Ocean Discharge Criteria Evaluation for GEG460000

Table of Contents

TABLES

FIGURES

1. Introduction

The U.S. Environmental Protection Agency (EPA), Region 4, is reissuing the National Pollutant DischargeElimination System (NPDES) General Permit for discharges from new and existing sources and new discharges of oil and gas extraction activities in its jurisdictional area of the Outer Continental Shelf (OCS) of the Gulf of Mexico (GOM). The permit will apply to exploration, development and production phases for both existing and new sources within the Eastern Planning Area and portions of the Central Planning Area of the U.S. Department of the Interior (DOI), Bureau of Ocean Energy Management (BOEM).

This Ocean Discharge Criteria Evaluation (ODCE) addresses the EPA's regulations for preventing unreasonable degradation of the receiving waters in portions of the Gulf of Mexico covered under this General Permit.

1.1 Background

Section 402 of the Clean Water Act (CWA) authorizes EPA to issue NPDES permits to regulate discharges to surface waters of the United States. Sections 402 and 403 of the CWA require that an NPDES permit for a discharge into the territorial seas (baseline to 3 miles), or farther offshore in the contiguous zone or the ocean, be issued in compliance with EPA's regulations for preventing unreasonable degradation of the receiving waters in Title 40 of the Code of Federal Regulations (CFR) Part 125, Subpart M.

Prior to permit issuance, discharges must be evaluated against the EPA's published criteria for determination of unreasonable degradation. The term "unreasonable degradation" is defined in the NPDES regulations (40 CFR 125.121)) as the following:

1. Significant adverse changes in ecosystem diversity, productivity, and stability of the biological community within the area of discharge and surrounding biological communities;

2. Threat to human health through direct exposure to pollutants or through consumption of exposed aquatic organisms

3. Loss of aesthetic, recreational, scientific, or economic values, which is unreasonable in relation to the benefit derived from the discharge.

Ten factors are specified at 40 CFR § 125.122 for consideration by EPA when determining whether a discharge will cause unreasonable degradation. They are the following:

1. The quantities, composition, and potential for bioaccumulation or persistence of the pollutants to be discharged;

2. The potential transport of such pollutants by biological, physical or chemical processes;

3. The composition and vulnerability of the biological communities which may be exposed to such pollutants, including the presence of unique species or communities of species, the presence of species identified as endangered or threatened pursuant to the Endangered Species Act

or the presence of those species critical to the structure or function of the ecosystem, such as those important for the food chain;

4. The importance of the receiving water area to the surrounding biological community, including the presence of spawning sites, nursery/forage areas, migratory pathways, or areas necessary for other functions or critical stages in the life cycle of an organism;

5. The existence of special aquatic sites including, but not limited to, marine sanctuaries and refuges, parks, national and historic monuments, national seashores, wilderness areas, and coral reefs;

6. The potential impacts on human health through direct and indirect pathways;

7. Existing or potential recreational and commercial fishing, including fin-fishing and shell-fishing;

8. Any applicable requirements of an approved Coastal Zone Management plan;

9. Such other factors relating to the effects of the discharge as may be appropriate; and

10. Marine water quality criteria developed pursuant to CWA Section 304(a)(1).

On the basis of the analysis in this ODCE, and other information contained in the Administrative Record for the permit, the EPA Region 4 Regional Administrator will determine whether the NPDES General Permit may be issued. Pursuant to 40 CFR § 125.123 , the Regional Administrator can make one of three findings:

1. The discharges will not cause unreasonable degradation of the marine environment, in which case the permit may be issued;.

2. The discharges will cause unreasonable degradation of the marine environment after application of all possible permit conditions specified in 40 CFR § 125.123(d), in which case the permit may not be issued; or

3. There is insufficient information to determine, before permit issuance, that there will be no unreasonable degradation of the marine environment, and issue the permit if, on the basis of available information, the Regional Administrator determines that:

    - Such discharge will not cause irreparable harm to the marine environment during the period in which monitoring will take place,
    - There are no reasonable alternatives to the on-site disposal of these materials, and
    - The discharge will be in compliance with additional permit conditions set out under (40 CFR §125.123(d)).

1.2 Scope

The reissued General Permit covers discharges from offshore oil and gas activities that fall into three operational categories:

1) Exploratory drilling operations, which identify the location of producing formations.
2) Development operations conducted on platforms from which multiple wells are drilled.
3) Production operations that occur during and after developmental drilling.

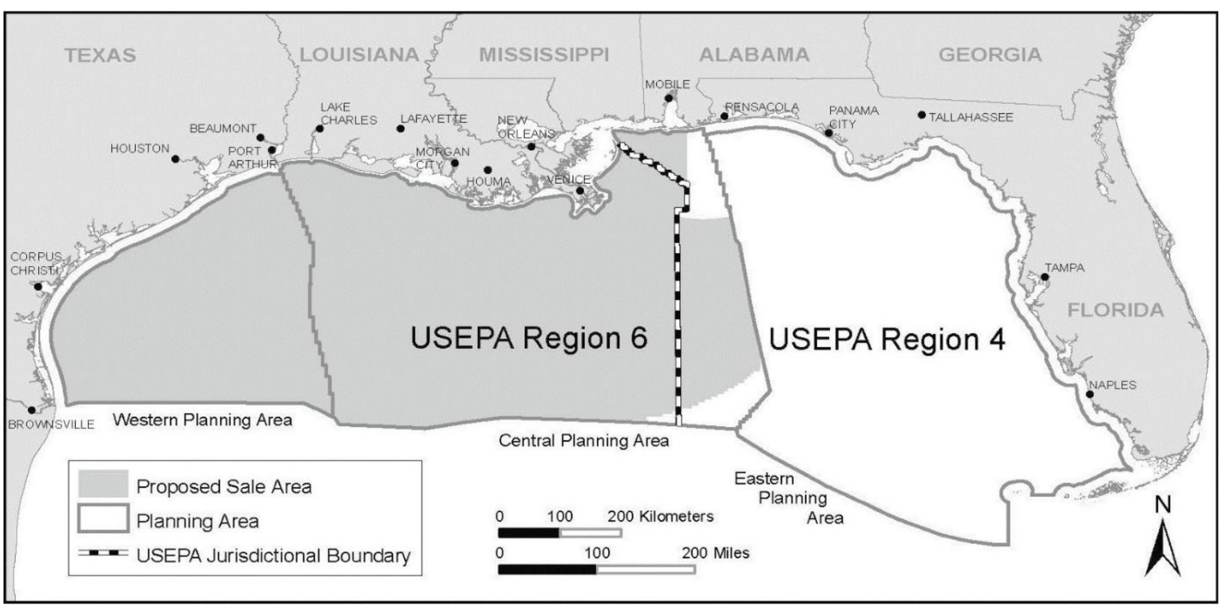
This ODCE evaluates the impacts from the waste discharges regulated under the permit including drilling fluids; drill cuttings; deck drainage; produced water; produced sand; well treatment, completion, and workover fluids; sanitary waste; domestic waste; and miscellaneous wastes.

In this evaluation the ODCE addresses the 10 factors for determining unreasonable degradation as outlined above and at 40 CFR § 125.122. It also assesses whether the information exists to make a "no unreasonable degradation" determination, including any recommended permit conditions that may be necessary to reach that conclusion.

1.3 Area of Coverage

Figure 1-1 shows the EPA Region 4 and 6 CWA jurisdictional boundary and its relationship with BOEM Eastern, Central and Western Planning Areas for leasing activities in the GOM. The CWA provides the EPA with federal jurisdiction for NPDES permitting beginning three statute miles from the landward boundary of the territorial seas, or "baseline," for all states bordering the GOM.

The General Permit will authorize new and existing source discharges from oil and gas activities within the Region 4 jurisdictional area seaward from the 200-meter depth contour, and seaward of the territorial seas offshore Alabama and Mississippi in the Mobile and Viosca Knoll lease blocks. Activities landward of the 200-meter depth contour, except in the Mobile and Viosca Knoll lease blocks, will require individual NPDES permits.



1.4 Evaluation of the Ten Ocean Discharge Criteria

Factor 1 - Quantities, Composition, and Potential for Bioaccumulation or Persistence of Pollutants

This factor requires consideration of the quantities, composition and potential for bioaccumulation or persistence of the pollutants to be discharged.

The quantities and composition of the discharged material is presented in Chapter 3 of Appenidx A and the potential for bioaccumulation or persistence is addressed in Chapter 5 of Appendix A. For discharges other than drilling fluids,the volume and constituents of the discharged material are not considered sufficient to pose a potential problem through bioaccumulation or persistence. However, to confirm the Agency's decision and as a precaution against any changes in operational practices that could change the Agency's assumptions, the discharged volumes of deck drainage, well treatment, completion, and workover fluids, and sanitary waste must be recorded monthly and reported once each year on the compliance monitoring report.

EPA is limiting the potential for bioaccumulation or persistence of discharge-related pollutants by placing specific limitations on metals contained in the barite added to water-based drilling fluids. The limits on cadmium and mercury will ensure that not only these two metals but an entire suite of other trace metals found in barite will be reduced in concentration, and their potential for bioaccumulation and persistence thereby decreased. Discharge limitations in the proposed permit are as follows:

Water Based Drilling Fluids	Statutory Basis
Discharge limited to a rate of 1,000 bbl/hour	BPJ
Report volume discharged (bbl/month)	CWA §308

Water Based Drilling Fluids	Statutory Basis
Whole effluent toxicity (WET) must meet both a daily minimum and a monthly average minimum limitation of 30,000 ppm (3.0% by volume), using a volumetric mud-to-water ratio of 1 to 9 [2]	BAT
No discharge of free oil as determined by the static sheen test	BCT/BAT
No discharge of fluids to which barite has been added if the barite contains mercury in excess of 1.0 mg/kg (dry weight) or cadmium in excess of 3.0 mg/kg (dry weight) [3]	BAT
No discharge within 100 meters of designated dredged material ocean disposal sites	BPJ
Record chemical usage inventory for each well	CWA §308

Synthetic Based Drilling Fluids	Statutory Basis
No discharge of OBM or SBM	BCT/BAT

Water Based Drill Cuttings	Statutory Basis
No discharge when using OBM or oil contaminated fluids	BCT/BAT
Report volume discharged (bbl/month)	CWA §308
WET must meet both a daily minimum and a monthly average minimum limitation of 30,000 ppm (3.0% by volume), using a volumetric mud-to-water ratio of 1 to 9	BAT
No discharge of free oil as determined by the static sheen test	BCT/BAT
No discharge of oil based drilling fluids	BCT/BAT
No discharge of fluids to which barite has been added if the barite contains mercury in excess of 1.0 mg/kg (dry weight) or cadmium in excess of 3.0 mg/kg (dry weight)	BAT
No discharge within 100 meters of designated dredged material ocean disposal sites	BPJ

Synthetic Based Drill Cuttings	Statutory Basis
No discharge if formation oil is detected in the drilling fluid as determined by GC/MS	BAT
Sediment toxicity test ratio shall not exceed 1.0 [4, 5]	BAT
Amount of SBM retained on cuttings must not exceed 6.9g	BAT

[2] Methodology is specified at 40 CFR Part 435, Subpart A, Appendix 2, Drilling Fluid Toxicity Test (EPA Method 1619).

[3] Methodologies are EPA Methods 200.7, 200.8, or Method 3050B followed by 6010B for cadmium and EPA 245.7 or 7471 A for mercury.

[4] Methodology is ASTM method no. E1367-92.

[5] Methodology is ASTM E1367-92 and equation in permit.

SBM/100g wet cuttings for C_{16}-C_{18} IOs or 9.4g SBM/100g wet cuttings for C_{12}-C_{14} or C_8 esters;[6] a default value of 14% retained fluid is used for compliance with discharges at the seafloor	
Polynuclear Aromatic Hydrocarbons (PAH) mass ratio must not exceed $1x10^{-5}$ [7]	BAT
Biodegradation rate ratio of the stock base fluid shall not exceed 1.0 [8]	BAT

Well Treatment, Completion and Workover Fluids	Statutory Basis
Report frequency/flow (bbl/month)	CWA §308
No discharge of free oil as determined by the static sheen test	BCT/BAT
Oil and grease must meet maximum limitation of 42.0 mg/l and monthly average limitation of 29.0 mg/l	BAT
No discharge of priority pollutants except in trace amounts	BAT

Sanitary Wastes	Statutory Basis
No discharge of floating solids	BCT
Manned by 10 or more: Total residual chlorine must be maintained at 1.0 mg/l at all times	BCT/BAT

Domestic Wastes	Statutory Basis
No discharge of floating solids or foam	BCT/BAT
No discharge except comminuted food waste (<25mm) may be discharged 12 nautical miles or more from land	BCT/MARPOL

Deck Drainage	Statutory Basis
Report frequency/flow	CWA §308
No discharge of free oil as determined by the visual sheen test	BCT/BAT

Miscellaneous Discharges	Statutory Basis
No discharge of free oil as determined by the visual sheen test	BCT/BAT
Toxicity limitation for Subsea Wellhead Preservation Fluids; Subsea Production Control Fluids; Umbilical Steel Tube Storage Fluids; Leak Tracer Fluids; and Riser Tensioning Fluids is a NOEC of no less than 50 mg/l	BPJ

[6] Methodology is the API Retort method specified at 40 CFR §435, subpart A of Appendix 7.
[7] Methodology is EPA Method 1654A and equation in permit.
[8] Methodology is ISO Method 11734:1995 and equation in permit.

Miscellaneous Discharges of Freshwater and Seawater to Which Treatment Chemicals Have Been Added	Statutory Basis
Report average flow (bbl/day)	CWA §308
No discharge of free oil as determined by the visual sheen test	BCT/BAT
Concentration of chemicals must meet the most stringent of: maximum concentration of product labeling, manufacturer's recommended concentration, or 500 mg/l	BPJ
Toxicity limitation is that NOEC must be equal to or greater than the critical dilution concentration as specified in the permit based on discharge rate, pipe diameter, and water depth	BPJ

The EPA believes that the limits imposed on the operational discharges authorized under the proposed permit are sufficient that no significant adverse impacts are likely to occur.

Factor 2 - Potential for Biological, Physical, or Chemical Transport

This factor requires consideration of the potential transport of pollutants by biological, physical or chemical processes.

Chapter 4 of Appendix A of this document is based on the literature available concerning the transport of water based andsynthetic based drilling fluids in the marine environment. Under a general permit, it is not possible to determine the potential for physical transport at each facility due to varying currents, discharge rates and configurations, and fluctuating effluent characteristics. Therefore, for drilling fluids, generalizations and assumptions were made to project scenarios to describe the industry and the coverage area. A protective modeling approach detailed in Chapter 4 of Appendix A, which was appropriate to the area of coverage of this permit, was used to determine potential physical transport processes and to regulate discharges of drilling fluids based on the predicted dilutions and dispersions.

Drilling fluids are regulated based on the modeling predictions about how the waste streams will behave when introduced into the marine environment. Discharge rate restrictions for drilling fluids are the result of the predicted transport of the constituents of the effluent.

Biological and chemical transport processes are not as well understood for drilling fluid discharges. The literature available is inconclusive about these processes and computer models do not account for them. Bioturbation should serve to mix sediments vertically, thereby enhancing the dispersion of muds and cuttings. However, the physical transport of these waste streams is considered to be the most significant source for dispersion of the wastes. Accordingly, the monitoring and discharge limitations/regulation to control physical dispersion described above will ensure that the biological and chemical transport processes will not result in unreasonable degradation.

Factor 3 - Composition and Vulnerability of Biological Communities

The third factor used to determine whether the discharge would cause unreasonable degradation of the marine environment is an assessment of the composition and vulnerability of the biological communities which may be exposed to the discharge of pollutants, including the presence of unique species or communities of species, the presence of species identified as endangered or threatened, or the presence of those species critical to the structure or function of the ecosystem, such as those important for the food chain.. Chapter 6 of Appendix Adescribes the biological community of theeastern Gulf including the presence of endangered species and factors that make these communities or species vulnerable to the permitted activities.

Drilling fluids (and the drilling fluids that adhere to cuttings) have been shown to cause smothering effects when discharged to shallow waters. To address the risk of smothering effects, the permit covers areas in deep waters of the Gulf of Mexicoand the permit prohibits the discharge of neat synthetic based fluids and restricts the water-based fluids discharge rate to 1,000 bbl/hr for all areas. The potential impacts due to toxic effects from drilling fluids have also been addressed by placing restrictions on total toxicity. This toxicity limitation ensures that the whole effluent will not be toxic to pelagic or benthic species once mixed with the receiving water.

In Chapter 6 of Appendix A, the biological community and its health are described according to available literature. Thepermit coverage area may include habitats that are sensitive to the discharges that may occur and special conditions have been implemented through the permit. BOEM has special stipulations for chemosynthetic communities in the Gulf and when an operator proposes to commence drilling on a lease containing these communities, BOEM may require mitigations to protect them from impact. These stipulations and mitigations, coupled with the permit conditions described above, ensure that the discharges will not result in unreasonable degradation.

Factor 4 - Importance of the Receiving Water to the Surrounding Biological Community

This factor requires consideration of the importance of the receiving water area to the surrounding biological community, including the presence of spawning sites, nursery/forage areas, migratory pathways, or areas necessary for other functions or critical stages in the life cycle of an organism.

The importance of the receiving waters to the species and communities of the eastern Gulf is discussed in Chapter 6 of Appendix A in conjunction with the discussion of the species and biological communities. The receiving water is considered when determining the discharge rate restrictions. The dispersion modeling considered concentrations of pollutants that may have impacts on aquatic life (through evaluation of marine water quality criteria - see Factor 10, below) and the toxicity limitations on both drilling fluids ensure that levels of the effluent is below levels that could have impacts on local biological communities. By protecting local biological communities, EPA has determined that adverse impacts on species migrating to coastal or inland waters for spawning or breeding will also be protected.

In addition, free oil, toxicity, oil content, oil and grease levels, solids, and chlorine concentrations are monitored in selected waste streams in order to ensure adequate water quality. Other requirements that apply to all discharges are no discharge of visible foam and minimal use of dispersants, surfactants, and detergents.

The permit also contains restrictions on proximity to areas of biological concern (ABC) and the 200 meter depth contour. These provisions limit the location of facilities in biologically productive areas and help to ensure the discharges will not result in unreasonable degradation. The 200-meter depth contour boundary for the General Permit was conceived in the 1998 iteration of the General Permit. In the General Permit prior to 1998, EPA found that the MMS (now BOEM) notice for leases regarding live bottom habitat included only high relief live bottom habitat (10 meters high or more). Concerned about protecting these habitats and others, EPA Region 4 added a provision requiring benthic imagery for all operators. Mapping these habitats was cumbersome and to make sure restrictions were fairly applied across operators, EPA Region 4 decided it best to exclude the shallow shelf from the general permit pursuant to 40 CFR 122.28(c) and established the 200-meter depth boundary.

Areas of biological concern (ABC) is a regulatory term from 40 CFR 128.28(c) referring to areas that require separate permit conditions. Areas of biological concern for water within the territorial seas (shoreline to 3-mile offshore) are those defined as “no activity zones” for biological reasons by the states of Alabama, Florida, and Mississippi. For offshore waters seaward of three miles, areas of biological concern include “no activity zones” defined by the Department of Interior (DOI) for biological reasons, or identified by EPA in consultation with the DOI, the states, or other interested federal agencies, as containing biological communities, features or functions that are potentially sensitive to discharges associated with the oil and gas industry. The permit contains provision that there shall be no discharge of drilling fluids and drill cuttings from those facilities within 1000 meters of an ABC.

Factor 5 - Existence of Special Aquatic Sites

The existence of special aquatic sites includes, but not limited to marine sanctuaries and refuges, parks, national and historic monuments, national seashores, wilderness areas and coral reefs. No Special Aquatic Sites are known to be present within or adjacent to the lease blocks covered by this permit. The draft permit prohibits discharges in proximity to Areas of Biological Concern and the 200 meter depth contour. Region 4's coverage area includes all discharges occurring in leases seaward of the 200 meter depth contour offshore Alabama and Florida. Areas of Biological Concern are defined in the above Factor 4 discussion. This permit contains three areas of biological concern, Southwest Rock, Southeast Banks and Fathom Hole, all located off the coast of Mississippi in the Mobile Block and Viosca Knoll lease blocks.

Factor 6 - Potential Impacts on Human Health

This factor requires consideration of potential impacts on human health through direct and indirect pathways. Due to the nature of the location of the discharges, there is little direct human exposure to the discharge. There is potential that humans will consume fish exposed to the discharges and the permit addresses that pathway.

Chapter 9 of Appendix A details the Federal and state human health criteria and standards for pollutants in drilling fluids.These criteria and standards are for marine waters based on fish consumption. These analyses found in Table 9-6 and 9-7 compare projected pollutant concentrations at 100 meter distance from the discharge point with these criteria and standards.

The permit prohibits the discharge of free oil, oil-based muds, synthetic based muds and muds with diesel oil added. These prohibitions are based on the potential effects of the organic pollutants in these discharges to human and aquatic life. In addition, the limitations that require low levels of cadmium and mercury in the barite added to drilling fluids also effectively lower the concentrations of other heavy metals found in barite. This will help to address bioaccumulation and exposure through consumption of fish by humans.

The following discharges are monitored and limited by the permit: Produced water, Completion Workover and Treatment Fluid discharged separately from produced water, Water based drilling fluids, Synthetic based drill cuttings and Water based drilling cuttings. All these listed discharges are subject to Whole Effluent Toxicity Testing limitations. These limitations will also address exposure through fish consumption.

Factor 7 - Recreational or Commercial Fisheries

This factor requires consideration of existing or potential recreational and commercial fishing, including fin fishing and shellfishing.

The commercial and recreational fisheries businesses in Alabama, Florida, and Mississippi are assessed in Chapter 7 of Appendix A. The conditions and limitations in the permit were determined to protect water quality and preserve the health of these fisheries. These permit conditions and limitations include no discharge of free oil, no discharge of oil-based or synthetic based muds, no discharge of diesel oil, no discharge of produced sand, and no discharge of produced water, discharge rate limitations around live-bottom areas, and limitations on the whole effluent toxicity of water based and synthetic based drilling fluids. The permit contains prohibitions on discharges in certain areas (areas of biological concern and the 200 m depth contour) as measures to ensure the most biologically productive areas are not affected.

Factor 8 - Coastal Zone Management Plans

This factor requires consideration of any applicable requirements of an approved Coastal Zone Management Plan.

