the radiation causing the dose and on the organs or tissues irradiated. Factors have been developed by the International Commission on Radiological Protection (ICRP, 1991) to account for these relationships in humans.

Radiation weighting factors are used to account for the differences in relative biological effectiveness (RBE) of different radiations. In the past these differences were accounted for by use of quality factors. The radiation weighting factor for gamma radiation (γ) and beta (β) particles has been assigned a value of 1. The weighting factor for alpha (α) particles is set to 20. The absorbed dose modified by the weighting factor is called the equivalent dose and is expressed in units of Joules per kilogram with the name Sievert (Sv) given to 1 Joule/kg. The traditional unit is the rem (see Table C-1). One Sievert is equal to 100 rem.

Tissue weighting factors are used to account for differences in the sensitivity to cancer induction of different human tissues and organs. A tissue weighting factor represents the relative contribution of that organ or tissue to the total effects resulting from uniform irradiation of the whole body. These factors are given in ICRP (1991). The equivalent dose weighted by these tissue weighting factors is referred to as the effective dose. For a uniform, whole body exposure, the equivalent and effective doses have the same value, and are both expressed in units of Sieverts (Sv).

The limited data for the relative biological effectiveness of various radiation types in man indicate that the RBE can be expected to be similar for aquatic organisms, (Woodhead, 1984), because the soft tissues of man and other organisms are generally similar in terms of water content and basic cell structure (IAEA, 1988). IAEA (1988) suggested that it is reasonable to apply the same quality factors (now radiation weighting factors) derived for humans to doses received by aquatic organisms. There are no parallel tissue weighting factors for aquatic organisms, and the usual approach to estimating doses to aquatic animals to assume that the dose is averaged over the whole body of the organism. NCRP (1991) suggests this approach is reasonable, as long as the average whole body exposure is representative of the dose to the gonads.

NCRP also suggests that it may be useful to estimate the dose to the most highly exposed tissue (NCRP, 1991).

C.2 Human Health Effects From Radium Ingestion

C.2.1 Carcinogenicity of Radium

The health effects of radium can be attributed to the radioactive emissions of the radium isotopes and their daughters. The alpha, beta and gamma radiation released by the decay of radium and its daughters cause ionization of cellular components which may result in the mutation or death of affected cells.

Most of the information concerning the health effects of radium come from studies of two groups of people: radium dial painters who ingested radium paint and patients who were injected with radium-224 for treatment of spinal arthritis and tuberculosis of the bone (NAS, 1988). The primary data come from studies of radium dial painters (Rowland et al., 1978, 1983). Radium body burdens were measured in the dial painters and were used to calculate lifetime intake.

In these studies, ingestion of ^{226}Ra resulted in bone cancers (osteosarcomas) and cancers of the linings of the cranial sinuses (head carcinomas). Ingestion of ^{228}Ra resulted in bone cancers. The dose-response function for bone cancer induced by ingestion of ^{226}Raor ^{228}Ra is purely quadratic, with no excess cancers at lower doses. From a practical point of view, the dose-response function exhibits a threshold at a dose to the skeleton that is well above the worst environmental exposures that have been documented.

The data for head carcinomas can fit either a linear or quadratic function. These carcinomas are attributed to radon-222, a daughter of ^{226}Ra. No excess head carcinomas are associated with ^{228}Ra. The half-life of its daughter product, radon-224, is too short to allow migration to and accumulation in cranial sinuses.

C.2.2 USEPA Risk Factors for Radium

Current practice in radiation protection is to assume there is a cancer risk associated with even miniscule doses of radiation. Risk factors are derived from epidemiological data and extrapolated down to low doses to describe the cancer risk associated with small exposures.

The Science Advisory Board (SAB) has recommended that the USEPA use the epidemiological evidence for bone and head cancers in radium dial painters to derive risk factors for radium (SAB, 1991). The evidence for radium-induction of other soft-tissue cancers is equivocal (Stebbings et al., 1984).

USEPA derived radium risk factors using the RADRISK model, based on effective dose equivalents given in ICRP (1977), modified to account for the specific metabolic behaviors of radioactive daughters (USEPA, 1991). RADRISK incorporates a toxicokinetic model based upon alkaline earth intake, retention and excretion. RADRISK is a linear, no-threshold model that uses the sum of weighted organ doses to arrive at a single dose coefficient used to predict either the risk of getting a cancer or the risk of dying from cancer. RADRISK incorporates a life-table analysis to adjust for age- and sex specific mortality from competing risks.