Chapter 8 of Appendix A provides an evaluation of the coastal zone management plans of Alabama, Florida, and Mississippi. The states will have an opportunity to review the proposed permit to determine consistency with their plans. As detailed in Chapter 8 of Appendix A, the permit meets the requirements of the plans implemented bythe states and has been developed by the Region to be in compliance with those plans.

Factor 9 - Other Factors Relating to Effects of the Discharge

This factor requires consideration of such other factors relating to the effects of the discharges as may be appropriate.

The BAT (Best Available Technology Economically Achievable) and BCT (Best Conventional Pollutant Control Technology) effluent limitation guidelines for the Offshore Subcategory were promulgated in 1993. BAT conditions within the permit include: cadmium and mercury limitations in barite; toxicity limitations in drilling muds; no free oil discharge from drilling fluids, well treatment, completion, and workover (TWC) fluids, deck drainage, well test fluids or minor wastes; no oil-based drilling fluids discharge; produced water and TWC fluid oil and grease limitations; no discharge of produced sand; residual chlorine limitations in sanitary wastes; and no floating solids in either domestic or sanitary wastes. Final Effluent Limitation Guidelines and Standards for Synthetic-based Drilling Fluids (promulgated in 2001) prohibit the discharge of neat synthetic based drilling fluids and limit the amount retained on drill cuttings discharges. These technology based limits help to ensure that the discharges will not result in unreasonable degradation of the marine environment.

Factor 10 - Marine Water Quality Criteria

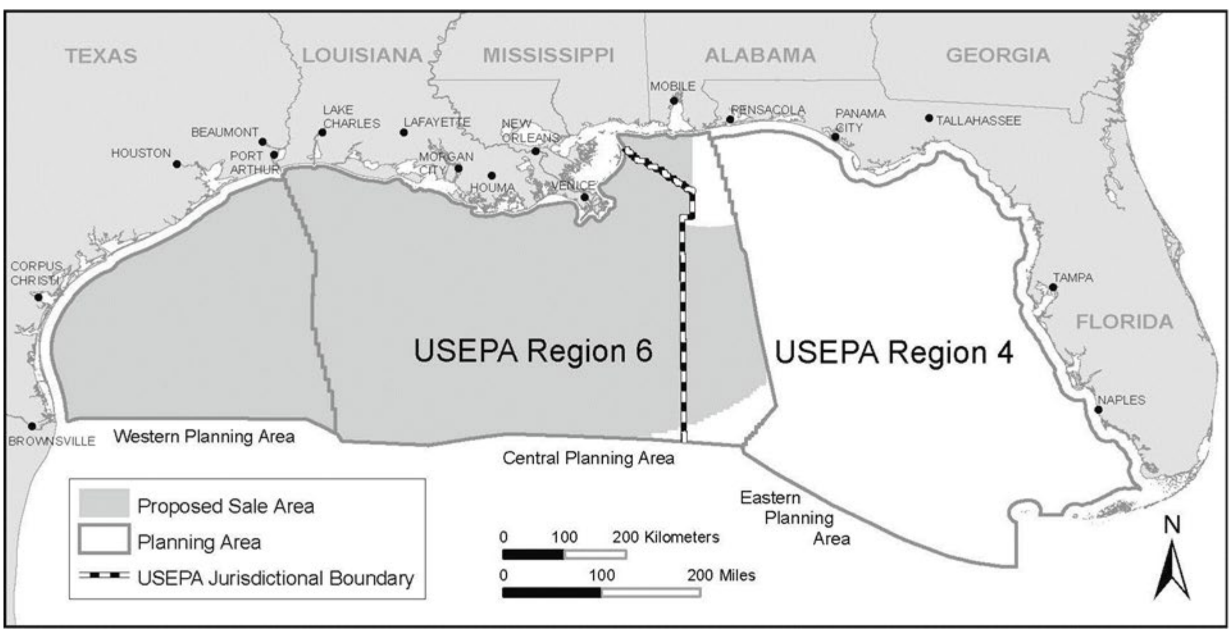
Factor 10 requires consideration of marine water quality criteria developed pursuant to Section 304(a)(1) of the CWA. The Federal and state marine water quality criteria and standards for pollutants found in drilling fluids are assessed in Chapter 9 of Appendix A. The potential effects due to organic pollutants in drilling fluids have been eliminated with the permit's prohibition of the use of oil-based muds and diesel oil and the discharge of neat synthetic based muds. In addition, the heavy metals that exist in drilling fluids will be reduced in concentration in authorized discharges by the permit's requirement to use clean barite measured by the concentration of cadmium and mercury.

There are no state water quality standards that apply in Federal waters outside any State jurisdictional line. 40 CFR 304 Subpart A are recommended criteria. In developing permit limits, the guidance at 40 CFR 304 Subpart A has been followed on the basis of Best Professional Judgment and to ensure that the discharges will not cause unreasonable degradation. Accordingly, these recommended criteria have been used for determining appropriate permit limits for discharges into federal waters. These criteria are used in Chapter 9 to compare effluent concentrations and determine if the effluent will cause degradation for the purpose of this document.

While the authorized discharges are located in federal waters and not state waters, EPA is required to confirm that the discharges will not cause violations of water quality standards in any nearby state waters where state water quality standards apply. Based on the amount of dilution in the Gulf, EPA has determined that the discharges will not result in any state water quality standard violations. The state CZMA agencies have an opportunity to identify any concerns regarding impacts on water quality in state waters or on the state CZMA plans.

10 Conclusions

After consideration of the ten factors discussed above and elsewhere in Appendix A, it is determined that no unreasonable degradation of the marine environment will result from the discharges authorized under this permit, with all permit limitations, conditions, and monitoring requirements in effect. After reviewing the available data, EPA Region 4 has included a variety of technology-based, water quality-based,and Section 403-based requirements in the final permit to ensure compliance with Section 403 of the Clean Water Act. The various permit limitations, conditions, and monitoring requirements of the permit support the no reasonable degradation determination and also ensure compliance with other relevant sections of the Act.



2.0 The Physical Environment

2.1 Physical Oceanography

The GOM is bounded by Cuba on the southeast; Mexico on the south and southwest; andthe U.S. Gulf Coast on the west, north, and east. The GOM has a total area of 564,000 square kilometers (km^2) (217,762 square miles [mi^2]). Shallow and intertidal areas (water depths of less than 20 meters (m)) compose 38 percent (%) of the total area, with continental shelf (22 %), continental slope (20 %), and abyssal (20 %) composing the remainder of the basin.

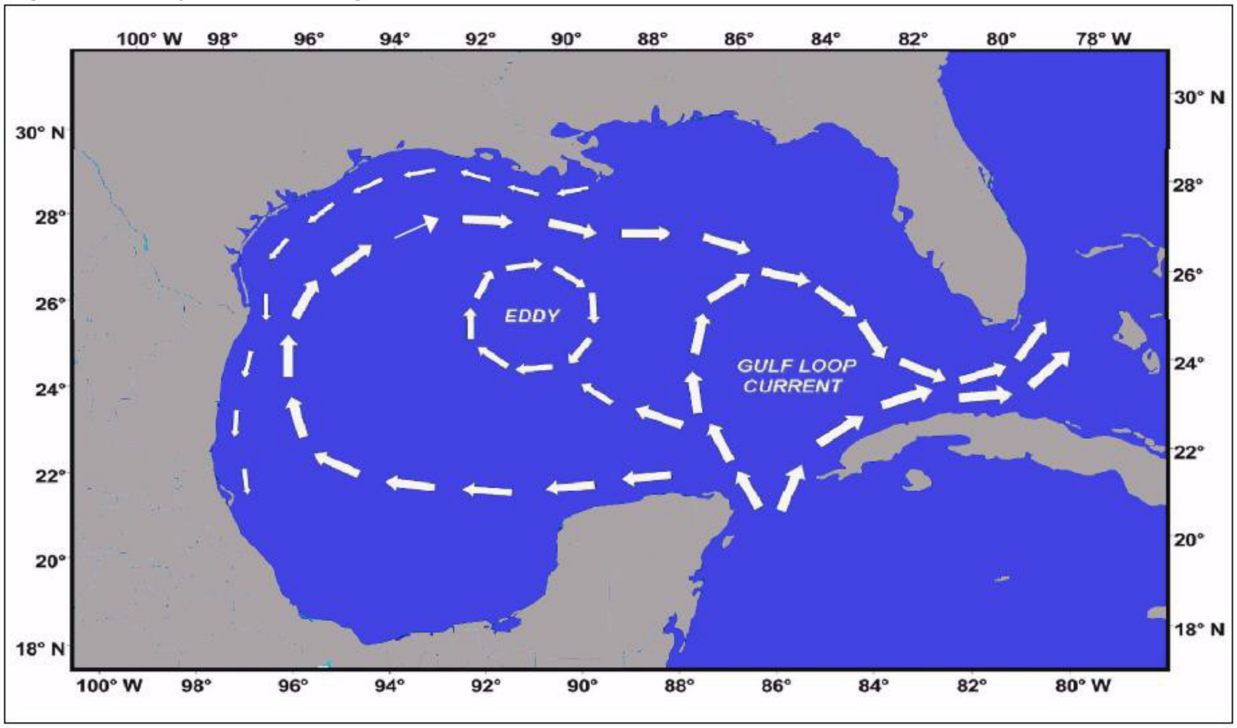
The GOM is separated from the Caribbean Sea and Atlantic Ocean by Cuba and other islands and has relatively narrow connections to the Caribbean and Atlantic through the Florida and Yucatan Straits. The GOM is composed of three distinct water masses, including the North and South Atlantic Surface Water (less than 100 m deep), Atlantic and Caribbean Subtropical Water (up to 500 m deep), and Subantarctic Intermediate Water.

2.1.1 Circulation

Circulation patterns in the GOM are characterized by two interrelated systems, the offshore or open Gulf, and the shelf or inshore Gulf. Both systems involve the dynamic interaction of a variety of factors. Open Gulf circulation is influenced by eddies, gyres, winds, waves, freshwater input, density of the water column, and currents. Offshore water masses in the eastern Gulf may be partitioned into a Loop Current, a Florida Estuarine Gyre in the northeastern Gulf, and a Florida Bay Gyre in the southeastern Gulf (Austin, 1970).

The strongest influence on circulation in the eastern GOM is the Loop Current (Figure 2-1). The location of the Loop Current is variable, with fluctuations that range over the outer shelf, the slopes, and the abyssal areas off Mississippi, Alabama, and Florida. Within this zone, short-term strong currents exist, but no permanent currents have been identified (US Minerals Management Service (MMS), 1990). The Loop Current forms as the Yucatan Current enters the Gulf through the Yucatan Straits and travels through the eastern and central Gulf before exiting via the Straits of Florida and merging with other water masses to become the Gulf Stream (Leipper, 1970; Maul, 1977). The Loop Current extends to about 1000 m depth with surface speeds as high as 150-200 centimeters per second (cm/s), decreasing with depth (MMS, 2000a).

Figure 2-1 Major current regime in the Gulf of Mexico.



Source: NOAA 2007

In the shelf or inshore Gulf region, circulation within the Mississippi, Alabama, and west Florida shelf areas is controlled by the Loop Current, winds, topography, and tides. Freshwater input also acts as a major influence in the Mississippi/Alabama shelf and eddy-like perturbations play a significant role in the west Florida shelf circulation. Current velocities along the shelf are variable. Brooks (1991) found that average current velocities in the Mississippi/Alabama shelf area were about 1.5 centimeters per second and east-west and northeast-southwest directions dominate. MMS (1990) data showed that winter surface circulation is directed along shore and westward with flow averaging 4 - 7 cm/s. During thespring and summer, the current shifts to the east with flow averaging 2 - 7 cm/s. The mean circulation on the west Florida shelf is directed southward with mean flow ranging from 0.2 - 7 cm/s (MMS, 1990).

Wind patterns in the Gulf are primarily anticyclonic (i.e., clockwise around high-pressure areas), and tend to follow an annual cycle; winter winds from the north and southeast and summer winds from the northeast and south (Figure 5). During the winter, mean wind speeds range from 8 knots to 18 knots. Several examples of mean annual wind speeds in the eastern Gulf are 8.0 millibars (mb) in Gulf Port, Mississippi; 8.3 mb in Pensacola, Florida; and 11.2 mb in Key West, Florida (NOAA, 1961-1986).

The tides in the Gulf of Mexico are less developed and have smaller ranges than those in other coastal areas of the United States. The range of tides is 0.3 - 1.2 m, depending on the location and time of year. The Gulf has three types of tides, which vary throughout the area: diurnal, semidiurnal, and mixed (i.e., both diurnal and semidiurnal). Wind and barometric conditions will influence the daily fluctuations in sea level. Onshore winds and low barometric readings, or offshore winds and high barometric readings, cause the daily water levels either to be higher or lower than predicted. In shelf areas, meteorological conditions occasionally mask local tide-induced circulation. Tropical storms in summer and early fall may affect the area with high winds (e.g., 18+ meters per second), high waves (7+ m), and storm surge (3 - 7.5 m). Winter storm systems also may cause moderately high winds,waves, and storm conditions that mask local tides.

2.1.2 Climate

The GOM is influenced by a maritime subtropical climate controlled mainly by the clockwise wind circulation around a semi-permanent, high barometric pressure area alternating between the Azores and Bermuda Islands. The circulation around the western edge of the high-pressure cell results in the predominance of moist southeasterly wind flow in the region. However, winter weather is quite variable. During the winter months, December through March, cold fronts associated with outbreaks of cold, dry continental air masses influence mainly the northern coastal areas of the GOM. Tropical cyclones may develop or migrate into the GOM during the warmer season, especially in the months of August through October. In coastal areas, the land-sea breeze is frequently the primary circulation feature in the months of May through October (BOEM, 2013).

2.1.2 Temperature

In the Gulf, sea-surface temperatures range from nearly isothermal (29-30˚C) in August to a sharp horizontal gradient in January, ranging from 25°C in the Loop core to values of 14-15°C along the shallow northern coastal estuaries. A 7°C sea-surface temperature gradient occurs in winter from north to south across the Gulf. During summer, sea-surface temperatures span a much narrower range. The range of sea-surface temperatures in the eastern Gulf tends to be greater than the range in the western Gulf, illustrating the contribution of the Loop Current.

Eastern Gulf surface temperature variation is affected by season, latitude, water depth, and distance offshore. During the summer, surface temperatures are uniformly 26.6°C or higher. The mean March isotherm varies from approximately 17.8°C in the northern regions to 22.2°C in the south (Smith, 1976).Surface temperatures range as low as 10°C in the Louisiana-Mississippi shelf regions during times of significant snow melt in the upper Mississippi valley (MMS, 1990).

At a depth of 1,000 m, the temperature remains close to 5°C year-round (MMS, 1990). In winter, nearshore bottom temperatures in the northern Gulf of Mexico are 3-10°C cooler than those temperatures offshore. A permanent seasonal thermocline occurs in deeper off-shelf water throughout the Gulf. In summer, warming surface waters help raise bottom temperatures in all shelf areas, producing a decreasing distribution of bottom temperatures from about 28°C at the coast to about 18-20˚C at the shelf break.

The depth of the thermocline, defined as the depth at which the temperature gradient is a maximum, is important because it demarcates the bottom of the mixed layer and acts as a barrier to the vertical transfer of materials and momentum. The thermocline depth is approximately 30-61 m in the eastern Gulf during January (MMS, 1990). In May, the thermocline depth is about 46 m throughout the entire Gulf (MMS, 1990).

2.1.3 Salinity

Characteristic salinity in the open Gulf is generally between 36.4 - 36.5 parts per thousand (ppt). Coastal salinity ranges are variable due to freshwater input, draught, etc. (MMS, 1990). During months of low freshwater input, deep Gulf water penetrates into the shelf and salinities near the coastline range from 29-32 ppt. High freshwater input conditions (spring-summer months) are characterized by strong horizontal gradients and inner shelf salinity values of less than 20l ppt (MMS, 1990).

2.2 Chemical Composition

Of the 92 naturally occurring elements, nearly 80 have been detected in seawater (Kennish, 1989). The dissolved material in seawater consists mainly of eleven elements. These are, in decreasing order, chlorine, sodium, magnesium, calcium, potassium, silicon, zinc, copper, iron, manganese, and cobalt (Smith, 1981). The major dissolved constituents in seawater are shown in Table 2.1. In addition to dissolved materials, trace metals, nutrient elements, and dissolved atmospheric gases comprise the chemical make-up of seawater.

Table 2.1. Major dissolved constituents in seawater with a chlorinity of 19 % and a salinity of 34.32%

Dissolved substance Ion or compound	**Concentration (grams per kilogram)**	**Percent by weight**
Chloride Cl-	18.980	55.04
Sodium Na+	10.556	30.61
Sulfate SO42-	2.649	7.68
Magnesium Mg2+	1.272	3.69
Calcium Ca2+	0.400	1.16
Potassium K+	0.380	1.10
Bicarbonate HCO3-	0.14	0.41
Bromide Br-	0.065	0.19
Boric Acid H3BO3	0.026	0.07
Strontium Sr2+	0.013	0.04
Fluoride F-	0.001	0.0
Totals	34.482	99.99

Source: Smith, 1981

2.2.1 Micronutrients

In GOM waters, generalizations can be drawn for three principal micronutrients; phosphate, nitrate, and silicate. Phytoplankton consume phosphorus and nitrogen in an approximate ratio of 1:16 for growth. The following nutrient levels and distribution values were obtained from MMS (1990): phosphates range from 0 - 0.25 ppm, averaging 0.021 ppm in the mixed layer, and with shelf values similar to open Gulf values; nitrates range from 0.0031 - 0.14 ppm, averaging 0.014 ppm; silicates range predominantly from 0.048 - 1.9 ppm, with open Gulf values tending to be lower than Outer Continental Shelf values.

In the eastern Gulf, inner shelf waters tend to remain nutrient deficient, except in the immediate vicinity of estuaries. On occasions when the loop current occurs over the Florida slope, nutrient-rich waters are upwelled from deeper zones (MMS, 1990).

2.2.2 Dissolved Gases

Dissolved gases found in seawater include oxygen, nitrogen, and carbon dioxide. Oxygen is often used as an indicator of water quality of the marine environment and serves as a tracer of the motion of deep-watermasses of the oceans. Dissolved oxygen values in the mixed layer of the Gulf average 4.6 mg/l, with some seasonal variation, particularly during the summer months when a slight lowering can be observed. Oxygen values generally decrease with depth to about 3.5 miligrams per liter (mg/l) through the mixed layer (MMS, 1990). Insome offshore areas in the northern Gulf of Mexico, hypoxic (<2.0 mg/l) and occasionally anoxic (<0.1 mg/l) bottom water conditions are widespread and seasonally regular (Rabalais, 1986). These conditions have been documented since 1972 and have been observed mostly from June to September on the inner continental shelf at a depth of 5 to 50 meters (Renauld, 1985; Rabalais et al., 1985).

3. DISCHARGED MATERIAL

3.1 Discharges Covered Under the Permit

In this chapter, the following discharges are characterized by their sources and uses during drilling and production operations and by their physical and chemical compositions.

Exploration and development activities for the extraction of oil and gas include work necessary to locate, drill, and complete wells. Exploration activities are those operations that involve drilling wells to determine potential hydrocarbon reserves. Exploratory activities are usually of short duration at a given site, involve a small number of wells, and are generally conducted from mobile drilling units. Development activities involve drilling production wells once a hydrocarbon reserve has been discovered and delineated. These operations, in contrast to exploration activities, may involve a large number of wells which may be drilled from either fixed or floating platforms or mobile drilling units. Production operations, which consist of the work necessary to bring hydrocarbon reserves from the producing formation, begin with the completion of each well at the end of the development phase. The primary wastewater sources from the exploration, development and production phases of the offshore oil and gas extraction industry produce the following wastewater sources:

Drilling Fluids
Drill Cuttings
Deck Drainage
Sanitary Waste
Domestic Waste
Completion Fluids
Cement
Workover Fluids
Blowout Preventer Control Fluids
Desalination Unit Discharge
Ballast and Storage Displacement Water
Bilge Water
Uncontaminated Seawater
Boiler Blowdown
Source Water and Sand

3.2 Drilling Fluids

Drilling fluids (muds), along with drill cuttings with adherent drilling fluid comprise the largest volume of waste discharges from drilling operations. Drilling fluids and drill cuttings are the most significant waste streams from exploratory and development operations in terms of volume and potentially toxic pollutants (EPA, 1993, 58 FR 12454, March 4, 1993, EPA 2009 citation from draft Environmental Assessment (EA)). The bulk of drilling muds consists of barite, clays, and a base fluid that can be any of a number of synthetic oils, mineral or diesel oil, or fresh/salt water that may or may not have an oil added for lubricity that are used in rotary drilling operations (EPA, 2009 citation from draft EA). The rotary drill bit is rotated by a hollowdrill stem made of pipe, through which the drilling fluid is circulated. Drilling fluids are formulated for each well to meet specific physical and chemical requirements. Geographic location, well depth, rock type, geologic formation, and other conditions affect the mud composition required. The number and nature of mud components varies by well, and several to many products may be used at any time to createthe necessary properties. The primary functions of a drilling fluid include the following.

Transport drill cuttings to the surface
Control subsurface pressures
Lubricate the drill-string
Clean the bottom of the hole
Aid in formation evaluation
Protect formation productivity
Aid formation stability (Moore, 1986).

The functions of drilling fluid additives and typical additives are listed on Table 3-1. Five basic components account for approximately 90 % by weight of the materials that compose drilling muds:barite, clay, lignosulfonate, lignite, and caustic soda (EPA, 1993).

Barite. Barite is a chemically inert mineral that is heavy and soft. In water-based muds, barite is composed of over 90 % barium sulfate. Synthetic-based fluids contain about 33% barium sulfate. Barium sulfate is virtually insoluble in seawater. Barite is used to increase the density of the drilling fluid to control formation pressure. The concentration of barite in drilling fluid can be as high as 700 pounds per barrel (lb/bbl) (Perricone, 1980). Quartz, chert, silicates, other minerals, and trace levels of metals can also be present in barite. Barium sulfate contains varying concentrations of metals depending on the characteristics of the deposit from where the barite is mined. One study indicates that there is a correlation between cadmium and mercury and other trace metals in the barite (SAIC, 1991). The EPA currently regulates cadmium and mercury concentrations in barite and refers to the stock barite that meets the EPA limitations as “clean” barite. Table 3-2 provides mean metals concentrations in “clean” barite compared to their concentration in the earth's crust.