RADRISK uses a gut uptake factor (f_1) of 0.2, the value recommended by the ICRP (1979). This value is based on data for adult humans who ingested radium in water or incorporated into food (ICRP, 1973; Stehney and Lucas, 1956). Weighting factors in RADRISK were modified from those of the ICRP (USEPA, 1991) to calculate the risks for all cancers (fatal and non-fatal). "Ingested radium is estimated to distribute about 85% to bone and 15% to soft tissue. (UNSCEAR, 1972)" (USEPA, 1991).

The RADRISK model results were adjusted for the over-prediction of leukemias and lack of prediction of head carcinomas (Federal Register, 1991), but the RADRISK model still produces a majority (about two-thirds) of the overall risk estimate for soft tissues, where either no evidence or marginal evidence exists for radium induced cancers. For example, increases in breast cancer and multiple myelomas correlate better with duration of employment, a surrogate for external dose of gamma radiation, than with radium intake (Stebbings et al., 1984). According to the USEPA, the ratio of all cancer risks to the risks for bone and cranial cancers may be overestimated by a factor of between two and five (Federal Register, 1991).

The analysis performed by the USEPA (Federal Register, 1991; USEPA 1991) assumes a linear dose-response relationship for bone sarcoma, although the best fit for bone sarcoma in the radium dial painters is quadratic (USEPA, 1991). If the true relationship is quadratic, the USEPA risk factors will be overestimates. There may also exist a practical threshold for bone sarcoma (USEPA, 1991). Additional uncertainties and assumptions in the USEPA analysis are described in USEPA (1991).

Using RADRISK, the United States Environmental Protection Agency (USEPA) estimated the risk factor associated with the ingestion of ^{226}Ra in drinking water to be 4.4×10^{-6} lifetime risk per pCi/l, and the risk factor for ^{228}Ra to be 3.8×10^{-6} lifetime risk per pCi/l (assuming lifetime exposure) (Table 23, Federal Register, 1991; USEPA, 1991). These risk factors are based on an assumed water intake of 2 l/day. Unit risk factors (individual lifetime fatal cancer risk per pCi/day) can be derived from these values by dividing the risk factors by two. The USEPA risk factors are then equivalent to 2.2×10^{-6} lifetime risk per pCi/day for ^{226}Ra

and 1.9 x 10^{-6} lifetime risk per pCi/day for ^{228}Ra (assuming lifetime exposure) (Table C-3).

C.2.3 Risk Factor Distribution

A risk factor distribution for ^{226}Ra and ^{228}Ra was derived by assuming that the USEPA values represent the upper 90% confidence limit of a lognormal distribution. The lower 90% confidence limit was based on the risk factors for the radium induced cancers in humans for which there is epidemiologic evidence (bone and head carcinomas for ^{226}Ra and bone sarcoma for ^{228}Ra). The methods of Layton et al. (1987) were used to establish lognormal distributions with the arithmetic means and standard deviations given in Table C-4.

Table C-3. USEPA risk factors for ^{226}Ra and ^{228}Ra*.

TYPE	USEPA RISK FACTORS		USEPA UNIT RISK FACTORS	
	^{226}Ra risk per pCi/l	^{228}Ra risk per pCi/l	^{226}Ra risk per pCi/day	^{228}Ra risk per pCi/day
Bone Sarcoma	9.4E-7	9.4E-7	4.7E-7	4.7E-7
Head Carcinoma	9.4E-7	0	4.7E-7	0
Leukemia, high LET	2.1E-7	2.6E-7	1.1E-7	1.3E-7
Leukemia, low LET	9.6E-8	2.6E-7	4.8E-8	1.3E-7
All Other	2.3E-6	2.3E-6	1.2E-6	1.2E-6
Total	4.4E-6	3.8E-6	2.2E-6	1.9E-6

* individual lifetime cancer risk, assuming lifetime exposure.
** from USEPA (1991, Table VIII-5, section 4).
*** divide USEPA risk factors (risk per pCi/l) by two to get risk per pCi/day.

Table C-4. Risk factor distribution for Ra-226 and Ra-228 (lognormal distributions, risk per pCi/day).

Parameter	^{226}Ra	^{228}Ra
Arithmetic Mean	1.5E-6	1.0E-6
Standard Deviation	9.0E-7	1.4E-6
Lower 90% Confidence Limit	9.4E-7	4.7E-7
Upper 90% Confidence Limit	2.2E-6	1.9E-6

Radium is retained in bone and delivers a dose over the remaining lifespan of the exposed individual. The risk factors calculated by the USEPA model

RADRISK take account of the total dose accumulated by tissues after intake (called the committed effective dose equivalent), and assume a lifetime exposure.