Clay. The most common clay used is bentonite, which is composed mainly of sodium montmorillonite clay (60 to 80%). It can also contain silica, shale, calcite, mica, and feldspar. Bentonite is used to maintain the rheologic properties of the fluid and prevent loss of fluid by providing filtration control in permeable zones. The concentration of bentonite in mud systems is usually 5-25 lb/bbl. In the presence of concentrated brine, or formation waters, attapulgite or sepiolite clays (10 - 30 lb/bbl) are substituted for bentonite (Perricone, 1980).

Table 3-1. Functions of Common Drilling Fluid Chemical Additives

Action	Typical Additives	Function
Alkalinity and pH Control	Caustic soda; sodium bicarbonate; sodium carbonate; lime	1. Control alkalinity 2. Control bacterial growth
Bactericides	Paraformaldehyde; alkylamines; caustic soda; lime; starch	Reduce bacteria count NOTE: Halogenated phenols are not permitted for OCS use
Calcium Removers	Caustic soda; soda ash; sodium bicarbonate; polyphosphate	Control calcium buildup in equipment
Corrosion Inhibitors	Hydrated lime; amine salts	Reduce corrosion potential
Defoamers	Aluminum stearate; sodium aryl sulfonate	Reduce foaming action in brackish water and saturated salt muds
Emulsifiers	Ethyl hexanol; silicone compounds; lignosulfonates; anionic and nonionic products	Create homogenous mixture of two liquids
Filtrate Loss Reducers	Bentonite; cellulose polymers; pregelated starch	Prevent invasion of liquid phase into formation
Flocculants	Brine; hydrated lime; gypsum; sodium tetraphosphate	Cause suspended colloids to group into "flocs" and settle out
Foaming Agents		Foam in the presence of water and allow air or gas drilling through formations producing water
Lost Circulation Additives	Wood chips or fibers; mica; sawdust; leather; nut shells; cellophane; shredded rubber; fibrous mineral wool; perlite	Used to plug in the well-bore wall to stop fluid loss into formation
Lubricants	Hydrocarbons; mineral oil; diesel oil; graphite powder; soaps	Reduce friction between the drill bit and the formation
Shale Control Inhibitors	Gypsum; sodium silicate; polymers; lime; salt	Reduce well collapse caused by swelling or hydrous disintegration of shales
Surface Active Agents (Surfactants)	Emulsifiers; de-emulsifiers; flocculants	1. Reduce relationship between viscosity and solids concentration 2. Vary the gel strength 3. Reduce the fluid plastic viscosity
Thinners	Lignosulfonates; lignite; tannis; polyphosphates	Deflocculate associated clay particles
Weighting Material	Barite; calcite; ferrophosphate ores; siderite; iron oxides (hematite)	Increase drilling fluid density
Petroleum Hydrocarbons	Diesel oil; mineral oil	Used for specialized purposes such as freeing stuck pipe

Source: EPA, 1993.

Table 3-2. Trace Metal Concentrations in Barite

Pollutant	Estimated Concentrations on Dry Weight Basis (mg/kg)	
	Barite	Earth's Crust
Aluminum	9,069.9	
Antimony	5.7	
Arsenic	7.1	2
Barium	359,747	
Beryllium	0.7	
Cadmium	1.1	0.2
Chromium	240	
Copper	18.7	45
Iron	15,344.3	50,000
Lead	35.1	15
Mercury	0.1	0.1
Nickel	13.5	80
Selenium	1.1	
Silver	0.7	
Thallium	1.2	
Tin	14.6	
Titanium	87.5	
Zinc	200.5	65

Source: EPA, 1993.

Lignosulfonate. Lignosulfonate is used to control viscosity in drilling muds by acting as a thinning agent or deflocculant for clay particles. Concentrations in drilling fluid range from 1- 15 lb/bbl. It is made from the sulfite pulping of wood chips used to produce paper and cellulose. Ferrochrome lignosulfonate, the most commonly used form of lignosulfonate, is made by treating lignosulfonate with sulfuric acid and sodium dichromate. The sodium dichromate oxidizes the lignosulfonate and cross linking occurs. Hexavalent chromium supplied by the chromate is reduced during reaction to the trivalent state and complexes with the lignosulfonate. At high down-hole temperatures, the chrome binds onto the edges of clay particles and reduces the formation of colloids. Ferrochrome lignosulfonate retains its properties in high soluble salt concentrations and over a wide range of alkaline pH. It also is resistant to common mud contaminants and is temperature stable to approximately 177°C (EPA, 1993).

Lignite. Lignite is a soft coal used in drilling muds as a deflocculant for clay, to control the filtration rate, and to control mud gelation at elevated temperatures. Concentrations vary from 1 - 25 lb/bbl (Perricone, 1980). Lignite products are more commonly used as thinners in freshwater muds.

Caustic Soda. Sodium hydroxide is used to maintain the pH of drilling muds between 9 and 12. A pH of 9.5 provides for maximum deflocculation and keeps the lignite in solution. A more basic pH lowers the corrosion rate and provides protection against hydrogen sulfide contamination by limiting microbial growth.

Drilling fluids can be water-based, oil-based, or synthetic-based. In water-based fluids (WBF), water is the suspending medium for solids and is the continuous phase, whether or not oil is present. Water-based drilling fluids are composed of approximately 50 - 90 % water by volume, with additives comprising the rest. Historically, most drilling in the GOM has been performed with water-based muds (WBMs). WBMs are more cost effective in drilling many shallow wells, and WBM will continue to be used in those instances. However, for more complicated or deeper wells, synthetic-based mud (SBM) is often used.

WBFs have been classified into eight generic types based on their compositions (EPA, 1993).

1. Potassium/polymer fluids are inhibitive fluids, as they do not change the formation after it is cut by the drill bit. They are used in soft formations such as shale where sloughing may occur.

2. Seawater/lignosulfonate fluids are also inhibitive. This type of mud is used to maintain viscosity by binding lignosulfonate cations onto the broken edges of clay particles. It is also used to control fluid loss and to maintain the borehole stability. Under more complicated conditions, such as higher temperatures, this type of mud can be easily altered.

3. Lime (or calcium) fluids are inhibitive fluids. The viscosity of the mud is reduced as calcium binds the clay platelets together to release water. This type of mud system can maintain more solids. Lime fluids are used in hydratable, sloughing shale formations.

4. Nondispersed fluids are used to maintain viscosity, to prevent fluid loss, and to provide improved penetration, which may be impeded by clay particles in dispersed fluids.

5. Spud fluids are noninhibitive muds that are used in approximately the first 300 meters of drilling. This is the most simple mixture of mud and contains mostly seawater and a few additives.

6. Seawater/freshwater gel fluids are inhibitive muds used in early drilling to provide fluid control, shear thinning, and lifting properties for removing cuttings from the hole. Prehydrated bentonite is used in both seawater and freshwater fluids and attapulgite is used in seawater when fluid loss is not a concern.

7. Lightly treated lignosulfonate freshwater/seawater fluids resemble seawater/ lignosulfonate muds except their salt content is less. The viscosity and gel strength of this mud are controlled by lignosulfonate or caustic soda.

8. Lignosulfonate freshwater fluids are similar to the muds at #2 and #7 except the lignosulfonate content is higher. This mud is used for higher temperature drilling.

Oil-based drilling fluids (OBF) are those with oil, typically diesel, as the continuous phase and water as the dispersed phase. These fluids were found to be toxic to marine organisms and are no longer permitted for discharge. Due to the high cost of hauling the muds to shore and proper land disposal, the use of oil-based muds, particularly in offshore areas, has decreased significantly.

3.2.1 Synthetic-Based Drilling Fluids

Synthetic-based drilling fluids (SBF) represent a relatively new technology which developed in response to the wide-spread permit discharge bans of oil-based drilling fluids. SBMs have drilling and operational properties similar to OBM systems and are used where OBMs are commonly used, e.g., in difficult drilling situations or highly directionally deviated holes, or where the properties of WBMs have limited performance, e.g., hydratable shales or salt. SBMs reduce drilling times compared to WBMs, reducing drilling rig costs, are less toxic than OBM, and have higher penetration rates in rock (MMS, 2003 as cited in EPA, 2009 cited in EA). An SBF has a synthetic material as its continuous phase and water as the dispersed phase. The types of synthetic material which have been used include vegetable esters, polyalpha olefins (PAO), linear alphaolefins, internal olefins, and esters (USEPA, 1996). A model SBF formulation consists of 47% synthetic base fluid, 33% solids, and 20% water (by weight), a 70%/30% ratio of synthetic base to water, typical of commercially available SBFs (USEPA, 1999).

SBFs are reported to perform as well as or better than OBFs in terms of rate of penetration, borehole stability, and shale inhibition. Due to decreased washout (erosion), drilling of narrower gage holes, and lack of dispersion of the cuttings in the SBF, compared to WBF the quantities of muds and cuttings waste generated is reduced, reportedly in some cases by as much as 70 %. (Burke and Veil, 1995; Candler,et al, 1993).

The pollutants of concern from water-based muds discharges are primarily metals, most of which are associated with the barite added to the mud system and organics, which are added for lubricity or to free stuck pipe. The pollutant concentrations in water-based drilling fluid discharges characteristic of most offshore operations are presented in Table 3-3. The naphthalene concentration in Table 3-3 is based on a pill volume of 100 bbl and is calculated for an average well depth and mud volume.

According to standard formulation data, all of the solids in synthetic-based fluids are barite, making SBF a source of heavy metals and total suspended solids. SBFs are also one source of the conventional pollutant oil and grease. Table 3-4 shows the waste characteristics of SBFs.

Table 3-3. Water Based Drilling Fluids Pollutant Concentrations

Pollutant	Concentration in Whole Mud (µg/l)
Aluminum	4,123,615
Antimony	2,592
Arsenic	3,228
Barium	163,558,125
Beryllium	318
Cadmium	500
Chromium	109,116
Copper	8,502
Iron	6,976,260
Lead	15,958
Mercury	45
Nickel	6,138
Selenium	500
Silver	318
Thallium	546
Tin	6,638
Titanium	39,800
Zinc	91,157
Naphthalene	330

Source: EPA, 1993.

Table 3-4. Synthetic-based fluids drilling waste characteristics. (Modified from USEPA, 1999).

Waste Characteristics	Value
SBF formulation	47% synthetic base fluid, 33%barite, 20% water (by weight)
Synthetic base fluid density	280 pounds per barrel
Barite density	1,506 pounds per barrel
SBF drilling fluid density	9.6 pounds per gallon
Percent (vol.) formation oil	0.2%
Pollutant Concentrations in SBF	
Conventionals	**lbs/bbl of SBF**
Total oil as synthetic base fluid	190
Total oil as formation oil	0.59
Total suspended solids as barite	133
Priority Pollutant Organics	**lbs/bbl of SBF**
Naphthalene	0.0010052
Fluorene	0.0005483
Phenanthrene	0.0013004
Phenol	7.22E-08
Priority Pollutant Metals	**mg/kg/Barite**
Cadmium	1.1
Mercury	0.1
Antimony	5.7
Arsenic	7.1
Berylium	0.7
Chromium	240
Copper	18.7
Lead	35.1
Nickel	13.5
Selenium	1.1
Silver	0.7
Thallium	1.2
Zinc	200.5
Non-Conventional Metals	**mg/kg Barite**
Aluminum	9069.9
Barium	120000
Iron	15344.3
Tin	14.6
Titanium	87.5
Non-Conventional Organics	**lbs/bbl of SBF**
Alkylated benzenes	0.0056587
Alkylated naphthalenes	0.0531987
Alkylated fluorenes	0.0064038

Alkylated phenanthrenes	0.0080909
Alkylated phenols	0.0000006
Total biphennyls	0.0105160
Total dibenzothiophenes	0.0000092

The discharge of neat SBF is prohibited under this permit; however, the permit will allow discharges of water-based fluids. Because of their cost, SBFs, used or unused, are considered avaluable commodity by the industry and not a waste. It is industry practice to continuously reuse the SBFwhile drilling a well interval, and at the end of the well, to ship the remaining SBF back to shore for refurbishment and reuse. Compared to water-based fluids, SBFs are relatively easy to separate from the drill cuttings because the drill cuttings do not disperse in the drilling fluid to the same extent. With WBF,due to dispersion of the drill cuttings, drilling fluid components often need to be added to maintain the required drilling fluid properties. These additions are often in excess of what the drilling system can accommodate. The excess "dilution volume" of WBF is discharged. This excess dilution volume does notoccur with SBF. For these reasons, SBF is only discharged as a contaminant of the drill cuttings waste stream. It is not discharged as neat drilling fluid (i.e., drilling fluid not associated with cuttings).

3.3 Drill Cuttings

Drill cuttings are fragments of the geologic formation broken loose by the drill bit and carried to the surface by the drilling fluids that circulate through the borehole. They are composed of the naturally occurring solids found in subsurface geologic formations and bits of cement used during the drilling process. Cuttings are removed from the drilling fluids by a shale shaker and other solids control equipment before the fluid is recirculated down the hole. Removed cuttings are discharged (EPA, 2009).

The volume of cuttings generated while drilling the SBF intervals of a well depends on the type of well (i.e., development or production) and the water depth. According to analyses of the model wells provided by industry representatives, wells drilled in less than 1,000 feet (ft) of water are estimated to generate 565 barrelsof cuttings for a development well and 1,184 barrels of cuttings for an exploratory well. Wells drilled in water greater than 1,000 ft deep are estimated to generate 855 barrels of cuttings for a development well, and 1,901 cuttings for an exploratory well (USEPA, 2000). These values assume 7.5 % washout, based on the rule of thumb reported by industry representatives of 5 to 10 % washout when drilling with SBF. Washout is caving in or sluffing off of the well bore. Washout, therefore, increases hole volume and increases the amount of cuttings generated when drilling a well. Assuming no washout, the values above become, respectively, 526, 1,101, 795, and 1,768, barrels of dry cuttings.

As the drilling fluid returns from downhole laden with drill cuttings, it normally is first passed through primary shale shakers, vibrating screens, which remove the largest cuttings, ranging in size of approximately 1- 5 millimeters. The composition of a shale-shaker discharge is presented in Table 3-4. The drilling fluid may then be passed over secondary shale shakers to remove smaller drill cuttings.

Finally, a portion or all of the drilling fluid may be passed through a centrifuge or other shale shaker witha very fine mesh screen, for the purpose of removing the fines. It is important to remove fines from the drilling fluid in order to maintain the desired flow properties of the active drilling fluid system. Thus, thecuttings waste stream usually consists of larger cuttings from a primary shale shaker, smaller cuttings from a secondary shale shaker, and fines from a fine mesh shaker or centrifuge. As a final step, the wet cuttings are sent to a dryer which uses high temperatures to separate SBFs from cuttings. The dried residue from the dryer consists of fine cuttings and SBF material and is transported to an onshore waste handling facility. The cleaned cuttings are then discharged overboard.

The recovery of SBF from the cuttings serves two purposes. The first is to deliver drilling fluid for reintroduction to the active drilling fluid system and the second is to minimize the discharge of SBF. The recovery of drilling fluid from the cuttings is a conflicting concern, because as more aggressive methods are used to recover the drilling fluid from the cuttings, the cuttings tend to break down and become fines. The fines are more difficult to separate from the drilling fluid (an adverse effect for pollution control purposes), but in addition they deteriorate the properties of the drilling fluid. Increased recovery from cuttings is more of a problem for WBF than SBF because in WBFs the cuttings disperse more and spoil the drilling fluid properties. Therefore, compared to WBF, more aggressive methods of recovering SBF from the cuttings waste stream are practical. These more aggressive methods may be justified for cuttings associated with SBF so as to reduce the incidental discharge of SBF. This, consequently, will reduce the quantity of toxic organic and metallic components of the drilling fluid discharged.

Table 3-5. Mineral Composition of a Shale-Shaker Discharge from a Mid-Atlantic Well

Pollutant	Percent by Weight (Dry Basis)
Barium Sulfate	3
Montmorillonite	21
Illit	11
Kaolinite	11
Chlorite	6
Moscovite	5
Quartz	23
Feldspar	8
Calcite	5
Pyrite	2
Siderite	4

Source: Adapted by NRC (1983) from Ayers et al. (1980b);65% solids, density 1.7 g/cm^3.

3.4 Produced Water

Produced water (also known as production water, process water, formation water, or produced brine) is the water brought up from the hydrocarbon-bearing strata with the produced oil and gas. Produced water includes small volumes of treating chemicals that return to the surface with the produced fluids and pass through the produced water system. It constitutes a major waste stream from offshore oil and gas production activities.

Produced water is composed of formation water that is brought to the surface combined with the oil and gas, injection water (if used for secondary oil recovery and has broken through into the oil formation), and various added chemicals (biocides, coagulants, corrosion inhibitors, etc.). The constituents include dissolved, emulsified, and particulate crude oil constituents, natural and added salts, organic and inorganic chemicals, solids, and trace metals. Chemicals used on production platforms such as biocides, coagulants, corrosion inhibitors, cleaners, dispersants, emulsion breakers, paraffin control agents, reverse emulsion breakers, and scale inhibitors also may be present.

Produced water constitutes the major waste stream from offshore oil and gas production activities. The pollutant concentrations in produced water used in this analysis were used for development of the final effluent guidelines for the offshore subcategory (EPA, 1993). The concentrations are based on treatment by gas flotation before discharge. The pollutants and their average concentrations are presented in Table 3-6.

Produced water can be classified into three groups--meteoric, connate, and mixed waters--depending on its origin. Meteoric water is water that originates as rain and fills porous or permeable shallow rocks or percolates through them along bedding planes, fractures, and permeable layers. Carbonates, bicarbonates, and sulfates in the produced water are indicative of meteoric water. Connate water is the water in which the marine sediments or the original formation was deposited. It comprises the interstitial water of the reservoir rock and is characterized by chlorides, mainly sodium chloride, and high concentrations of dissolved solids. Mixed waters have both high chloride and sulfate-carbonate-bicarbonate concentrations suggesting meteoric water mixed or partially displaced by connate water (MMS, 1982).

The salinity and chemical composition vary from different strata and different petroleum reserves. The chlorides content of produced water ranges from 3,400 mg/l - 172,500 mg/l based on a study of 30 platforms in the Gulf of Mexico (U.S. EPA, 1985). Produced water generally contains little or no dissolved oxygen and the water may contain high concentrations of total organic carbon and dissolved organic carbon (Boesch & Rabalais, 1989).

Produced waters have also been found to include radioactive materials such as radium. Normal surface waters in the open ocean contain 0.05 pCi/liter of radium. Radionuclide data from Gulf coast drilling areas show Ra-226 concentrations of 16 - 393 pCi/liter and Ra-228 concentrations of 170 - 570 pCi/liter (USEPA, 1978). After treatment using gas flotation, produced water radium concentrations arereduced by 10% (EPA, 1993).

Produced water production rates depend on the method of recovery used and the formation being drilled. Discharge rates can vary from none at some platforms to large quantities from central processing facilities. The EPA 30 Platform Study reported estimated discharge rates at 134 - 150,000 bbl/day for offshore platforms in the central and western Gulf of Mexico (Burns & Roe, 1983). A 2005 report of the produced water volumes from 50 operators in the GOM reported annual averages ranging from 3- 63, 828 bbl/day (Veil et.al., 2005).

After treatment in an oil-water separator, produced water is usually discharged into the sea, or in some cases is reinjected for disposal or pressure maintenance purposes.

Table 3-6. Produced Water Pollutant Concentrations

Pollutant	Concentration (ug/l)
Oil and Grease	23.5 mg/l
TSS	30.0 mg/l
Priority and Non-Conventional Organic Pollutants:	
Anthracene	7.40
Benzene	1,225.91
Benzo(a)pyrene	4.65
2-Butanone	411.58
Chlorobenzene	7.79
Di-n-butylphthalate	6.43
2,4-Dimethylphenol	250.00
Ethylbenzene	62.18
n-Alkanes	656.60
Naphthalene	92.02
p-Chloro-m-cresol	10.10
Phenol	536.00
Steranes	31.00
Toluene	827.80
Triterpanes	31.20
Xylene (total)	378.01
Priority and Non-Conventional Metal Pollutants:	
Aluminum	49.93
Arsenic	73.08
Barium	35,560.83
Boron	16,473.76
Cadmium	14.47
Copper	284.58
Iron	3,146.15
Lead	124.86
Manganese	74.16
Nickel	1,091.49
Titanium	4.48
Zinc	133.85
Radionuclides:	
Radium-226	0.00020365
Radium-228	0.00024904

Source: EPA, 1993.

Under the proposed permit produced water from the last stage of processing must meet a 29/42 mg/l (monthly average/daily maximum). The limitation is based on the use of gas flotation for oil-water separation.

3.5 Produced Sand

Produced sand is the material removed from the produced water. Produced sand also includes desander discharge from the produced water waste stream and blowdown of water phase from the produced water treating system. Sands that are finer and of low volume may be drained into drums on deck or carried through the oil-water treatment system and appear as suspended solids in the produced water effluent, or they may be settled out in treatment vessels. If sand volumes are larger and sand particles coarser, the solids are removed in cyclone separators, thereby producing a solid-phase waste. The sand that drops out in these separators is generally contaminated with crude oil (i.e., oil production) or condensate (gas production) and requires washing to recover the oil. The sand is washed with water combined with detergents, or solvents. The oily water is directed to the produced water treatment system or to a separate oil-water separator to become part of the produced water discharge following oil separation. The final effluent guidelines, and therefore, the proposed permit prohibit the discharge of this waste stream.

3.6 Deck Drainage

Deck drainage is waste resulting from platform washings, deck washings, deck area spills, rainwater, and runoff from curbs, gutters, and drains, including drip pans and wash areas. The runoff collected as deck drainage also may include detergents used in deck and equipment washing.

In deck drainage, oil and detergents are the pollutants of primary concern. During drilling operations, spilled drilling fluids also can end up as deck drainage. Acids (hydrochloric, hydrofluoric, and various organic acids) used during workover operations may also contribute to deck drainage, but generally these are neutralized by deck wastes and/or brines prior to disposal. Based on an analysis of 950 platforms in the GOM from 1982-1983, EPA (1993) determined that the oil and grease levels reported for deck drainage discharges were 28 mg/l monthly average and 75 mg/l daily maximum, greatly exceeding the current NPDES General Permit limit of no free oil as determined by visual sheen.

A typical platform-supported rig is equipped with pans to collect deck and drilling floor drainage. The drainage is separated by gravity into waste material and liquid effluent. Waste materials are recovered in a sump tank, then treated and disposed, returned for use in the drilling mud system, or transported to shore. The liquid effluent, primarily washwater and rainwater, is discharged. It is expected that, following treatment, deck drainage discharge will meet the no free oil prohibition in the general permit.

The 1993 EPA study determined that deck drainage quantities range from 1- 4,304 bbl/day/platform with an average discharge of 50 bbl/day.

3.7 Sanitary Waste

The sanitary wastes discharged offshore are human body wastes from toilets and urinals. The volume and concentrations of these wastes vary widely with time, occupancy, platform characteristics, and operational situation. Usually, the toilets are flushed with brackish water or seawater. Due to the compact nature of the facilities, the wastes have less dilution water than common municipal wastes. This creates greater waste concentrations. Some platforms combine sanitary and domestic waste waters for treatment; others maintain sanitary wastes separate for chemical or physical treatment by an approved marine sanitation device.

3.8 Domestic Waste

Domestic wastes (gray water) originate from sinks, showers, safety showers, eye wash stations, laundries, food preparation areas, and galleys on the larger facilities. Domestic wastes also include solid materials such as paper, boxes, etc. These wastes are governed by the Coast Guard under MARPOL 73/78 (i.e., the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto). The Coast Guard regulations at 33 CFR Part 151 specify regulations for disposal of garbage. These are summarized in Table 3-7.

3.9 Cement

In order to protect the well from being penetrated by aquifers, it is necessary to install a casing in the bore hole. The casing is installed in stages of successively smaller diameters as the drilling progresses. The casings are cemented in place after each installation.

A cement slurry is mixed on site and is pumped through a special valve at the well head through the casing to the bottom and up the annular space between the bore hole wall and the outside of the casing to the surface. The cement is allowed to harden and drilling is resumed.

Most wells are cemented with an ordinary Portland cement slurry. Additives are used to compensate for site-specific temperature and saltwater conditions. The amount of cement used for each well depends on the well depth and the volume of the annular space. Typically, excess cement discharges are less than 10 barrels/year/well.

Table 3-7. Garbage Discharge Restrictions[a]

Garbage Type	Fixed or Floating Platforms & Associated Vessels[b] (33 CFR 151.73)
Plastics - includes synthetic ropes and fishing nets and plastic bags.	Disposal prohibited (33 CFR 151.67)
Dunnage, lining and packing materials that float.	Disposal prohibited
Paper, rags, glass, metal bottles, crockery and similar refuse.	Disposal prohibited
Paper, rags, glass, etc. comminuted or ground.[c]	Disposal prohibited
Victual waste not comminuted or ground.	Disposal prohibited
Victual waste comminuted or ground.[c]	Disposal prohibited less than 12 miles from nearest land and in navigable waters of the U.S.
Mixed garbage types.	See footnote d.

[a] Source: EPA, 1993.
[b] Fixed or floating platforms and associated vessels include all fixed or floating platforms engaged in exploration, exploitation, or associated offshore processing of seabed mineral resources, and all ships within 500 m of such platforms.
[c] Comminuted or ground garbage must be able to pass through a screen with a mesh size no larger than 25 mm (1 inch) (33 CFR 151.75).
[d] When garbage is mixed with other harmful substances having different disposal requirements, the more stringentdisposal restrictions shall apply.

3.10 Well Treatment, Workover, and Completion Fluids

The following definitions are from the development document for the final effluent guidelines for offshore oil and gas activities (EPA,1993).

> "Well treatment fluids" are any fluid used to restore or improve productivity by chemicallyor physically altering hydrocarbon-bearing strata after a well has been drilled.
>
> "Workover fluids" are salt solutions, weighted brines, polymers and other specialty additives used in a producing well to allow safe repair and maintenance or abandonment procedures.
>
> "Completion fluids" are salt solutions, weighted brines, polymers, and various additives used to prevent damage to the wellbore during operations which prepare the drilled well for hydrocarbon production.

The volume of fluids needed for workover, treatment, and completion operations depends on the type of well and the specific operation being performed. Chevron has based estimates average volumes of fluids (accounting for reuse of the fluids) as 300 bbl of workover fluids per job and 250 bbl of treatment fluids per treatment operation. Based on an assumption of one treatment or one workover every four years, an average of 200 bbl of treatment or workover fluid can be expected to be used per well every four years.

Well treatment fluids are acid in water solutions (i.e., using hydrochloric acid, hydrofluoric acid, and acetic acid). Formation solubility, reaction time, and reaction products determine the type of acid used. A treatment operation consists of a preparation solution of ammonium chloride (3-5 %) to force the hydrocarbons into the formation; an acid solution; and a post-flush of ammonium chloride the remains in the formation for 12 - 24 hours to force the acid farther into the formation before being pumped out.

Solvents also may be used for well treatment, including hydrofluoric acid, hydrochloric acid, ethylene diaminetetraacetic acid (EDTA), ammonium chloride, nitrogen, methanol, xylene, and toluene. Additives such as corrosion inhibitors, mutual solvents, acid neutralizers, diverters, sequestering agents, and antisluding agents are often added to treatment fluid solutions. The pollutant concentrations for a well treatment fluid used in two wells at a Total Human Models for Safety (THUMS) facility in California are presented in Table 3-8.

Workover fluids are put into a well to allow safe repair and maintenance, for abandonment procedures, or to reopen plugged wells. During repair operations, the fluids are used to create hydrostatic pressure at the bottom of the well to control the flow of oil or gas and to carry materials out of the well bore. To reopen wells, fluids are used to stimulate the flow of hydrocarbons. Both of these operations must be accomplished without damaging the geologic strata.

Fluids used for hydraulic fracturing are considered well treatment or stimulation fluids in the proposed general permit. To reopen or increase productivity in a well, hydraulic fracturing of the formation may be necessary. Hydraulic fracturing is achieved by pumping fluids into the bore hole at high pressure, frequently exceeding 10,000 pounds per square inch (psi). Proper fracturing accomplishes the following:

- Creates reservoir fractures thereby improving the flow of oil to the well
- Improves the ultimate oil recovery by extending the flow paths, and
- Aids in the enhanced oil recovery operation.

Hydraulic fracturing has also been used in the GOM since the early 1990’s in combination with gravel packing as a type of well stimulation and sand control technology commonly referred to as “Frac Pack” operations (API, 2015). Most of the petroleum bearing formations in the GOM consist of highly permeable unconsolidated sands. Produced sand occurs when the loose formation sands back up into the well piping and production equipment. To limit and prevent sand production the gravel pack places a courser sand filter in the immediate vicinity of the well at the depth of production to limit migration of fine sands into the well pipe. The fracturing component uses treated seawater under high pressure to fracture the formation and force additional sand into the producing formation a greater distance from the well to increase the size of the sand filter (i.e.,, gravel pack). The Frac Pack sand filter may be up to 10 timeslarger than that resulting from a conventional gravel pack completion. The unconsolidated producing formations in the GOM make them less brittle than shales and tight sands therefore the fracture networkproduced by a Frac Pack completion are less dense and remain close to the bore hole

Middle East and Asia Reservoir Review, 2007; API, 2015).

Hydraulic fracturing used in repair of damaged formations or as well stimulation/sand control in the GOM differs from that used to recover hydrocarbons from low permeability shales, coal beds and other tight formations being produced in the continental U.S. mainly with regard to the magnitude of the intended fracturing in the surrounding formation. The permeability of these tight formations may be as low as 1/1000 of 1% of the permeability of the more conventional formations on the GOM shelf and, therefore, require much more extensive fracturing to stimulate flow (King, 2012). Typical Frac Pack completions in the GOM may inject 50,000 pounds (lbs) to over 200,000 lbs of proppant into the producing formation within a radius of usually less than 30 meters of the well pipe, whereas a shale gas operation may inject up to 4 million lbs of proppant suspended in 0.5-10 million gallons of water into a single well(USEPA, 2015). Fractures may extend for hundreds or several thousand ft from the well pipe (GWPC & IOGCC, 2016). Added chemicals in operations this large may range from 80-330 tons.

Deepwater (i.e., greater than 500 m of water) oil and gas production is becoming more prevalent in the GOM following the discovery of significant reserves at water depths as great as 3000 meters. In these cases, the oil-bearing formations may be an additional 8,000 m below the mudline. The technical challenges to production include much higher overburden pressures and temperatures and may require larger scale fracturing to maximize production (Mullen et. al, 2003; Dribus et. Al., 2008; Dutton and Loucks, 2014).

New information indicates that hydraulic fracturing of oil may have the potential to cause potential health and environmental effects. Some of the pollutants released by hydrofracking include benzene, toluene, xylene and ethyl benzene (BTEX); particulate matter and dust; ground-level ozone; nitrogen oxides; carbon monoxide; formaldehyde; and metals contained in diesel fuel combustion. These pollutants can travel in the atmosphere. The exposure to these chemicals could cause short-term effects to human health and the environment (Shonkoff, 2014; Elliott, et. al, 2016). This information indicates that potential risks of hydrofracking may be greater from onshore activities as compared to offshore OCS-related activities (BOEM, 2015b).

High solids drilling fluids used during workover operations are not considered workover fluids by definition and therefore must meet drilling fluid effluent limitations before discharge may occur. Packer fluids, low solids fluids between the packer, production string, and well casing, are considered to be workover fluids and must meet only the effluent requirements imposed on workover fluids.

Table 3-8. Analysis of Fluids from an Acidizing Well Treatment

Analyte	Concentration (ug/l)	Analyte	Concentration (ug/l)
Aluminum	53.1	Tin	6.66
Antimony	< 3.9	Titanium	0.68
Arsenic	< 1.9	Vanadium	36.1
Barium	12.6	Yttrium	0.19
Beryllium	< 0.1	Zinc	28.5
Boron	31.9	Aniline	434
Cadmium	0.4	Naphthalene	ND
Calcium	35.3	o-Toluidine	1,852
Chromium	19	2-Methylnaphthalene	ND
Cobalt	< 1.9		
		2,4,5-Trimethylanine	2,048
Copper	3.0	Oil and Grease	619
Iron	572	pH	2.48
Lead	< 9.82		
Magnesium	162		
Molybdenum	< 0.96		
Nickel	52.9		
Selenium	< 2.9		
Silver	< 0.7		
Sodium	1,640		
Thallium	5.0		

Source: EPA, 1993.

Well completion occurs if a commercial-level hydrocarbon reserve is discovered. Completion of a well involves setting and cementing the casing, perforating the casing and surrounding cement to provide a passage for oil and gas from the formation into the wellbore, installing production tubing, and packing the well. Completion fluids are used to plug the face of the producing formation while drilling or completion operation are conducted in hydrocarbon-bearing formations. They prevent fluids and solids from passing into the producing formation, thereby reducing its productivity or damaging the oil or gas.

The production zone is a porous rock formation containing the hydrocarbons, either oil or gas, and can be damaged by mud solids and water contained in drilling fluids. The completion fluids create a thin film of solids over the surface of the producing formation without forcing the solids into the formation. A successful completion fluid is one that does not cause permanent plugging of the formation pores. The composition of the completion fluid is site-specific depending on the nature of the producing formation. Drilling muds remaining in the wellbore during logging, casing, and cementing operations or during temporary abandonment of the well are not considered completion fluids and are regulated as drilling fluids discharges.

Treatment, workover, and completion fluids are either collected and disposed onshore if there are priority pollutants detected or otherwise treated for oil and grease, pH neutralized, and commingled with produced water for discharge (EPA, 2009). Region 4 is including the components of the fracking process as they occur in existing waste streams: slurried particles from hydraulic fracturing are covered under the produced sand waste stream; fluids and materials used in or derived from the fracking process are included in the well treatment, completion, and workover fluids waste stream.

3.11 Blowout Preventer Fluids

A vegetable or mineral oil solution or antifreeze (i.e., polyaliphatic glycol) is used as a hydraulic fluid in blowout prevention (BOP) stacks while drilling a well. The blowout preventer may be located on the seafloor and is designed to contain pressures in the well that cannot be maintained by the drilling mud. Small quantities of BOP fluid are discharged to the seafloor during weekly testing of the blowout preventer device. The volume of BOPfluid discharge ranges from 67 - 314 bbl/day when testing (EPA, 1993).

3.12 Desalination Unit Discharge

This is the residual high-concentration brine discharged from distillation or reverse-osmosis units used for producing potable water and high-quality process water offshore. It has a chemical composition and ratio of major ions similar to seawater, but with high concentrations. This waste is discharged directly to the sea as a separate waste stream. The typical volume discharged from offshore facilities is less than 240 bbl/day.

3.13 Ballast Water and Storage Displacement Water

Ballast and storage displacement water are used to stabilize the structures while drilling from the surface of the water. Two types of ballast water are found in offshore producing areas (i.e., tanker and platform ballast). Tanker ballast water would not be covered under an NPDES permit.

Platform stabilization (ballast) water is taken on from the waters adjacent to the platform and may be contaminated with stored crude oil and oily platform slop water. More recently designed and constructed floating storage platforms use permanent ballast tanks that become contaminated with oil only in emergency situations when excess ballast must be taken on. Oily water can be treated through an oil-water separation process prior to discharge.

Storage displacement water from floating or semi-submersible offshore crude oil structures is mainly composed of seawater. Much of its volume can usually be discharged directly without treatment. Water that is contaminated with oil may be passed through an oil-water separator for treatment.

3.14 Bilge Water

Bilge water, which seeps into all floating vessels, is a minor waste for floating platforms. This seawater becomes contaminated with oil and grease and with solids such as rust where it collects at low points in vessels. This bilge water is usually directed to the oil-water separator system used for the treatment of ballast water or produced water, or it is discharged intermittently. The total volume of ballast/bilge water discharged is from 70 - 620 bbl/day (EPA, 1993).

3.15 Uncontaminated Seawater

Seawater used on the rig for various reasons is considered uncontaminated if chemicals are not added before it is discharged. Included in this discharge are waters used for fire control equipment and utility lift pump operation, pressure maintenance and secondary recovery projects, fire protection training, pressure testing, and non-contact cooling.

3.16 Boiler Blowdown

Boiler blowdown discharges consist of water discharged from boilers as is necessary to minimize solids build-up in the boilers, including vents from boilers and other heating systems.

3.17 Diatomaceous Earth Filter Media

Diatomaceous earth filter media are used in the filtration unit for seawater or other authorized completion fluids. They are periodically washed from the filtration unit for discharge.

4. TRANSPORT AND PERSISTENCE

The discussion of transport processes affecting drilling wastes treats the two major waste streams, water-based drilling fluids (WBF) and synthetic-base drilling fluids (SBF) separately, due to differences in characteristics, mode of entry and behavior in the environment. The synthetic-based fluids associated with cuttings discharges are expected to behave differently from WBFs due to several important differences:

- Only SBF-cuttings are discharged, with retention of the SBF base fluid generally ranging between a low of 2 % for the larger cuttings and a high of 20 % for the smallest cuttings (fines). Effluent guidelines will limit the maximum retention to 6.9 %. With WBFs, in addition to the WBF-cuttings, large volumes of WBF are discharged. Thus, for an equal volume of hole drilled, the volume of WBF-related discharge is expected to be much greater than the volume of SBF-related discharge.

- WBFs contain very high levels of suspended and settleable solids (and are, in fact, referred to as "muds" in the industry) that disperse in the water column and produce a plume with many fine particles that settle rather slowly. Hence, they may be transported large distances. SBF-cuttings, however, tend not to disperse in the water column nearly to the same extent as WBFs because the particles are "oil" wet with the synthetic material. Compared to WBF-cuttings, SBF-cuttings tend to be larger than WBF-cuttings. Again, the reason is that SBFs do not disperse the cuttings particles to the same extent as WBFs. Because larger particles settle faster than smaller particles, SBF-cuttings tend to be deposited in a smaller impact area than WBF-cuttings.

- SBF-cuttings have a significant organic component that is not present in WBFs, namely the synthetic base fluid. The synthetic base fluid, in general, is insoluble in water and deposits in the sediment with the cuttings. The fluids separation technologies used on SBF cuttings remove the fine cuttings, causing what remains to settle rapidly upon discharge and accumulate nearer the point of discharge than WBF wastes.

These differences suggest that discharge plumes characteristic of WBF discharges will not be an important mechanism for the transport of SBF wastes.

4.1 Water-Based Drilling Fluids

Drilling fluids contain quantities of coarse material, fine material, dissolved solids, and free liquids. While all of these components are affected by the momentum of the discharge jet, density-driven turbulent mixing, and diffusive processes, the larger particulates of drilling fluids separate more rapidly from the fines and soluble portions of the discharge plume due to the additional effect of gravitational settling. Fall velocities are largely controlled by particulate size, with larger particulate separating out more rapidly from the plume. Upon discharge, this mixture appears to separate rapidly. An upper plume is formed from shear forces and local turbulent flow at the discharge pipe. This upper plume contains about five to seven percent, by weight, of the total drilling fluid discharge (Ayers et al., 1980b). This plume migrates to its level of neutral buoyancy while particulates slowly settle to the bottom and is advected with prevailing currents. The fine solids settle at a rate depending on aggregate particle size, which is very dependent on flocculation.

A lower plume contains the remainder of the discharged drilling fluids. Coarser materials fall rapidly out of the lower plume. Ayers et al. (1980b) found that the lower plume components deposited on the bottom within a few meters of the discharge point from an outfall located 3 m below the surface in a water depth of 23 m. In deeper waters, settleable solids will deposit over a larger area, depending upon the total fall depth, the settling velocity of the particles, and current speeds. If water depths are great enough to prevent bottom impact of the discharge plume, fine particulates in the lower plume will reach a level ofneutral buoyancy and will be advected with ambient current flow, similar to their behavior in the upper plume.

Both upper and lower plumes are affected by three different transport processes or pathways: physical, chemical, and biological. Physical transport processes affect concentrations of discharge components in the water column through dilution[1], dispersion[1], and settling. Physical processes include currents, turbulent mixing, settling, and diffusion. These processes include current speed and direction, tidal regime, kinetic energy availability, and the characteristics of the receiving water such as water depth and density stratification. Physical processes are the most understood of the three transport pathways.

Chemical and biological processes more frequently produce changes in the structure and/or speciation of materials that affect their bioavailability and toxicity. Chemical processes include the dissolution of substances in seawater, particle flocculation, complexing of compounds that may remove them from the water column, redox/ionic changes, and absorption of dissolved pollutants on solids. Biological processes include bioaccumulation and biomagnification in soft or hard tissues, fecal agglomeration and settling of materials, and physical reworking to mix solids into the sediment (i.e., bioturbation).

4.1.1 *Physical Transport Processes*

Pollutant concentrations resulting from offshore platform discharges are influenced by several factors related to the discharge and the medium into which it is released. Discharge-related factors include the solids content of the effluent, distribution of particle sizes and their settling rates, effluent chemical composition, discharge rates and duration, and density.

Environmental factors that affect dispersion and transport of discharged materials include current speed, current direction, tidal influences, wave action, wind regime, density structure of the water column, topography of the ocean bottom, bottom currents, and turbulence caused by platform wake. These factors influence dispersion and dilution of effluents in the water column, and resuspension and transport of

---

[1] In analyzing the impacts of discharged drilling fluids, the behavior of either the mud solids or the aqueous portion of the effluent can be measured. In this document, the term “dispersion” refers to tracking the behavior of the plume with respect to its solids content; dilution refers to a volumetric tracking of plume behavior and is intended to apply to soluble components of drilling fluids. The term “dispersion” in the ODCE does not necessarily refer to settling and removal of solids from the water column as they settle on the seafloor, but may also only refer to the concentration of suspended solids in the water column.

solids settled on the seafloor. Areas of high hydrodynamic energy will disperse discharges more rapidly than less energetic areas. Current speed and boundary conditions also affect mixing because turbulence increases with current speed and proximity to the seafloor. Currents and turbulence can vary markedly with location and site characteristics and affect the movement of suspended matter and the entrainment, resuspension, and advection of sedimented matter.

Two studies by Houghton et al. (1980; 1981) suggest that turbulence induced by submerged portions of the drilling platform also may significantly contribute to the dispersion of the muds. Houghton et al. (1981) concluded that turbulence became a major source of dispersion when current speeds ranged from 5 to 10 cm/sec (0.16 - 0.32 ft/sec), or greater. However, this wake-effect has not been systematically studied at other locations. Ray and Meek (1980), for example, observed little change in plume dilution at Tanner Bank, offshore southern California, with current speed variations between 2 - 45 cm/sec (0.076 - 1.48 ft/sec).

Physical Transport Processes Affecting the Upper Plume

The upper plume contains only a small portion of the discharge effluent (some 5%), which is split off from the main, lower plume and is thought to be due to sheer forces in the immediate vicinity of the discharge pipe. Finer suspended materials are contained in the upper plume. Relative to the lower plume, the initial mixing of the upper plume (in which the momentum of the initial jet is dissipated) is less of a factor, and passive diffusion (in which the plume is transported at the speed and direction of prevailing currents) is a more important factor. Sinking rates of solids in the upper plume will largely depend on the following four factors:

- Discharged material properties
- Characteristics of receiving waters
- Currents and turbulence
- Flocculation and agglomeration.

The physical properties of the discharged materials affect mixing and sedimentation. For suspended clay particulates, particle size and both physical and biological flocculation will determine settling rates. While oil exhibits little tendency to sink, it has displayed the ability to flocculate clay particles and to adsorb to particulates and sink with them to the bottom (Middleditch, 1980).

One of the major receiving water characteristics influencing plume behavior is density structure and stratification. In a stratified water column, density drives the collapse of the plume, i.e., the spreading of the plume at its level of neutral buoyancy. After sufficient spreading, the spreading rate of the plume from dynamic forces declines to a rate comparable to that resulting from turbulence ("far-field" or "passive" dispersion). Density stratification may concentrate certain components along the pycnocline. If flocculation produces particles large enough to overcome the barrier, settling will continue. If density stratification is weak or the pycnocline is above the discharge point, it may not affect plume behavior.

Ecomar (1978), as reported in Houghton et al. (1981), noted that upper plumes in the Gulf of Mexico follow major pycnoclines in the receiving water. A similar finding has been observed by Trefry et al. (1981), who traced barium levels along pycnoclines. This type of transport is a potential concern because sensitive life stages of planktonic, nektonic, and benthic organisms may collect along the pycnocline. Ayers et al. (1980a) observed that the bottom of the upper plume followed a major pycnocline after drilling fluid discharges at rates of 275 bbl/hr and 1,000 bbl/hr in the GOM.

Flocculation and agglomeration affect plume behavior by increasing sedimentation rates as larger particles are formed. Flocculation is enhanced in salt or brackish waters due to increased cohesion of clay particles (Meade, 1972). Agglomeration also occurs when larger particles are formed from a number of smaller ones through the excretion of fecal pellets by filter-feeding organisms.