Retention is the amount of a substance remaining in a tissue or organ at some time after uptake. Within 10 years after an initial intake of radium, most of the radium in the body has been eliminated (*Norris et al.*, 1955). This observation suggests a way to adjust the USEPA lifetime risk factors (and the distributions of risk factors) for exposure periods less than a lifetime. If ten years (to account for the radium left in the body, and delivering a dose after intake and uptake have stopped) is added to the expected exposure period, the maximum risk factor for the expected exposure period can be calculated:

$$RF(EP) = \frac{[(EP + 10)] \times URF(70)}{70 \text{ years}}$$

where:
RF(EP) = risk factor as a function of exposure period EP (lifetime risk per pCi/day)
EP = exposure period (years)
URF(70) = USEPA unit risk factor for lifetime exposure (lifetime risk per pCi/day)

This modified risk factor was used in the probabilistic risk assessment for radium described in this report. This method will slightly overestimate the committed dose, but the estimate is less conservative than assuming a seventy year exposure when such an assumption is not realistic.

C.3 Effects on Aquatic Organisms

Exposure to ionizing radiation can result in injury at the molecular, cellular and whole body levels. Most of the available studies of the effects of radiation on aquatic organisms are concerned with the induction of deterministic, somatic effects. These effects include increases in mortality and pathophysiological, developmental and reproductive effects. There is little information available concerning induction of cancer and genetic effects, although a few studies of stochastic genetic effects in organisms are available (Anderson and Harrison, 1986).

Reproductive and early developmental systems of vertebrates are the most sensitive to radiation, and invertebrates appear to be relatively resistant (NCRP, 1991).

Most studies of the effects of radiation on aquatic organisms were performed in the laboratory, with effects determined on individual animals. A few studies of the effects of radiation on natural populations have been performed. The most important consideration on assessing the effects of radionuclides discharged in produced water is the influence radiation exposure has on reproductive success in populations, and consequences in populations and ecosystems. If exposures are limited to protect fertility and fecundity of the population as a whole, it is unlikely that other effects in individuals will be important to the population (NCRP, 1991).

IAEA (1976) and Templeton (1980) examined the possible effects of chronic, low level radiation on recruitment, fecundity and mortality by considering the known regulatory mechanisms of natural populations. Recruitment for highly fecund species is not directly related to standing stock size and the mortality rate operating on eggs and larvae varies from year to year. Survival of eggs and larvae depend to a large degree on the availability of food, and a large number of eggs are produced at each spawning (Templeton, 1980). Density dependent mortality reduces fish larvae populations to the level that can be supported by the available food. If mortality is enhanced by low levels of radiation, recruitment to the stocks of highly fecund fish is not likely to be affected, unless the stocks are already at risk due to over-exploitation or other environmental stresses (IAEA, 1976; IAEA, 1988; NCRP, 1991).

For species with low fecundity (e.g., sharks and marine mammals), recruitment is closely related to parent stock size. It is not possible to predict the effects on recruitment for these species, although effects could be more significant than for highly fecund species. However, at low dose rates, it is reasonable to assume that effects will be small compared to fishing and other pressures (IAEA, 1976). For species with special social value (endangered and threatened species, marine mammals) effects on individuals may be of importance.

Effects at the ecosystem level have been demonstrated only for the large doses received at Eniwetok and Bikini atolls in the Pacific Proving Grounds (Templeton, et al., 1971).

The National Council on Radiation Protection and Measurements recently reviewed the literature on the effects of ionizing radiation on aquatic organisms, and suggested reference levels that would protect aquatic populations (NCRP, 1991). Major conclusions of this review included:

- Experimental studies in the laboratory have shown detectable effects on fecundity down to 10 mGy/d.

- Effects not necessarily deleterious at the population level have been detected at dose rates between 1 and 10 mGy/d. Deleterious effects on natural populations were observed at dose rates ≥ 10 mGy/d. Clearly deleterious effects which would be detected at the population level appear in the range of 10-100 mGy/d.

- Lowest dose rate causing no effect in natural populations: 0.5 mGy/d; lowest dose rate causing no effect in laboratory: 10 mGy/d.

NCRP (1991) suggests a reference dose rate to protect aquatic populations of 10 mGy/d. NCRP also suggests a detailed assessment if an initial analysis results in estimated dose rate above 2.4 mGy/d.

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