Most studies of upper plume behavior have measured particulate components and paid less attention to the liquid and dissolved materials present. Presumably, these latter components are subject to the same physical transport processes as particulate matter, with the exclusion of settling. Studies suggest that suspended solids in the upper plume may undergo a higher dispersion rate than dissolved components.

Houghton et al. (1980) measured upper plume transport in Lower Cook Inlet, using a soluble, fluorescent dye (fluorescein) in current speeds of 41 - 103 cm/sec. The water depth at the site is 63 m (207 ft) but the plume never sank below 23 m (75 ft). From transmissometry data collected in the GOM, Ayers et al. (1980b) estimated upper plume volume and found that a 275 bbl/hr drilling fluid discharge exhibiteda dilution ratio of 32,000:1 after 60 minutes and a 1,000 bbl/hr discharge showed a dilution ratio of 14,500:1 after 62 minutes. Dispersion ratios for suspended solids at these distances would be approximately one to two orders of magnitude greater than for soluble components.

From radiotracer data collected for offshore Southern California and Cook Inlet, Petrazzuolo (1983) estimates dilution rates of "soluble" tracers (based on generalized estimates of distances to specified levels of dispersion; Table 4-1).

Physical Transport Processes Affecting the Lower Plume

The physical transport processes affecting the lower plume differ little in nature from those influencing the upper plume; differences are more related to the relative contribution of the various processes. The lower plume contains the main body of the discharged material. The initial momentum of the discharge jet is more dominant a factor in lower plume behavior but is still followed by a dynamic collapse phase and then passive diffusion. The lower plume contains a component composed of coarser material that settles rapidly to the bottom regardless of current velocity. This rapid settling is most pronounced during high-rate bulk discharges in shallow waters. With the high downward momentum of these discharges, the plume reaches the bottom. At Tanner Bank, the lower plume was relatively unaffected by average currents of 21 cm/sec (0.69 ft/sec) and bottom surges of up to 36 cm/sec (1.18 ft/sec) (Ecomar, 1978).

Table 4-1. Estimates of Distances Required to Achieve Specified Levels of Dilution of a Soluble Drilling Fluid Tracer in the Upper Plume at Fixed Current Speeds based on Field Study Data[a]

	Distance Required (m)[b] Current Speed (cm/sec)		
Dilution Criterion	5	10	15
10^4	10 - 17	19 – 34	29 - 51
10^5	80 -146	169 - 291	240 - 437
5×10^5	355 - 657	709 - 1,313	1,063 - 1,970
10^6	673 - 1,256	1,345 - 2,512	2,018 - 3,768

[a]Source: Petrazzuolo, 1983.
[b]Ranges in distances represent discharge rates of 21 to 1,200 bbl/hr.

The amount of fine solids settling to the bottom from the lower plume appears to depend to some degree on the aggregation of clay particles, which in turn depends on suspended material concentration, salinity, and the cohesive quality of the material. Fine particles tend to flocculate more readily than larger particles. Houghton et al. (1981) cites earlier work by Drake (1976), which concluded that physical-chemical flocculation can increase settling rates an order of magnitude over rates for individual fine particles.

4.1.2 *Seafloor Sedimentation*

Houghton et al. (1981) produced an idealized pattern for drilling fluids sedimentation around an offshore platform located in a tidal regime (Figure 4-1). Zero net current was assumed. The area of impact may have been overestimated from the true field case. Because no initial downward motion was assumed, longer settling times and greater plume dispersion were achieved. The result was an elliptical pattern, with the coarse fraction (10 milimeter (mm)-2 mm) deposited within 125 to 175 m of the discharge point, the intermediate fraction (250 µm-2 mm) deposited at 1,000 to 1,400 m, and the medium fraction (250 - 74 µm) deposited beyond that distance. This is the greatest areal extent of bottom sedimentation for continuous discharges under the assumed conditions. Discontinuous discharges will be transported by currents at the time of release and will form a starburst pattern over time (Zingula, 1975).

Studies have shown the extent of drilling fluid accumulation on the bottom to be inversely related to the energy dynamics of the receiving water. Vertical mixing also appears to be directly related to energy dynamics. Analysis of sediments at Tanner Bank showed no visible evidence of cuttings or mud accumulation 10 days after the last discharge, even though over 800,000 kg (882 short tons) of solids had been discharged over an 85-day period (Ray & Meek, 1980). Size analysis also indicated little change in the grain size distribution.

Low-energy environments, however, are not subject to (or only intermittently subject to) currents removing deposited material from the bottom or mixing it into sediments. In the low-energy Mid-Atlantic environment, for example, Menzie (1982) reported that cuttings piles were visibly distinct one

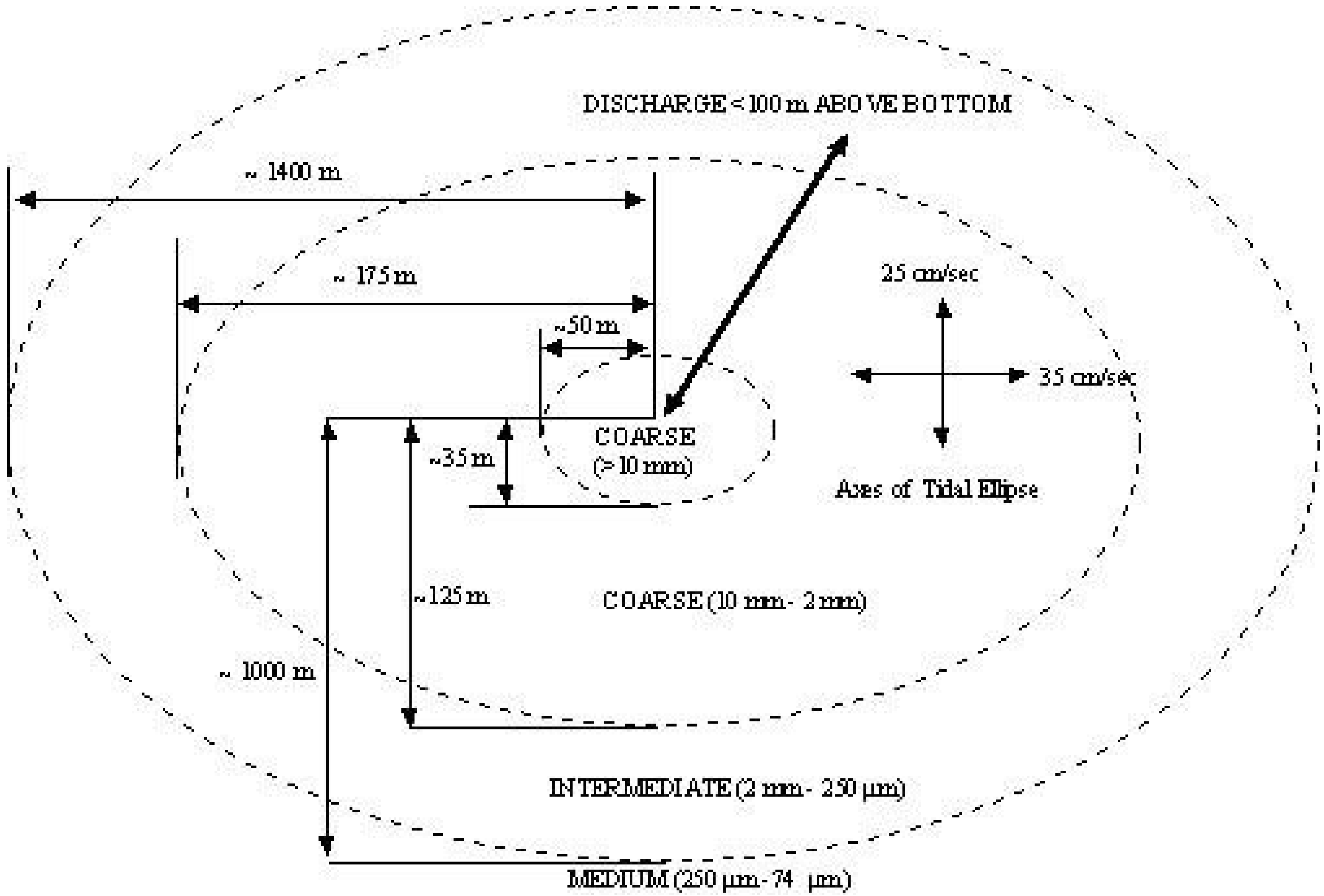


Figure 4-1. Approximate Pattern of Initial Particle Deposition (modified from Houghton et al., 1981)

year after drilling had ceased. Zingula (1975) also reported visible cuttings pile characteristics in the Gulf of Mexico shortly after drilling had terminated.

One study in the Gulf of Mexico (Ayers et al., 1980b) examined the short-term sedimentation of drilling fluids and cuttings in 23 m of water. Sediment traps were deployed only to a distance of 200 m. No distance-dependent quantitative estimates were possible from the data. More material, 10 to 100-fold, was collected in traps after a 1,000 bbl/hr discharge than after a 275 bbl/hr discharge. The relative barium, chromium, and aluminum contents of collected matter was more similar to that found in the initially discharged fluid for the 1,000 bbl/hr discharge than for the 275 bbl/hr discharge. This suggests a reduced influence of differential dispersion of drilling fluid components during the higher rate discharge.

Vertical incorporation of plume components into sediments is caused by physical and biological reworking of sediments. The relative contributions of these processes to vertical entrainment haev not beenwell-described. Petrazzuolo (1983) cites a GOM operation where barium concentration was substantially enriched to a 4-cm (1.6 in) depth at both 100-m (330 ft) and 500-m (1,600 ft) distances.

The upper 2 cm (0.8 in) of sediment was highly enriched with barium. This study was conducted along one transect (not aligned with major current flows) after four wells had been drilled at the platform. Boothe and Presley (1985) describe excess sediment barium concentrations that penetrate to depths of 5 to 20 cm (up to 30 cm at 30 m from one well site), with penetration depth generally decreasing with distance from the well site.

4.1.3 *Biological Transport*

Biological transport refers to the movement of pollutants through the environment via biological processes. Bioaccumulation, the accumulation of tissue burdens of pollutants contributes to transport of pollutants through the food web through predation. Bioaccumulation is discussed in Chapter 5. Another pathway of biological removal of pollutants involves a process known as bioturbation, benthic organisms reworking sediment and mixing surface material into deeper sediment layers.

Bioturbation generally mixes surface components into deeper sediment layers, although bioturbation can also expose previously buried materials. No work was found to quantify bioturbation effects, although a few studies have observed organisms living on a cuttings pile or in the vicinity of drilling discharges (Menzie et al., 1980; Ayers et al., 1980b). However, if the environment is one which rapidly removes cuttings piles, or where physical forces dominate resuspension and reworking processes, then biological mixing activities may not prove significant.

4.1.4 *Chemical Transport Processes*

Chemical transport of drilling fluids is poorly described. Much must be gleaned from general principles and studies of other related materials. Several broad findings are suggested, but the data for a quantitative assessment of their importance are lacking. Chemical transport will most likely arise from oxidation/reduction and reactions that occur in sediments. Changes in redox potentials will affect the speciation and physical distribution (i.e., sorption-desorption reactions) of drilling mud constituents.

Dissolved metals tend to form insoluble complexes through adsorption on fine-grained suspended solids and organic matter, both of which are efficient scavengers of trace metals and other contaminants. Trace metals, when adsorbed to clay particles and settled to the bottom, are subjected to different chemical conditions and processes than when suspended in the water column. If the sediments become anoxic, conversion of metals to insoluble sulfides is the most probable reaction, and the metals are then removed from the water column. Environments that experience episodic sediment resuspension favor metal release if reducing conditions existed previously in buried sediments; such current conditions also allow further exposure of organic matter complexes for further reduction and eventual release.

Alterations in Sediment Barium Levels

The long-term fate of discharge drilling fluids has been followed in several studies using sediment barium levels as a tracer. Four studies have been performed in the GOM from which data have been analyzed to estimate the dispersion of sediment barium. The subsequent fate of deposited material depends primarily on the physical processes that resuspend and transport particulates or entrain them into the sediments. Biological or chemical factors also could be important in stabilizing or mobilizing the material on the seafloor (e.g., through covalent binding of sediments or bioturbation). High concentrationsof barium persistently found near a well site suggest a lower energy bottom environment, which favors deposition. If elevated levels cannot be found, even soon after drilling, resuspension and sediment transport have taken place and a higher energy bottom environment is suggested.

A series of power-law regression analyses were developed to relate average barium levels to distances from the discharge source (Petrazzuolo, 1983). These equations predicted the distance-dependent decreases in sediment barium levels that were obtained in four field studies. A multivariate analysis was used to estimate average sediment barium levels with respect to distance and number of wells. At locations of approximately 100 m to 30,000 m from a nine-well platform, this analysis suggested that sediment barium data collected early in the development phase of an operation may provide accurate predictions of sediment barium levels later in the operation.

Data from exploratory drilling operations have been used to examine deposition of metals resulting from drilling operations. These data indicate that any of several metals may be deposited, in a distance-dependent manner, around platforms, including cadmium, chromium, lead, mercury, nickel, vanadium, and zinc. These sediment metal studies, when considered as a group, suggested that the enrichment of certain metals in surficial sediments may occur as a result of drilling activities (Table 4-2). While confounding factors occur in most of these studies (i.e., seasonal variability and other natural and anthropogenic sources of metal enrichment), discharged drilling fluids and cuttings are probably not the only drilling-related source. The only two metals clearly associated with drilling fluids that appear to be elevated around rigs or platforms are barium and chromium.

Metals that appear to be elevated as a result of drilling activities, and are not solely related to drilling fluids, include cadmium, mercury, nickel, lead, vanadium, and zinc. Cadmium, lead, and zinc in drilling fluids are the result of the use of pipe dope or pipe thread compounds. Mercury, nickel, and zinc may originate from sacrificial anodes. Cadmium, lead, and vanadium may also originate from the release of oil in drilling operations. This release can result from burning, incidental discharges or spills from the rig or supply boat traffic or use of oil as a lubricant in drilling fluids. Vanadium also may derive from wearing of drill bits. In a GOM platform study, brine (formation water) discharges were identified as anadditional potential source of metal contamination.

Although a variety of trace metals were variously found to be enriched in the sediment, enrichment factors were generally low to moderate, seldom exceeding a factor of 10. The spatial extent of this sediment enrichment also was limited. Either of two cases occurred: enrichment was generally distributed but undetectable beyond 300-500 m, or enrichment was directionally based by bottom current flows and extended further (to about 1,800 m) within a smaller angular component. These considerations suggest that exploratory activities will not result in environmentally significant levels of trace metal contamination. A study in the Canadian Arctic found that mercury would be the best trace metal tracer of discharged fluids (Crippen et al., 1980). However, reanalysis of the data also has suggested that the alterations in sediment mercury levels may have resulted from construction of the gravel island.

Alterations in sediment trace metal levels resulting from development drilling operations have not been as well characterized as those from exploratory operations. Two efforts have been made to estimate spatial distribution and fate of discharged material from a two-well operation in the GOM. One industry-sponsored analysis indicates that 49 percent of discharged barium is dispersed beyond a radius of1,250 m from the platform (Mobil Oil Corporation, 1978). Another analysis of these data indicates that 78%of the barium is located within a 1,000-m radius, and essentially all of the barium (calculated as 111 %) is located within 1,250 m.

Table 4-2. Summary of Sediment Trace Metal Alterations from Drilling Activities[a]

Location	Trace Metal								
	As	Cd	Cr	Cu	Hg	Ni	Pb	V	Zn
Gulf of Mexico, Mustang Island Area									
suspended sediment	ND[b]	-	+(8-31X)	+(7-10X)	ND	-	-	+(6-25X)	-
surficial sediment	ND	+(3-9X)	-	-	ND	-	-	-	+(2.5-3.5X)
Gulf of Mexico, Mustang Island Area	ND	±	±	±	ND	±	-	-	ND
Central Gulf of Mexico	ND	+	+	+	ND	+	+	+	
Mid-Atlantic	-	-	-	-	BLD	+(2.5X)	+(4-4X)	+(2-9.5X)	+(4X)
Mackenzie River Delta	+(1.2-2.5X)	+(2-6X)	+(4-7X)	ND	+(1.2-15X)	ND	+(1.5-2.2X)	ND	+(11.7X)
Beaufort Sea	ND	+(2-6X)	+(1.4-2X)	±	-	ND	+(1.2-2.6X)	ND	+(1.2-1.4X)

[a]Adapted from Tillery and Thomas (1980); Mariani et al. (1980); Crippen et al. (1980) in Petrazzuolo (1983).

[b]Abbreviations:

- ND - not determined
- \+ - increased levels (magnitude change in parentheses) related to drilling
- \- - decreased levels related to drilling
- ± - isolated increases, not a clearly distance-related pattern
- BLD - below the level of detection

Boothe and Presley (1985) conducted a survey of sediment chemistries around six platforms in the GOM. They concluded that only a small fraction of the total barium discharged is present in sediments near the discharge site. They estimated only 1 - 1.5% of discharged barium within 500 m of thedischarge at shallower sites (13 - 34 m) and only 9 - 12% at deeper sites (76 - 102 m). Similarly, within a 3 km radius, their estimates accounted for 5 - 7% at the shallower sites and 47 - 84% at the deeper sites. Statistically significant barium enrichment (≥ twice background) existed in surface sediments at 25 of the 30 control stations located at a distance of 3 km from the drill sites.

In the Santa Maria Basin, offshore Southern California, barium was found to be the only metal enriched in sediments near development drilling operations (Steinhauer et al., 1994). Sporadic elevations in sediment trace metals also were noted by Boothe and Presley. Mercury and lead were significantly correlated to barium at several sites; distance dependent decreases were noted at two sites for mercury and one site for lead. Significant increases were noted generally only out to 125 m from the site; however, the trend indicated increases perhaps to 300 - 500 m. The large statistical variability of the trace metal data set makes statistical inferences difficult.

The general conclusion of this study is that barium and probably other drilling fluid contaminants associated with the settleable fraction of drilling muds appear to be relatively mobile. Thus, drilling discharges are expected to be spread over a large area (i.e., > 3 km from their discharge source) on time scales of a year or so. These data are consistent with other data that indicate drilling discharges can be distributed widely (Continental Shelf Associates, 1983; Ng and Patterson, 1982; Bothner et al., 1983 as cited in Boothe & Presley, 1985).

4.2 Discharge Modeling - Drilling Fluids

Two approaches have been used to project plume behavior for the purposes of water quality assessments. One approach uses a range of generalized operational, effluent, and ambient data to broadly assess plume behavior and water quality impacts. The second approach uses project-specific operational and a range of effluent and ambient data to assess these same parameters. Both approaches are discussed below; results of the water quality impact assessments are presented in Chapter 9 of this document.

The first approach uses two sets of Offshore Operator's Committee (OOC) Mud Discharge Model runs previously conducted for EPA Region 10 using a broad set of environmental and operational conditions. One set of OOC model scenarios (USEPA Region 10, 1984) are based on a varied set of operational and environmental conditions for operations in Alaskan waters. A second set of model runs, intended to confirm and extend the earlier model runs conducted for Region 10, was completed for Region 10 by Dr. Maynard Brandsma (Brandsma Engineering, 1991). This last set of model runs was completed using the OOC Mud and Produced Water Discharge Model, Version 1.2F, which is an updated version of the 1983 OOC Mud Discharge Model used previously. Although these model runs were conducted for Region 10, many of these discharge scenarios are also generally appropriate to the present GOM analysis and were used to evaluate drilling fluids plume behavior.

The characteristics and results of these modeling exercises have been compiled and reviewed. A subset of cases was identified that comprise cases conducted for minimum water depths of 10 m and at the maximum discharge rate authorized in the GOMGeneral Permit (1,000 bbl/hr). This subset is believed to represent a reasonable range of potential drilling fluid discharge scenarios and, therefore, presents a reasonable indication of the dilutions and dispersions that may be expected for high rate drilling fluid discharges. Mean drilling fluids dilution among these 1,000 bbl/hr discharge scenarios, for 15-m, 40-m, and 70-m water depth scenarios, were used by the Region for the purpose of conducting water quality assessments.

4.2.1 *OOC Mud Discharge Model*

The OOC Mud Discharge Model is the most general of the available drilling fluid plume models and is the discharge model used for both approaches. It uses LaGrangian calculations to track material (clouds) settling out of a fixed pipe and a Gaussian formulation to sum the components from the clouds. The OOC model includes the initial jet phase, the dynamic collapse phase, and the passive diffusion phase of plume behavior.

The minimum waste stream data input requirements for the OOC Mud Discharge Model include effluent bulk density and particle size distribution. The dispersion of up to 12 drilling fluid particle size solid fractions (i.e., settling velocity fractions) can be followed. For each constituent particle fraction, its settling velocity and its fractional proportion of total solids must be input to the model. The OOC model requires the following operational data input: the depth of the discharge, diameter of the discharge pipe, discharge rate, and orientation of the discharge relative to ambient currents. Ambient environmental data input requirements of the OOC model include current, density stratification, and bathymetry.

Operational data are generally adequate to fulfill the data input needs for the OOC Mud Discharge Model. Waste stream input data requirements are adequately addressed by existing information, with the possible exception of settling velocities for drilling fluid solids fractions. Currently, these data are both extremely limited and a key model parameter. Existing settling velocity data are available for only a very few drilling muds. Thus, lacking data on more mud samples, it is difficult to know if the available data adequately represent drilling fluids. Also, settling velocity profiles are a key parameter in the model, forming the basis for calculating the effect of gravitational setting of drilling fluid solids. Thus, any shift in the particle size distribution (i.e., settling velocity distribution) will have significant effects on the calculated behavior of the plume. Particle size (settling velocity) data should be considered minimally adequate.

4.2.2 *Derivation of Generalized Dispersion/Dilution Estimates*

The first set of model scenarios run for Region 10 was conducted over a range of environmental and operational conditions. The mud weight used, with the exception of one 9.0 lb/gal case, was a 17.4 lb/gal mud with a total suspended solids concentration (TSS) of 1,441,000 mg/l. Surface current speeds ranged from 2 cm/sec to 32 cm/sec; density stratification ranged from 0.008 σ_t/m to 0.1 σ_t/m. Operationally, discharge rates ranged from 100 bbl/hr to 1,000 bbl/hr, the discharge was located 1 foot below the water line, and the discharge pipe was 12 inches in diameter. Water depths ranged from 5 m to 120 m.

The second data set on modeling of drilling fluids dispersion and dilution (Brandsma Engineering, 1991) was conducted to confirm and extend the first data set prepared for Region 10. Thus, the input data used were the same as for the first data set. The principle alteration for this set of modeling data was that a newer, revised version of the OOC model was used. Also, in comparing the results of the earlier versus the more recent model runs, Brandsma noted that a computational error occurred in the derivation of soluble tracer dilution in the earlier data set. This error has been corrected for the first Region 10 data set in the ODCE review of the data.

4.2.3 *Model Results from Generalized Input*

The results of these two drilling fluids modeling data sets are compiled and presented in Table 4-3. Results have been sorted first by discharge rate and second, by dilution at 100 m. These data havebeen analyzed in several ways. Data that were considered special cases of the model scenarios were eliminated from these analyses. These included model runs that excluded the rig wake effect from the model algorithm

Table 4-3. Summary of OOC Mud Model Drilling Fluid Plume Behavior

Case #	Water Depth (m)	Rate (bbl/h)	Current (cm/s)	Density Gradient (sigma-t/m)	100 m Dispersion	100 m Dilution
TT 8	10	100	10	0.07	3,859	2,579
TT 4	40	100	10	0.10	5,246	4,728
MB 3	5	250	10	0.10	2,318	222
MB 4	5	250	30	0.10	1,582	468
TT 18	5	250	10	0.02	6,109	662
TT 19	15	250	2	0.07	8,873	1,426
TT 20	15	250	10	0.07	2,558	1,617
MB 5	5	500	10	0.10	1,136	124
MB 6	5	500	30	0.10	770	211
MB 7	20	500	10	0.10	1,640	1,035
MB 8	20	500	30	0.10	1,626	1,583
MB 10	20	750	30	0.10	1,024	676
MB 9	20	750	10	0.10	1,305	789
TT 9	10	1,000	10	0.07	299	107
TT 5	5	1,000	10	0.02	4,810	127
TT 11	15	1,000	10	0.07	1,748	335
TT 6	10	1,000	10	0.07	1,785	341
TT 12	15	1,000	30	0.07	752	575
MB 11	20	1,000	10	0.10	942	655
TT 13	20	1,000	10	0.05	1,092	689
TT 14	40	1,000	10	0.01	731	755
TT 10	15	1,000	2	0.07	11,407	776
TT 3	40	1,000	10	0.10	905	818
MB 12	20	1,000	30	0.10	1,130	973
TT 15	70	1,000	10	0.04	1,803	1,721

Source: MB - Brandsma, 1991; TT - TetraTech, 1984.

and model runs that were conducted for pre-diluted drilling fluid discharges. Table 4-4 presents a summary of dilution results for data sorted by discharge rate. Table 4-5 presents a summary of dilution results for 1,000 bbl/hr discharges, sorted by water depth. These results are generally consistent with what would be expected for these discharges. Dilutions decrease with increasing discharge rates when they are considered in terms of their mean behavior, although there is considerable overlap between the ranges of dilution observed among the various discharge rates.

Table 4-4. Summary of OOC Mud Discharge Model Results by Discharge Rate

Discharge Rate (bbl/hr)	100-m Dilution Mean (Range)	100-m Dispersion Mean (Range
100	3,654 (2,579 - 4,728)	4,552 (3,859 - 5,246)
250	879 (222 - 1,617)	4,288 (1,582 - 8,873)
500	738 (124 - 1,583)	1,293 (770 - 1,640
750	733 (676 - 789)	1,165 (1,024 - 1,305)
1,000	656 (107 - 1,721)	2,284 (299 - 11,407)

Table 4-5. Summary of OOC Mud Discharge Model Results by Water Depth for High Weight (17.4 lb/gal) Muds Discharged at 1,000 bbl/hr

Water Depth (bbl/hr)	100-m Dilution Mean (Range)	100-m Dispersion Mean (Range)
5	127 (127)	4,810 (4,810)
10	224 (107 - 341)	1,042 (299 - 1,785)
15	562 (335 - 776)	4,636 (752 - 11,407)[a]
20	772 (655 - 973)	1,055 (942 - 1,130)
40	787 (755 - 818)	818 (731 - 905)
70	1,721 (1,721)	1,803 (1,803)

[a]Includes the only model run for 17.4 lb/gal muds at 1,000 bbl/hr at 2 cm/sec current speed (all others run at 10-30 cm/sec); if deleted from data set, the mean dispersion at 15 m is 1,250-fold.

Likewise, the general trend for dilution is to increase water depth; the effect of water depth on dispersion appears less clear from this data set, with no well-defined trend. Others (USEPA, Region 10, 1984) noted an apparent biphasic behavior in their more homogenous data set.

For the water quality assessment (see Chapter 9), the results of mean dilution at the maximum authorized discharge rate were used. For this assessment, mean dilution at 100 m for a water depth of 15 mwas 562 dilutions; for water depths of 40 m and 70 m, the respective means were 787 dilutions and 1,721 dilutions.

4.3 Synthetic-Based Drilling Fluids

4.3.1 Dispersal and Accumulation of SBF Drill Cuttings

Laboratory dispersal experiments showed that the various types of SBF's displayed a relative dispersibility as follows: Ester > Di-Ether >> Linear alkyl benzene > PAO > Low-Toxicity Mineral Oil. It is expected that the IOs and LAOs, the most commonly used synthetics today, should fall between esters and PAOs in dispersibility.

Because most SBF cuttings do not disperse efficiently in the water column following discharge, the rapid settling results in accumulation on the bottom near the platform discharge site. The field studies reviewed (Neff et al., 2000) show a high degree of variability in the depth of the SBF cuttings piles and distribution of cuttings on the seafloor. The variety of methods used in the studies and variation in discharge depths, discharge rates, total volumes discharged and oceanic conditions prevent drawing clear relationships between cuttings pile depths and distributions and SBF type, water depths and cuttings mass.

Generally, the distance from the rig to the highest concentration of SBF cuttings on the bottom varies depending on distance from the discharge to the seafloor, the net water current speed, and cuttings density. Results of some field studies indicate that SBF cuttings are distributed very heterogeneously in surface and subsurface sediments around deep-water drilling sites. The uneven distribution of cuttings on the bottom appears to be caused by clumping of the hydrophobic SBF-coated cuttings falling to the seafloor in large clumps. The distributions of SBF cuttings accumulations on the bottom is controlled by the direction and velocity of water currents at different depths in the water column.

Because of the variability in the data reviewed, it is not possible to draw any firm conclusions about rates of biodegradation, dilution, or washout of different types of SBF cuttings from sediments. Generally, the rate of loss of SBFs, other than esters, from sediments appears to be low. Ester concentrations in sediments near rigs using ester SBFs were lower than concentrations of other SBFs near the platforms using other SBFs. This observation lends support to the hypothesis that esters biodegrade rapidly in sediments.

Based on the data reviewed, no clear relationship can be determined between concentrations of SBFs in sediments and water depth, mass of cuttings discharged, or mass of SBFs discharged. There was a trend for SBF cuttings concentrations in sediments near discharging platforms to decrease as water depth increased. In most cases, SBF cuttings do not penetrate and mix deeply into surface sediments near the platform. SBF concentrations usually are higher in the surface layer (0 - 2 cm) of sediments than in deeper layers (2 - 5 cm and 5 - 8 cm). Approximately a year after completion of drilling, concentrations of SBF in the surface layer of sediments often decrease; however, concentrations at greater depths in the sediment core may increase or decrease. Temporal changes in SBF concentrations below the sediment surface probably are controlled by the amount of sediment reworking (by bioturbation and current-induced bed transport) and biodegradation. After more than a year, SBF concentrations at all depths in sediment may decline to low values, particularly if ester SBF cuttings were discharged.

The distribution of SBF concentrations in sediments around platforms discharging SBF cuttings varied widely from one site to another. The distribution of SBF cuttings piles around drilling rigs in the UK Sector of the North Sea ranges from less than 2800 m^2 to 94,250 m^2. The cuttings are not evenly distributed in sediments around the rig with most cuttings settling in the direction of the net current flow.

The distance from the rig to the highest concentration of SBF cuttings on the bottom varied depending on distance from the discharge to the seafloor, the net water current speed, and cuttings density. In studies of SBF discharges to the UK Sector of the North Sea the highest concentrations of SBF in sediments were located 0 m to 224 m from the rig immediately after drilling. Approximately one year after completion of drilling, the highest SBF concentrations in sediments were located 5 m to 153 m from the former drilling sites. The distance from the rig sites to sediment SBF concentrations below about 1,000 mg/kg ranged from 40 m to about 500 m from the rigs.

4.3.2 Biodegradation of SBFs

Microbial metabolism is the main mechanism of degradation of SBF base materials into harmless byproducts. Natural populations of sediment-dwelling bacteria, fungi, and protists are able to biodegrade some hydrocarbons and related oxygen-containing organic chemicals (e.g., esters, ethers, acetals) and use the carbon fragments as a source of nutrition.

Hydrocarbons vary in their susceptibility to biodegradation. The biodegradation of paraffins and olefins decreases sharply with increasing carbon chain length and molecular weight. As a result, high molecular weight, insoluble SBF base chemicals, such as PAOs, are less bioavailable and biodegradable than lower molecular weight, slightly soluble base chemicals, such as IOs. Generally,, linear hydrocarbons aremore easily biodegraded than branched or aromatic hydrocarbons. Biodegradation rate of linear paraffins decreases as chain length increases. Branching of hydrocarbon chains tends to slow biodegradation. Carbon-carbon double bonds and internal oxygen atoms (e.g., esters) are more readily attacked by microbes than carbon-carbon single bonds. Hydrocarbons are biodegraded mainly by oxidation; therefore, biodegradation of SBFbased materials and other hydrocarbons is much more rapid under aerobic conditions than in anaerobic environments.

A normal alkane (e.g., linear paraffin) or an alkene (e.g., LAO, IO, and PAO) is oxidized by microbes to an alcohol; the alcohol is oxidized further to a fatty acid. Two atoms of oxygen are consumed for each atom of fatty acid formed. Fatty acids are storage and structural nutrients for all plants and animals. The fatty acids derived from oxidation of SBF base chemicals are oxidized two carbons at a time through oxidation. The resulting acetate (CH_3COOH) molecules are incorporated into the energy and synthetic pathways of the microorganism. Thus, SBF base chemicals are biodegraded completely under aerobic conditions, with the reduction of a large amount of oxygen. Aerobic biodegradation of SBFs may deplete the oxygen in sediments, rendering the sediments anaerobic, if loading of the sediments with biodegradable organic matter from SBF cuttings is high and aeration of sediments is slow. In the absence of oxygen, SBF base chemicals are dehydrogenated to alcohols that are converted to fatty acids via chemical reactions are very inefficient under anaerobic conditions, and their rate probably limits the overall net rate of SBF biodegradation in marine sediments. Carbon-carbon double bonds and ester linkages are more easily oxidized than carbon-carbon single bonds by marine anaerobic bacteria. Thus, esters and unsaturated SBF base chemicals would be expected to biodegrade more rapidly than paraffins, linear alkyl benzenes, ethers, and acetals in anoxic sediments. Under anaerobic conditions, fatty acid oxidation also is inefficient. Alternatives to oxygen (e.g., NO_3^-, SO_4^{-2}, and CO) are used by the microbes to oxidize fatty acids, producing byproducts, such as hydrogen sulfide, ammonia, and methane, that are toxic to some sediment-dwelling marine organisms. Sulfate is abundant in seawater (~ 29 mM) and marine sediments; therefore, it is the dominant terminal electron acceptor for microbial oxidation of SBF base chemicals in anoxic marine sediments. Methanogenesis (reduction of CO_2 to CH_4) occurs only when most of the available sulfur has been reduced to sulfide. Sulfate reducing bacteria are more aggressive than methanogens, and olefins and esters should biodegrade more rapidly in marine sediments than indicated by anaerobic biodegradation tests, most of which are based on methanogenesis. The most important environmental factors affecting biodegradation rate of SBFs in sediments are temperature, oxygen concentration, and seafloor energy.

Results of laboratory biodegradation tests reviewed by Neff et al. (2000) indicate that aerobic and anaerobic biodegradation rates of synthetics occur in the following order: ester>LA>IO>PAO> acetal>ether. Mineral oils are less biodegradable than SBF-based chemicals, particularly under anaerobic conditions.

Considering the high concentrations of SBFs measured in surficial sediments within 100 m of some offshore platforms discharging SBF cuttings, it is probable that most SBF biodegradation will occur under anaerobic conditions after sediment oxygen concentration is reduced to low levels by the initial aerobic biodegradation of the SBF cuttings. In low energy environments where cuttings dispersion at the seafloor is a minor factor, anaerobic degradation of SBF cuttings probably is the rate-limiting step in recovery of benthic marine ecosystems contaminated with SBF cuttings. Anaerobic biodegradation rate is highest for esters, followed by LAOs. In general, SBF base chemicals, other than ester, do not biodegrade anaerobically at a substantially higher rate than mineral oils used in OBFs. Alkylbenzenes are not biodegraded under anaerobic conditions. Of the possible degradation products, alcohols are highly biodegradable, and ethers are resistant to anaerobic biodegradation.

4.4 Produced Water

The major processes affecting the fate of discharged produced water and associated chemicals include dilution and advection, volatilization, and adsorption/sedimentation. Hydrocarbons that become associated with sedimentary particles by adsorption can accumulate around production platforms, either settling to the seafloor through the water column or more directly through bottom impact of the discharge plume. Sediment contamination by produced water hydrocarbons was observed in shallow water studies at Trinity Bay, Texas (Armstrong et al., 1979) and at coastal Texas and Louisiana sites (Roach et al., 1992; Boesch and Rabalais, 1989; Rabalais et al., 1992). Roach et al. (1992) sampled sediments in the vicinity of produced water discharges at two coastal sites in Texas. Elevated levels of PAHs, aliphatics, and oil and grease were observed to a distance of 370 m from the discharge. Boesch and Rabalais (1989) noted that concentrations of naphthalenes in the sediment were enriched compared to effluent levels (21 mg/kg in the sediment versus 1.62 mg/liter in the effluent) and naphthalene levels were elevated in the immediate vicinity of the discharge with a subsurface concentration maximum in the sediment. Rabalais et al. (1992) compared sediment contamination and benthic community effects at 14 study sites in Louisiana (Table 4-6). Alkylated PAH were found to the maximum distance of the study transects at two sites (to 1,000 and 1,300 m) and from <100 to 500 m at the other sites. The two sites with no contaminants detected had outfalls that directed flow to a holding pond or marsh area. Benthic community effects were detected to a maximum distance of 800 m.

Table 4-6. Comparison of Extent of Sediment Contamination, and Benthic Community Impacts for Produced Water Discharges in the Gulf of Mexico

Site	Discharge (bbl/day)	Receiving Water Depth (m)	Environment	Zone of Sediment Contaminants (m)	Extent of Benthic Community Impacts (m)
Bayou Rigaud[1,2]	146,000	4-5	Dredged Bayou	1,300	700
Pass Fourchon[1,2]	48,000	3-4	Canal-Dredged Bayou	1,000	800
East Timbalier Island[1,2]	26,000	1.5-2	Canals Near Bay	360	100
Eugene Island Block 18[1,2]	21,000	2	Shallow Shelf	250	300
Romere Pass[1,2]	20,200	2	Miss. R. Distributary	450	None
Empire Waterway[1,2]	11,000	3	Marsh, Dredged Canal	None	None
Trinity Bay[3]	4,000-10,000	3	Open Bay	250-300	150
Emeline Pass[1,2]	3,700	3-6	Marsh, Miss. R. Distributary	None	None
Lake Pelto[4]	3,700	2	Open Bay (near pass)	100	20
Lafitte Field[5]	3,700	2	Dredged Canal	500	250
Eugene Island 120[4]	3,700	12	Shallow Shelf	100	20
Golden Meadow Field[5]	2,800	2-3	Dredged Canal, Bayou	100	100
Bayou Sale Field[5]	2,500	2-3	Dredged Canal	500	100
Buccaneer Field[6]	120-2,000	20	Shallow Shelf	200	NA

References:

1 Boesch and Rabalais (1989a)
2 Rabalais et al. (1991)
3 Armstrong et al. (1979)
4 Neff et al. (1989)
5 Boesch and Rabalais (1989b)
6 Middleditch (1981)

Source: Rabalais et al., 1992.

The sediment accumulation observed in these shallow water studies is provided for comparison and is not expected to directly compare to the open Gulf areas covered by the general permit for the eastern Gulf. Studies of sediment impacts for open waters are not available to the extent that coastal studies are. One study, Neff et al. (1988), reports little chemical contamination at their offshore study sites that exceeded a 300 m radius. Neff (1997) reviewed the available scientific literature on the fates and effects of produced water in the ocean. Saline produced waters dilute rapidly upon discharge to well-mixed marine waters.

Dispersion modeling studies of the fate of produced water differ in specific details but all predict a rapid initial dilution of discharges by 30- to 100-fold within the first few tens of meters of the outfall, followed by a slower rate of dilution at greater distances (Smith, 1993; Terrens and Tait, 1993; Smith et al., 1994; Stromgren et al., 1995; Brandsma and Smith 1996). Terrens and Tait (1993) modeled the fate of produced water discharged to the Bass Strait off southeastern Australia. Under typical oceanographic conditions for the area, the produced water is diluted nearly 30-fold within 10 m of the discharge and by 1,800-fold 1,000 m down-current of the produced water discharges. Brandsma and Smith (1996) modeled the fate of produced water discharged under typical Gulf of Mexico conditions. For a median produced water discharge rate of 115 m^3/d (772 bbl/d), a 500-fold dilution was predicted at 10 m from the outfall and a 1,000-fold dilutions was predicted at 100 m from the outfall. For a maximum discharge rate of 3,978 m^3/d (25,000 bbl/d), a 50-fold dilution was predicted at 100 m from the outfall. High volume discharges of warm high-salinity produced water to the North Sea are diluted by about 500-fold within about 60 m of the outfall under well-mixed water column conditions. Under conditions of stratified water column, a 300-fold dilution is reached 60 m from the discharge (Stephenson et al., 1994). Further dilution is slower; a 1,000-fold dilution is attained after about 1 hour when the produced water plume has drifted about 1,000 m.

Field measurements of produced water dilution are highly variable but confirm the predictions of modeling studies that dilution is rapid. Continental Shelf Associates (1993) reported that radium from a 6,570 bbl/d produced water discharge in a water depth of 18 meters in the Gulf of Mexico was diluted by a factor of 426 at 5 m from the discharge, and by a factor of 1,065 at 50 m from the discharge. Smith et al. (1994) used a dye tracer to measure dilution of produced water being discharged at a rate of 2,900 bbl/d to 6,500 bbl/d in a water depth of 82 m and found a 100-fold dilution within 10 m of the discharge and a 1,000-fold dilution within 103 m of the discharge. Somerville et al. (1987) measured a 2,800-fold dilution of produced water 1,000 m downcurrent from a North Sea produced water discharge. Rabalais et al. (1992) were able to measure elevated (compared to background) concentrations of radium, but not volatile hydrocarbons, to about 1,000 m downcurrent of a high-volume produced water discharge to shallow coastal waters of Louisiana.

Chemical processes important to the fate of produced water constituents generally are those that affect metal and petroleum hydrocarbon behavior in marine systems. Factors affecting metals have been described above under drilling fluids. An important factor affecting the fate of hydrocarbons in produced water is volatilization. Produced water contains a high fraction of volatile compounds (e.g., benzene), which can be lost from the system over time. However, because produced water can be much more dense than seawater (salinities >150 ppt are not uncommon), discharge plumes sink rapidly. Thus, elevated levels of benzene in bottom water have been observed in shallow coastal waters (Boesch & Rabalais, 1989; Rabalais et al., 1992).

For compounds with higher molecular weights, a major chemical process involves biodegradation of compounds. Polynuclear aromatic hydrocarbons tend to be more resistant to such degradation and, thus, can persist in the environment (primarily in sediment) for extended periods. The subsequent fate of petroleum hydrocarbons associated with sediments will depend on resuspending and transporting processes, desorption processes, and biological processes. Because produced waters provide a continuous input of light aromatic hydrocarbons over the life of a field (generally 10 to 30+ years), there is the potential for these chemicals to accumulate in sediments. This differs from oil spill situations wherein the chemicals are rapidly lost, and the sediments generally exhibit a decline of lighter aromatics with time.

The most abundant hydrocarbons of environmental concern in produced water are the light, one-ring aromatic hydrocarbons. Because they are volatile, they can be expected to evaporate rapidly from the water following produced water discharge. Brooks et al. (1980) reported that the maximum concentration of benzene measured in seawater immediately below the produced water discharge pipe at a production platform in the Buccaneer Field off Galveston, Texas was 0.065 ug/l, representing a nearly 150,000-fold dilution compared to the concentration of benzene in the produced water effluent (9,500 ug/l).

Concentrations of total gaseous and volatile hydrocarbons, including BTEX aromatics (75 percent of the total) decreased from 22,000 ug/l in the effluent, to 65 ug/l at the air/water interface below the outfall, to less than 2 ug/l in the surface water about 50 m away, indicating very rapid evaporation and dilution of the volatile components of the produced water. Concentrations of volatile liquid hydrocarbons discharged with produced water (600 bbl/d) at the Buccaneer Field were reduced on the order of 10^{-4} to 10^{-5} within 50 m from the platform (Middleditch, 1981).

BTEX concentrations in the upper water column near production platforms off Louisiana ranged from 0.008 - 0.332 ug/l (Sauer, 1980) compared to background concentrations of 0.009 - 0.10 ug/l of benzene in surface waters of the outer continental shelf off Texas and Louisiana (Sauer et al., 1978). These compounds are very volatile with half-lives in the water column of a few hours or days, dependingon water temperature and mixing conditions.

Terrens and Tate (1996) measured concentrations of BTEX and several PAHs in ambient sea water 20 m from an 11 million liter/d (69,000 bbl) produced water discharge from a platform in the Bass Straits off Australia. There was an inverse relationship between molecular weight (and thus, volatility) and the dilution of individual aromatic hydrocarbons. Individual monoaromatic hydrocarbons were diluted by 53,000-fold (benzene) to 12,000-fold (xylenes). PAHs were diluted by 12,000-fold (naphthalene) to 2,000-fold (pyrene). Concentrations of higher molecular weight PAHs were below the detection limit (0.0002 micrograms per liter (ug/l)) in the ambient sea water 20 m from the outfall. The inverse relationship between molecularweight of the aromatic hydrocarbons and their rates of dilution probably was attributed to the high temperature (95° C) of the discharged produced water.

Dilution of BTEX from produced water is less rapid where a large volume of highly saline produced water is discharged to poorly mixed, low-salinity estuarine waters. The concentration of total volatile hydrocarbons (including BTEX) approached 100 ug/l on one occasion in the bottom water in the vicinity of three produced water discharges (total volume ~ 43,000 bbl/d) to Pass Fourchon, a shallow marsh area in south Louisiana (Rabalais et al., 1991). BTEX compounds do not adsorb strongly to suspended or deposited marine sediments. Their concentrations in sediments near produced water discharges are usually low (Armstrong et al., 1979; Neff et al., 1989).

However, higher molecular weight aromatic and aliphatic hydrocarbons may accumulate in sediments near produced water discharges (Armstrong et al., 1979; Neff et al., 1989; Means et al., 1990; Rabalais et al., 1991). In well-mixed estuarine and offshore waters, elevated concentrations of saturated hydrocarbons and PAHs in surficial sediments may be observed out to a few hundred meters from a large-volume produced water discharge. In shallow, poorly mixed estuarine environments, elevated concentrations of PAHs in sediments may be detected to distances of at least 1,300 m from large-volume produced water discharges (Rabalais et al., 1991; 1992). Sediment contamination is greatest and extends the farthest from the discharge sites where large volumes of produced water (48,000 to 145,000 bbl/d) have been discharged to shallow (2 to 5 m) salt marsh canals.

4.4.1 Biological Transport Processes

Biological transport processes occur when an organism performs an activity with one or more of the following results.

- An element or compound is removed from the water column
- A soluble element or compound is relocated within the water column
- An insoluble form of an element or compound is made available to the water column
- An insoluble form of an element or compound is relocated.

Biological transport processes include bioaccumulation in soft and hard tissues, biomagnification, ingestion and excretion in fecal pellets, and reworking of sediment to move material to deeper layers (bioturbation).

Ingestion and Excretion

Organisms remove material from suspension through ingestion of suspended particular matter and excretion of this material in fecal pellets. These larger pellets exhibit different transport characteristics than the original smaller particles. Houghton et al. (1981) notes that filter-feeding plankton and other organisms ingest fine suspended solids (1 µm - 50 µm) and excrete large fecal pellets (30 µm - 3,000 µm) with a settling velocity typical of coarse silt or fine sand grains. The study also notes that copepods are important in forming aggregate particles.

Zooplankton have been found to play a major role in transporting metals and petroleum hydrocarbons from the upper water levels to the sea bottom (Hall et al., 1978). The largest fraction of ingested metals moves through the animal with the unassimilated food and passes out with the fecal pellets in a more concentrated state (Fowler, 1982). Zooplankton fecal pellets have also been found to contain high concentrations of petroleum oil, especially those of barnacle larvae and copepods. Hall et al. (1978) calculate that a population of calanoid copepods grazing on an oil slick could transport three tons of oil per square kilometer per day to the bottom.

Bioaccumulation and Biomagnification

Studies assessing biomagnification of certain petroleum hydrocarbons are more limited than for other pollutants. The data available suggest that these contaminants are not subject to biomagnification. One reason for this observation is that the primary source of these compounds for organisms may be absorption from the water column rather than ingestion. Additionally, biological half-times of some petroleum hydrocarbons may be short, with many species purging themselves within a few days.

There is some evidence that hydrocarbons discharged with produced water are bioaccumulated by various marine organisms. In a central GOM study (Nulton et al., 1981), analyses revealed the presence of low levels of alkylated benzenes, naphthalenes, alkylated naphthalenes, phenanthrene, alkylated three- ring aromatics, and pyrene in a variety of fish and epifauna. Isomer distributions of alkylated benzenes and naphthalenes were similar to those seen in crude oil.

Middleditch (1980) analyzed hydrocarbons in tissues of organisms in the Buccaneer Field. During the first two years of the study, tissue from barnacles from the platform fouling community at depths approximately 3 m below the surface contained up to 4 ppm petroleum alkanes. Middleditch (1980), in studying the fouling community and associated pelagic fish, found that many species were contaminated with hydrocarbons discharged in produced water. Middleditch claims that biodegradation of petroleum hydrocarbons in the barnacles was apparently efficient. Analyses of the fouling mat on the platform revealed that most samples contained petroleum hydrocarbons, and concentrations were particularly high in those collected just below the air/sea surface.

Middleditch (1980) found petroleum hydrocarbons in 15 of 31 fish species examined around the Buccaneer Field platform. Analyses were focused on four species--crested blenny, sheepshead, spadefish, and red snapper. Virtually every specimen of crested blenny examined contained petroleum alkanes. In this species, the n-octadecane/phytane ratio was similar to that of produced water but the n- octadecane/pristane ratio is distorted by the presence of endogenous pristane of biogenic origin. The meanalkane concentration in this species was 6.8 ppm. This species feeds on the platform fouling community, and it was suggested that this food was the source of petroleum hydrocarbons to the fish. Similar results were obtained with sheepshead, which also partially feed on the platform community. Petroleum alkanes were found in about half of the muscle samples and in about one quarter of the liver samples. The mean alkane concentration in these tissues were 4.6 and 6.1 ppm, respectively. Spadefish exhibited lower concentrations of alkanes in muscle and liver (0.6 and 2.0 ppm), and this species does not utilize the platform fouling community as a food source to the same extent as the two previously described species. Lower levels of alkanes were also observed in red snapper (1.3 ppm in muscle, and 1.1 ppm in livers).

With one exception, most shrimp analyzed by Middleditch did not contain alkanes. This probably reflectsthe highly migratory behavior of these animals. Similarly, the petroleum hydrocarbons were not found in white squid. Middleditch also examined nine benthic organisms for petroleum hydrocarbons. Yellow corals (*Alcyonarians*) contained alkanes, but Middleditch suggested these could be of biogenic origin.

Various hydrocarbon profiles were observed in species. Few of the specimens of winged oyster (*Pteria colymbus*) contained petroleum alkanes while they did contain methylnaphthalenes and benzo(a)pyrene.The results presented above, however, are rendered ambiguous inasmuch as Middleditch may not have clearly differentiated between biogenic and petrogenic alkanes.

4.4.2 Discharge Modeling - Produced Water

The fate of produced water discharges was projected using the CORMIX expert system, which was developed as a regulatory assessment tool for the EPA Environmental Research Laboratory at Athens, Georgia (Doneker & Jirka, 1990). A review of the model by LimnoTech Inc. (1993) for application to the OCS Federal waters resulted in the modified version used for the projections in this assessment.

4.4.2.1 CORMIX Expert System Description

The Cornell Mixing Zone Expert System (CORMIX) is a series of software subsystems for the analysis, prediction, and design of aqueous conventional or toxic pollutant discharges into watercourses (Doneker &Jirka, 1993). CORMIX (Version 2.10) was developed to predict the dilution and trajectory of submerged, single port discharges of arbitrary buoyancy (positive, negative, neutral) into water body conditions representative of rivers, lakes, reservoirs, estuaries, or coastal waters (i.e., shallow or deep, stagnant or flowing, uniform density or stratified). CORMIX assumes steady state flow conditions both for the discharge and the ambient environment.

The CORMIX expert system emphasizes the geometry and initial mixing of the discharge, predicting concentrations and dilutions, and the shape of the regulatory mixing zone. CORMIX requests necessary data input, checks the input data for consistency, assembles and executes the appropriate hydrodynamic models, interprets results of the simulation with respect to the specified legal mixing zone requirements (including toxic discharge criteria), and suggests design alternatives to improve dilution characteristics.

CORMIX uses the expert system shell VP-Expert (Paperback Software, Inc.) and Formula Translation (FORTRAN). CORMIXuses knowledge and inference rules, based on hydrodynamic expertise captured in the system, to classify and predict jet mixing. CORMIX was developed with the intent to provide an expert system that would work for a large majority of typical discharges (better than 95%), ranging from simple cases to fairly complex cases.

CORMIX requires input of water depth, selection of stratification profile (it provides four profiles from which to choose), surface/bottom water densities and stratification height if one exists, ambient current velocity (uniform), distance to the nearest bank, outfall port diameter, flow rate, depth of the outfall port (restricted to the lower third of the water column), vertical and horizontal discharge angles, effluent density, and the shape and dimension of regulatory mixing zones.

In response to industry comments on a previously proposed general NPDES permit issued by EPA Region 6, EPA requested a review of CORMIX to determine the system's applicability to discharges to open waters of the Gulf of Mexico. While it was determined that CORMIX was the best choice of the dispersion/ dilution models available, it was also determined that two adjustments were needed to make the far-fieldprojections more accurate.

The first adjustment concerns the limitation imposed by the system requiring that the discharge pipe opening be located in the bottom one-third of the water column. For produced water outfalls located at or above the water surface and is a negatively buoyant effluent (such as produced water), this configuration does not provide an accurate prediction of scenarios where the full water column is available for mixing. To correct for this, the water column and discharge densities have been inverted for two of the three discharge modeling scenarios where surface discharges occur, in the following manner. (The remaining case, where the discharge is shunted into the lower third of the water column, no adjustments to CORMIX were necessary.)

Based on a linear stratification with a density gradient (σ_t/m) of 0.163 kg/m^3/m, the bottom density is calculated using a surface density of 1,023 kg/m^3. The water column is "inverted" by using the surface density as the bottom density and calculating a new surface density, keeping the density differential constant (e.g., for a 10 m water depth, the new surface density would be 1,023 kg/m^3- (10 *0.163 kg/m^3) = 1,021.37 kg/m^3). The effluent density is inverted to create a positively buoyant plume keeping the produced water ambient density differential consistent with the original scenario. This is accomplished by reducing the effluent density at the outfall by the difference between it and the original ambient density (e.g., the initial density differential of 1,070 kg/m^3 - 1,023 kg/m^3 = +47 kg/m^3 is transformed into a density differential of -47 kg/m^3 by changing the effluent density to 1,023 kg/m^3 - 47 kg/m^3 = 976 kg/m^3). The inverted scenario is run through the CORMIX system with the discharge located at the seafloor creating a mirror image of a negatively buoyant discharge located just below the water surface. Trial runs of the CORMIX system verify that these scenarios produce identical results.

The second adjustment to the CORMIX system corrects for an underestimation of far-field dilutions as discussed in Wright (1993). For model projections that do not result in the plume impacting the seafloor (or the surface in the case of the inverted scenario), Brook's 4/3 power law is applied to the control volume outflow results of the model at the end of the impingement zone to predict the dilutions at the edge of the mixing zone. The derivation from the Brook's equation used to calculate far-field dilution is:

$$C_i = \mathrm{erf}[(1.5/((1 + 8\ A\ H^{4/3}\ (t/H^2))^3 - 1))^{1/2}]$$

where,

H = the width of the collapsed plume
A = 0.000453 m$^{2/3}$/s
t = travel time from the end of the plume collapse to 100 m (edge of the mixing zone) (100/u-T); where T is the time to complete the collapse phase
erf = the error function
C_i = the maximum concentration in the far field after travel time t_i.

The input needed for this equation is provided by the CORMIX output.

4.4.2.2 Derivation of Dilution Estimates

Input data for stratification conditions in the CORMIX model predictions used for the general assessment of produced water dilution were primarily based on a study by Temple et al. (1977). A study transect off Mobile Bay was monitored for temperature and salinity over one year. The 7- and 14-meter stations were used to determine the average surface water density and density gradient in the water column. For the existing produced water outfalls located offshore Alabama, a surface density of 1,023 kg/m^3 and a gradient (σ_t/m) of 0.163 kg/m^3/m were used. The effluent density of 1070 kg/m^3, used as input for the model, was derived from data obtained from the Louisiana Department of Environmental Quality (*Avanti* Corporation, 1992). The density represents a produced water with a salinity of 100 ppt (approximately the lower 33rd percentile of coastal and offshore Louisiana produced water chlorinity) and an effluent temperature of 105°F (approximately the upper 90th percentile of coastal and offshore Louisiana produced water temperature).

The current speed used for this assessment of produced water dilution (5 cm/sec) is the median of current speeds recorded for offshore Alabama by Texas A&M (1991). The current meter was placed at a 10 m depth in 30 m of water.

Operational data for the three existing produced water outfalls were supplied by the operators at the request of EPA Region 4. This data as well as other input parameters needed for the CORMIX model are listed in Table 4-7. Shell, operating in Mobile Block 821, is located in 49 ft (15.25 m) of water. The outfall is shunted to40 ft (12.2 m) below the water surface and the average produced water discharge rate is 1500 bbl/day from a 35-inch pipe. Because the outfall is within the bottom one-third of the water column, inversion of the water column densities was not needed. Also, because CORMIX indicated plume interaction with the seafloor, the Brook's equation modification for the far-field dilution was not applied in this case. Chevron isoperating in Mobile Block 990 located in 54 ft (17.5 m) of water with the outfall located above the surface of the receiving water. The discharge averages 450 bbl/day from a 4-inch pipe. Callon Petroleum is located in Mobile Block 908 in 66 ft (21.1 m) of water with the outfall located above the receiving water surface. The average discharge rate is 2 bbl/day from a 6-inch pipe.

4.4.3 Model Results

The results of the CORMIX model are presented in Table 4-7 for a 100-meter mixing zone. These results are used for the water quality analysis in Chapter 9 of this document. Both the Chevron and Callon Petroleum produced water outfalls are located above the water surface. In these cases, the ambient water densities and effluent/ambient density differential were inverted; because the discharge plume does not impact the surface, the Brook's equation was used to estimate far-field dilution. The CORMIX dilution at 100 m, without the Brook's modification was used for the Shell facility produced water modeling scenario.

Table 4-7. Summary of CORMIX Input Parameters and Model Results for Produced Water Discharges

Input Parameter[a]	Shell (MOB 821)	Chevron (MOB 990)	Callon Petroleum (MOB 908)
Water Depth	49 ft. (15.25 m)	54 ft. (17.46 m)	66 ft. (21.1 m)
Pipe Depth	40 ft. (12.2 m) or 3.05 m from bottom	Above surface or 0 m from bottom	Above surface or 0 m from bottom
Pipe Diameter	35 in. (0.889 m)	4 in. (0.1016 m)	6 in. (0.1524 m)
Discharge Rate (bbl/d)	1,500 bbl/day	450 bbl/day	2 bbl/day
Current Speed (m/s)	0.05 m/s	0.05 m/s	0.05 m/s
Ambient Surface Density (kg/m^3)	1,023	1,020.15	1,019.56
Ambient Bottom Density (kg/m^3)	1,025.49	1,023	1,023
Density Stratification (sigma-t/m)	0.163	0.163	0.163
Produced Water Density (kg/m^3)	1,070	976	976
Dilutions at 1,000 m	333	3,570	89,235

[a] Input data provided to Region 4 by operators; current speed and density stratification determined from data for the Gulf of Mexico offshore Alabama (Texas A&M, 1991; Temple et al., 1977).

5. TOXICITY AND BIOACCUMULATION

5.1 Overview

The release of drilling and production wastes from oil and gas platforms is of interest due to the potential toxicity and the potential for bioaccumulation. The following is a brief summary of the available data regarding water-based and synthetic-based drilling fluids. It is important to note that the permit limits the toxicity of drilling fluids (30,000parts per million (ppm) of the suspended particulate phase), prohibits the discharge of any muds containing diesel, the discharge of neat synthetic-based fluids, and limits the cadmium and mercurycontent of muds so that only the less contaminated sources of barite may be use in mud formulations.

5.2 Toxicity of Drilling Fluids

Toxicity testing data are often used to assess the toxicological characteristics of an effluent. Toxicity tests have been conducted with a wide variety of drilling muds, drilling mud fractions, and test organisms. The presence of diesel oil in used drilling mud also has been shown to contribute to increased toxicity (Conklin et al., 1983; Duke and Parrish, 1984).

The "fractions" or “phases” of drilling fluids that have been used in toxicity testing include:

Suspended Particulate Phase (SPP). One part by volume of drilling fluid is added to nine parts seawater. The drilling fluid-seawater slurry is well-mixed and the suspension is allowed to settle for one hour before the supernatant SPP is decanted off. The SPP is mixed for five minutes and then used immediately in bioassays. Testing protocol currently employed by EPA specifies testing of the SPP.

Layered Solid Phase (LSP). A known volume of drilling fluid is layered over the bottom of the test vessel or added to seawater in the vessel. Although little or no mixing of the slurry occurs during the test, the water column contains a residual of very fine particulates which do not settle out of solution.

Suspended Solids Phase (SSP). Known volumes of drilling fluids are added to seawater and the mixture is kept in suspension by aeration or mechanical means.

Mud Aqueous Fraction (MAF). One part by volume of drilling fluid is added to either four or nine parts seawater. The mixture is stirred thoroughly and then allowed to settle for 20-24 hours. The resulting supernatant MAF is siphoned off for immediate use in bioassays. The MAF is similar to the SPP but has a longer settling time, so the concentration of particulates in the supernatant is lower.

Filtered Mud Aqueous Fraction (FMAF). The mud aqueous fraction of whole drilling fluid is centrifuged and/or passed through a 0.45 micrometer (µm) filter and the resulting solution is the filtered mudaqueous fraction.

Because the synthetic-base fluids are water insoluble and the SBFs do not disperse in water as WBFs do, but rather tend to sink to the bottom with little dispersion,most research has focused on determining toxicity in the sedimentary phase as opposed to the aqueous phase.

5.2.1 *Acute Toxicity*

Acute toxicity tests of whole drilling fluids have generally produced low toxicity. Petrazzuolo (1983) summarized the results of 415 such tests of 68 muds in 70 species and found 1 to 2 % had lethal concentrations to which 50% of organism die (LC50s) ranging from 100 to 999 ppm, 6 percent had LC50s ranging from 1,000 to 9,999 ppm, 46 percent had LC50s ranging from 10,000 to 99,999 ppm, and 44 percent had LC50s of greater than 100,000 ppm (Table 5-1).

Test results also indicate that whole drilling fluid is more toxic than the aqueous or particulate fractions (Table 5-2). These data show whole fluid toxicity ranging from one to five times that of the aqueous fraction, and 1.3 times the toxicity of the particulate fraction. The reason for this increased toxicity is unclear, although a combination of chemical and physical interactions is possible. Also, in terms of using toxicity test results to project potential receiving water impacts, drilling fluids generally undergo a rapid physical separation of their solids components over once discharged.

Acute toxicity test results for used drilling fluids and drilling fluid components are presented in Appendix A. Criterion values for drilling fluid fractions in the table have been converted to whole fluid equivalents to provide greater comparability to whole fluid tests. For example, the MAF is prepared by mixing one-part drilling mud with 9 parts seawater, so an LC50 value derived from 100 % MAF is the supernatant from a 10 % drilling fluid mixture and is therefore expressed as 100,000 ppm (10 % whole fluid equivalent).

Petrazzuolo (1981) used a semi-quantitative procedure to rank organisms in terms of sensitivity to drilling fluids, based on laboratory tests. The results ranked groups of organisms as follows, in order of decreasing sensitivity: copepods and other plankton; shrimp; lobster; mysids and finfish; bivalves; crab; amphipods; echinoderms; gastropods and annelids; and isopods. This ranking is admittedly biased because it is limited by the actual bioassay test results that have been published, and not based on theoretical considerations. For example, if more tests, more toxic drilling fluids, and more sensitive life stages have been tested on certain types of organisms, they would appear to be more sensitive in the rankings. These shortcomings notwithstanding, the ranking is a reasonable general indicator of the relative sensitivity of organisms to drilling fluids.

Table 5-1. Summary Table of the Acute Lethal Toxicity of Drilling Fluid[a]

	Number of species tested	Number of fluids tested	Number of tests	Not determinable	Number of 96-hr LC50 values (ppm)[b]				
					< 100	100-999	1,000-9,999	10,000-99,000	> 100,000
Phytoplankton	1	9	12	5	0	0	7	0	0
Invertebrates									
Copepods	1	9	11	1	0	3	5	2	0
Isopods	2	4	6	0	0	0	0	1	5
Amphipods	4	11	22	0	0	0	0	7	15
Gastropods	5	5	10	0	0	0	0	2	8
Decapods									
Shrimp	9	23	66	0	0	6(1)[c]	5	36	19
Crab	8	18	32	1	0	0	3	17	11
Lobster	1	2	7	0	0	0	1	3	3
Bivalves	11	22	59	19	0	0	1	19	20
Echinoderms	2	2	4	0	0	0	0	1	3
Mysids	4	17	64	2	0	0	1	29	32
Annelids	7	14	34	3	0	0	0	12	19
Finfish	15	24	80	0	0	0	2	50	36
TOTALS	70	40[d]	407	31	0	4-9	25	179	0.00

[a]Source: Adapted from Petrazzuolo, 1983.

[b]Placement in classes according to LC50 value. Lowest boundary of range if LC50 expressed as a range. Cited values if given as ">" or "<." There were 199 such LC50 values; 95 were >100,000 ppm; 20 were <3,200 ppm.

[c]These include tests conducted on drilling fluids obtained from Mobile Bay, Alabama, and which may not be representative of drilling fluids used and discharged on the OCS. The value in parentheses is the result of not including those drilling fluids.

[d]The fluids used in Gerber et al., 1980, Neff et al., 1980, and Carr et al., 1980 were all supplied by API. Their characteristics were very similar and they may have been subsamples of the same fluids. If so, the total number of fluids tested would be 35.

Table 5-2. Comparison of Whole Fluid Toxicity and Aqueous and Particulate Fraction Toxicity for Some Organisms

Organism	Whole fluid vs. aqueous fraction	Whole fluid vs. particulate fraction
Gammarus (amphipod)	> 1.4 to 3.6:1	
Thais (gastropod)	> 1.2:1	
Crangon (shrimp)	> 1.1 to 1.4:1	
Carcinus (crab)	> 1.1 to 1.5:1	
Homarus (lobster)	> 3.5 to 5.3:1	
Strongylocentrotus (sea urchin)	> 2:1	
Coregonus (whitefish)	< 1.7:1	
Neomysis (shrimp)		1.3:1

Source: Petrazzuolo, 1981

Toxicity tests also highlight the toxicity variations that occur during a given organism's life cycle. Larval stage organisms are generally more sensitive than adult stages, and invertebrates are more sensitive while molting than during intermolt stages. These variations affect the potential for impact associated with offshore operations. Drilling fluids discharged into an area occupied by an adult community will presumably cause less impact than if the area were occupied by juvenile communities or if the area serves as a spawning ground.

Toxicity tests with larvae of the grass shrimp (*Palaemonetes intermedius*; Table 5-3) indicate that they are not as sensitive to whole muds as mysids. Average 96-hour LC50 values for whole muds ranged from 142-100,000 ppm. *Mercenaria mercenaria* one-hour-old larvae showed a lack of development (48-hour EC50) at relatively low concentrations of the liquid and suspended solids phases of the muds (Table 5-4). Concentrations as low as 87 and 64 ppm (respectively) halted larval development. Similarly, embryogenesis of *Fundulus* and echinoderms was affected by drilling fluid exposure. "Safe" levels (defined as a concentration of 10 % of that having an adverse effect on the most sensitive assay system) ranged from one to 100 ppm. A study of sublethal effects of drilling mud on corals (*Acropora cervicornis*) indicated a decrease in the calcification rate and changes in amino acids at concentrations of 25 ppm.

All of the muds tested in an earlier drilling mud study (Duke & Parrish, 1984) were found to contain some No. 2 fuel (diesel) oil. Surrogate "diesel" oil content ranged from 0.10 - 9.43 mg/g in the whole mud. Spearman rank order correlation of the relationship between toxicity and fuel oil content showed a significant correlation between these factors in all tests.

Table 5-3. Drilling Fluid Toxicity to Grass Shrimp (*Palaemonetes intermedius*) Larvae

Mud	Type	96-h LC50 (95% CI)	
MIB	Seawater Lignosulfonate	28,750 ppm	(26,332-31,274)
AN31	Seawater Lignosulfonate	2,390 ppm	(1,896-2,862)
SV76	Seawater Lignosulfonate	1,706 ppm	(1,519-1,922)
P1	Lightly Treated Lignosulfonate	142 ppm	(133-153)
P2	Freshwater Lignosulfonate	4,276 ppm	(2,916-6,085)
P3	Lime	658 ppm	(588-742)
P4	Freshwater Lignosulfonate	4,509 ppm	(4,032-5,022)
P5	Freshwater/Seawater	3,570 ppm	(3,272-3,854)
P6	Lignosulfonate	100,000 ppm	---
P7	Low Solids Nondispersed	35,420 ppm	(32,564-38,877)
P8	Lightly Treated Lignosulfonate	2,577 ppm	(2,231-2,794)
NBS	Seawater/Potassium/Polymer		
Reference		17,917 ppm	(15,816-20,322)

Source: Adapted from Duke and Parrish (1984). All tests conducted at 20 ppt salinity and 20+2°C with day-1 larvae.

Table 5-4. Results of Continuous Exposure (48 hr) of 1-hr Old Fertilized Eggs of Hard Clams (*Mercenaria mercenaria*) to Liquid and Suspended Particulate Phases of Various Drilling Fluids

Drilling Fluid	Liquid Phase EC50 (µl/l)[a]		Control % "D" Stage	Suspended Particulate EC50 (µl/l)[b]		Control % "D" Stage
AN31	2,427	(2,390-2,463)	88	1,771	(1,710-1,831)	93
MIB	>3,000		95	>3,000		95
SV76	85	(81-88)	88	117	(115-119)	93
P1	712	(690-734)	97	122	(89-151)	99
P2	318	(308-328)	97	156	(149-162)	99
P3	683	(665-702)	98	64	(32-96)	99
P4	334	(324-345)	98	347	(330-364)	99
P5	385	(371-399)	98	382	(370-395)	99
P6	>3,000		97	>3,000		93
P7	>3,000		97	2,799	(2,667-2,899)	93
P8	269	(257-280)	93	212	(200-223)	93

aEC50 and 95% confidence interval. The percentage of each test control (n = 625+125 eggs) that developed into normal straight-hinge or "D" stage larvae and the EC50 are provided.
Source: NEA, 1984.

Other studies also implicated diesel and mineral oil in the toxicity of certain drilling fluids. In these studies, the toxicity of drilling fluids with and without added diesel or mineral oil were compared (Table 5-5). The drilling fluids tested included "used" fluids as well as a National Bureau of Standards (NBS) reference fluid which contained no measurable amount of diesel. In each case, the addition of diesel or mineral oil increased the toxicity of the drilling fluids.

Conklin et al. (1983) also found a significant relationship between the toxicity of drilling fluids and diesel oil content. Their study was designed to assess the roles of chromium and petroleum hydrocarbons in the total toxicity of whole mud samples from Mobile Bay to adult grass shrimp (*Palaemonetes pugio*). The range of 96-hour LC50 values was from 360 - 14,560 ppm. The correlation between chromium concentration of the mud and the LC50 value was not significant; however, the correlation between diesel oil concentration and the LC50 value was significant. As the concentration of diesel oil in the muds increased, there was a general increase in the toxicity values. Similar toxicity tests using juvenile sheepshead minnows (*Cyprinodon variegatus*) showed higher LC50 levels but no significant correlation between either chromium or diesel oil content and toxicity.

Diesel oil appeared to be a key factor in drilling fluid toxicity. It may explain some of the increased toxicity of used versus unused drilling fluids. As a result of these data, EPA has prohibited the discharge of drilling fluids to which diesel oil has been added.

Table 5-5. Toxicity of API #2 Fuel Oil, Mineral Oil, and Oil-Contaminated Drilling Fluids to Grass Shrimp (*Palaemonetes intermedius*) Larvae

Materials Tested	Oil Added (g/l)	Total Oil Content (g/l)	96-hr LC50 (95% CI)[a] (ppm; µl/l)
API #2 fuel oil[b]	---	---	1.4 (1.3-1.6)
Mineral Oil[c]	---	---	11.1 (9.8-12.5)
P7 mud	None	0.68	35,400 (32,564-8,877)
P7 mud + API #2 fuel	17.52	18.20	177 (165-190)
P7 mud + API #2 fuel oil (hot-rolled)	17.52	18.20	184 (108-218)
P7 mud + mineral oil	17.52	18.20	538 (446-638)
P7 mud + mineral oil (hot-rolled)	17.52	18.20	631 (580-674)
NBS reference drilling mud	None	0	17,900 (15,816-20,332)
NBS mud + API #2 fuel oil	18.20	18.20	114 (82-132)
NBS mud + API #2 fuel oil (hot-	18.20	18.20	116 (89-133)
rolled)	18.20	18.20	778 (713-845)
NBS mud + mineral oil	18.20	18.20	715 (638-788)
NBS mud + mineral oil (hot-rolled)	None	18.20	142 (133-153)
P1 drilling mud			

[a]95% confidence intervals computed by using a "t" value of 1.96.
[b]Properties: Specific gravity at 20°C, 0.86; pour point -23°C; viscosity, saybolt, 38°C, 36; saturates, wt% 62; aromatics, wt% 38; sulfur, wt%, 0.32.
[c]Properties: Specific gravity at 15.5°C, 0.84-0.87; flash point, 120-125°C; pour point, -12 to -15°C; aniline point, 76-78°C; viscosity, cst 40°C, 4.1 to 4.3; color saybolt, +28; aromatics, wt%, 16-20; sulfur, 400-600 ppm.
Source: Adapted from Duke and Parrish, 1984.

SBFs have routinely been tested using the Suspended Particulate Phase (SPP) Toxicity Test and found to have low toxicity (Candler et al., 1997). Rabke et al. (1998), have recently presented data from an interlaboratory variability study indicating that the SPP toxicity results are highly variable when applied to SBFs, with a coefficient of variation of 65.1 %. Variability reportedly depended on such things as mixing times and the shape and size of the SPP preparation containers. As part of the coastal effluent guidelines effort, published in December 1996, the EPA identified the problems with applying the SPP toxicity test to SBFs due to the insolubility of the SBFs in water (USEPA, 1996).

North Sea testing protocols require monitoring the toxicity of fluids using a marine algae (*Skeletonema costatum*), a marine copepod (*Arcartia tonsa*), and a sediment worker (*Corophium volutator* or *Abra alba*). The algae and copepod tests are performed in the aqueous phase, whereas the sediment worker test uses a sedimentary phase. Again, because the SBFs are hydrophobic and do not disperse or dissolve in the aqueous phase, the algae and copepod tests are only considered appropriate for the water-soluble fraction of the SBFs, while the sediment worker test is considered appropriate for the insoluble fraction of the

SBFs (Vik et al., 19960. As with the aqueous phase algae and copepod tests, the SPP toxicity test mentioned above is only relevant to the water-soluble fraction of the SBFs (Candler et al., 1997).

Both industry and EPA identified the need for more appropriate toxicity test methods for assessing the relative toxicities of various SBFs. Data presented by industry and the EPA have shown that the abbreviated acute toxicity test of 96 hours increases the discriminatory power between the toxicity of individual SBFsand between the toxicity of SBFs and diesel (USEPA, 2000). Both the EPA and industry data have indicated that esters are the least toxic followed by internal olefin (IO), linear alpha olefin (LAO) and paraffins.

These data also indicate toxicity for all base fluids tested and variability within individual tests both increase with increased test duration. Industry data indicate that a suitable 100%-formulated sediment for dilution sediment has yet to be developed. The toxicity data on SBFs and SBF-based fluids are summarized in Table 5-6 and Table 5-7.

Table 5-6. Reported Toxicities of Synthetic-Based Fluids (LC50s)	***Ampelisca abdita***	***Leptocheirus plumulosus***	***poxynius ronius***	***Corophium volutator***	***Abra alba***	***keletonema costatum***	***Acartia tonsa***	***Fundulus grandis***
BASE FLUID - Natural Sediment								
Candler, 1997 Rabke, 1998b Still, 1997	879 mg/kg 1.0 ml/kg 0.7 ml/kg	 850 mg/kg	 mg/kg	840 mg/kg				
Candler, 1997 Still, 1997	557 mg/kg	 251 mg/kg	 mg/kg	7146 mg/kg				
Candler, 1997 Rabke, 1998b Vik, 1996 Still, 1997	121 mg/kg 4.0 ml/kg 3.0 ml/kg	 3.7 ml/kg 2,944 mg/kg	 mg/kg	30,000mg/kg 7,100 mg/l	 300 mg/l	 2,050 mg/l	 10,000 mg/l	
Candler, 1997 Rabke, 1998b Vik, 1996 Still, 1997	0,690 mg/kg 13.4 ml/kg 12.5 ml/kg	 9,636 mg/kg	 mg/kg	30,000mg/kg 12.0 ml/kg 3.0 ml/kg	 7,900 mg/l	 3,900 mg/l	 50,000 mg/l	
Vik, 1996a					100,000 mg/l	60,000 mg/l	50,000 mg/l	
Vik, 1996a					549 mg/l	100,000 mg/l	100,000 mg/l	
Vik, 1996a					1,021 mg/l	10,000 mg/l	10,000 mg/l	
BASE FLUID - Formulated Sediment								

Rabke, 1998b		1.0 ml/kg 0.7 ml/kg						
WHOLE FLUID - Natural Sediment								
Rabke, 1998b	1.5 ml/kg	9.4 ml/kg						
Rabke, 1998b Friedheim et al., 1996	1.5 ml/kg	2.3 ml/kg		 7,131 mg/kg	 303 mg/kg			
Rabke, 1998 Jones, 1991 Friedheim et al., 1996 Vik, 1996a	3.7 ml/kg	36.5 ml/kg		 10,000 mg/kg >10,000 mg/l	 572 mg/kg 7,000 mg/l	 82,400 mg/l	 50,000 mg/l	 8.4% TPH
Vik, 1996a							00-145,000 mg/l	50,000 mg/l
Friedheim et al., 1996				1,268 mg/kg	277 mg/kg			
WHOLE FLUID - Formulated Sediment								
Rabke, 1998b		2.9 ml/kg 1.7 ml/kg 0.7 ml/kg 1.3 ml/kg						
Rabke, 1998b	3.6 ml/kg	2.5 ml/kg 2.7 ml/kg 10.5 ml/kg						

Hood, 1997		2,279 mg/kg 4,498 mg/kg 2,245 mg/kg 1,200 mg/kg 943 mg/kg						
Rabke, 1998b		<2.5 ml/kg						
WHOLE FLUID -No Sediment								
	Mysidopsis bahia							
Rabke, 1998a Hood, 1997	21,436 - >1,000,000 ppm (SPP) 56,500 - >1,000,000 ppm (SSP)							

Table 5-7. Minimum and Maximum LC50 Values for New Sediment Toxicity Data Presented as Comment Response on Either the Proposed Rule (12/99) or the Notice of Data Availability (4/00) for Effluent Limitations Guidelines for the Oil and Gas Extraction Point Source Category.

	Minimum and Maximum LC 50 Values (mg/kg)				
	96-h LC 50			10-day LC 50	
Base Fluid	Minimum	Maximum		Minimum	Maximum
Diesel NS[a]	NA	NA		343[b,c]	NA
	776[b,d]			340[b,d]	
	892[e]	1133[e]		585[e]	951[e]
	703[b,f]			138[f]	635[f]
Diesel FS[g]	255[e]	374[e]		157[e]	312
	450[h]	703[h]		495[h]	495[h]
Ester NS	7686[d]	21824[d]		4275[d]	10,219[d]
	>12,800[b,e]			8743[b,e]	
Ester FS	27,986[b,e]			2816[b,e]	
IO NS	5874[c]	6306[c]		464[c]	2501[c]
	2675[d]	>8000[d]		2416[d]	2530[d]
	10,306[e]	19,522[e]		1988[e]	5270[e]
	27,269[f]	37,035[f]		2075[f]	16,131[f]
IO FS	<500[c]	2624[c]		<500[b,c]	

	3128[e]	17,501[e]		626[e]	1422[e]
	2289[h]	5913[h]		--	--
Paraffin NS	--	--		111[c]	1047[c]
	2263[b,d]			1151[b,d]	
	3241[b,f]			600[b,f]	1233[b,f]
LAO NS	--	--		205[c]	407[c]
	930[d]	2921[d]		1065[d]	1207[d]
PAO NS	2841[b,e]			707[b,e]	
PAO FS	2275[b,e]			333[b,e]	

[a] natural sediment
[b] one data point reported
[c] reported by Commenter III.B.b.9 Public Comments PR
[d] EPA unpublished data
[e] Commenter A.a.13 NODA
[f] Commenter A.a.30 NODA
[g] Formulated Sediment
[h] Commenter A.a.29 NODA

Summary

Since the original EA for the proposed SBF guidelines, both the EPA and industry have conducted studies to evaluate thesediment toxicity of SBFs. Industry's initial attempt to examine different test organisms yielded a series of range-finder data that lead to the use of the amphipod *Leptocheirus plumulosus* as the primary test organism. Industry also examined the use of formulated sediments. Results of testing formulated sediments and estuarine organisms appeared to be more difficult than expected and industry, although continuing research on the issue, has suspended further testing with formulated sediments. Both the EPA and industry's data have led to the following assumptions on the toxicity of SBF.

_ The ranking for the SBF toxicity from least toxic to most is esters-IOs-LAOs-PAOs-paraffins.

_ Although formulated sediments appear to indicate more discriminatory power between individual base fluids, control mortality continues to be a problem with 100% formulated sediments.

_ The abbreviated acute test of 96 hours increases discriminatory power between individual SBFs, however they are not to true measure of SBF toxicity.

_ The toxicity of SBFs appear to increase with time (in comparison of a 96-hour exposure to a 10-day exposure).

5.2.2 *Chronic Toxicity*

Stress Tests on Corals

There has been considerable investigation regarding the effects of whole drilling fluids on corals, due to their sensitivity, ecological interest, and presence in the Texas Flower Garden Banks area. Respiration, excretion, mucous production, degree of polyp expansion, and clearing rates for materials deposited on the surface are all useful parameters for indicating stress.

Laboratory experiments using the corals *Montastrea* and *Diplora* showed essentially unchanged clearing rates after applications of calcium carbonate, barite, and bentonite. However, exposure to a used drilling fluid significantly decreased clearing rates, although dose quantification was not possible (Thompson & Bright, 1977). When seven coral species were studied using *in situ* exposures to used drilling fluid, *Montastrea* and *Agaricia* displayed no mortality after a 96-hour exposure to 316 ppm concentration, but 100 % mortality at the 1,000 ppm level (Thompson & Bright, 1980). Stress reaction were displayed by six species at the 316 ppm exposure level, including partial or complete polyp retraction and mucous secretion. A similar response was observed after a 96-hour exposure to 100 ppm.

Thompson, in an undated report to the USGS, exposed *Montastrea* and *Porites* to used drilling fluids from a well of 4,200 m (13,725 ft) drilling depth. The corals were buried for eight hours under the fluid and then removed to a sand flat to observe recovery. The exposure produced tissue atrophy and decay, formation of loose strands of tissue, and expulsion of zooxanthellae (zooxanthellae are algae living within coral cells in a symbiotic relationship), all indicative of severe stress. The *Montastrea* colonies were dead 15 hours after removal, and the *Porites* colonies were dead after 10 days.

The effects of thin layer application to these species were also observed. *In situ* exposures of drilling mud produced no apparent effects on clearing rates; however, laboratory application did demonstrate effects. Applications of 10-mm thick carbonate sand or drilling fluid from a depth of either 4,200 m (13,800 ft) or 1,650 m (5,413 ft) were applied to the corals, with the following results:

- Colonies in the sand experiment cleared themselves in 4 hours
- Colonies in the 1,650-m fluid experiment cleared themselves in 2 hours
- Colonies in the 4,200-m fluid experiment were 20% (*Montastrea*) and 40% (*Porites*) cleared after 4 hours, 20% (*Montastrea*) and 100% (*Porites*) cleared after 26 hours.

Additional testing with *Porites* indicated that the 4,200-m fluid was more toxic than the 1,650-m fluid, probably because the use of additives increases with well depth. No data are available on actual drilling fluid composition, however.

Krone and Biggs (1980) exposed coral (*Madracis decactis*) to suspensions of 100-ppm drilling mud from Mobile Bay, Alabama, which had been spiked with 0, 3, and 10 ppm ferrochrome lignosulfonate (FCLS). The drilling mud was presumably one with a low (<1 ppm) FCLS concentration. The corals were exposed for 17 days, at which time they were placed in uncontaminated seawater and allowed to recover for 48 hours. All of the corals exposed to the FCLS-spiked mud exhibited short-term increases in oxygen consumption and ammonia excretion. Photographic documentation of the corals revealed a progressive development of the following conditions: 1) a reduction in the number of polyps expanded indicating little or no active feeding; 2) extrusion of zooxanthellae; 3) bacterial infections with subsequent algal overgrowth; and 4) large-scale polyp mortality in two of the colonies. Coral behavior and condition improved dramatically during the recovery period. Polyps of surviving corals reexpanded and fed actively on day two of the recovery period.

Dodge (1982) evaluated the effects of drilling fluid exposure on the skeletal extension of reef-building corals (*Montastrea annularis*). Corals were exposed to 0, 1, 10, or 100 ppm drilling fluid ("Jay" fluid) for 48 days in a flow-through bioassay procedure. The drilling mud composition was changed approximately weekly as new mud taken from the well was added. One significant change in mud composition was in the diesel oil content, which was 0.4% by weight from the fourth week to the end of the experiment. Corals exposed to 100 ppm had significantly depressed linear growth rates and increased mortality. Calcification rates of corals exposed to 100 ppm decreased by 53% after four weeks and by 84% after six weeks. There was no indication of lowered growth rates for either the 1- or 10-ppm exposure.

Hudson and Robbin (1980) exposed corals (*Montastrea annularis*) to unused drilling fluid in heavy doses of 2- 4-mm layers applied four times at 150-minute intervals. Drilling mud particles were generally removed by a combination of wave action, tentacle cleansing action, and mucous secretions. At the end of the exposure period, corals were placed in protected waters for six months. At the end of another six months, the corals were removed and examined for growth characteristics. Results of the growth analysis indicated that heavy concentrations of drilling mud applied directly to the coral surface over a period of only 7½ hours reduced growth rates and suppressed variability. Trace element analyses of the corals indicated that neither barium nor chromium incorporated into the skeletal materials.

Experiments with the coral *Acropora cervicornis* revealed reduced calcification rates after exposure to concentrations as low as 25 ppm of used Mobile Bay drilling mud (Kendall et al., 1983). Calcification rates in growing tips were reduced to 88%, 83%, and 62% of control values after 24-hour exposures to 25, 50, and 100 ppm (v/v) drilling mud, respectively. Effects on soluble tissue protein and ninhydrin positive substance were also noted at these or higher levels. Further experiments with kaolin, designed to reproduce the turbidity levels of the drilling mud without its chemical effects, revealed slight metabolic changes to the corals that were much less pronounced than those observed for the drilling mud treatments.

5.2.3 *Long Term Sublethal Effects*

Crawford and Gates (1981) examined the effect of a Mobile Bay drilling mud (mud XVI) on the fertilization and development of the sand dollar *Echinarachnius parma*. Fertilization studies showed that sperm were highly refractive to the toxic action of this drilling mud. Exposure even at 10,000 mg solids/ml (a 26-fold dispersion of the whole mud) reduced fertilization by only 7 %. Eggs were more sensitive; exposure to 1,000 mg/ml (262-fold dilution of the whole fluid) reduced fertilization from 88-90 % to 4-6 %. No effect was noted at 100 mg/ml (2,620-fold whole mud dilution). At this same exposure level (100 mg solids/ml), no effects were observed in development. At 1,000 to 10,000 mg solids/ml, development was delayed.

No effect concentration at 50 % (EC50)/LC50 ratio could be determined from these data. However, the apparent lower limit of 1,000 ppm drilling mud as the lowest level that results in statistically significant sublethal reproductive changes is consistent with other data. For example, killifish (*Fundulus heteroclitus*) embryos were exposed to a seawater-lignosulfonatemud (Neff et al., 1980). Several parameters were examined, including percentage hatch, percentage increased time to hatch, percentage decreased heart rate, and anomalies at day 16. Although no EC50/LC50 ratios could be calculated, data were available to plot and obtain EC01 values. These ranged from 1,000 to 6,000 ppm. For the shrimp *Palaemonetes pugio*, exposure to 1,000 to 10,000 ppm of a high-density lignosulfonate mud did not alter the duration of any larval instar (Neff et al., 1980).

The effects of 6-week exposures to the aqueous phases of both medium- and high-density lignosulfonate muds on the condition index (dry meat weight/shell weight) of oyster spat (*Crassostrea gigas*) have been reported (Neff et al., 1980). For the medium-density mud (12.6 lb/gal), no effect was noted at 5,000 ppm or 10,000 ppm whole mud equivalents. The index was reduced about 20 percent at 20,000 ppm. For the high-density mud (17.4 lb/gal), approximately a 30 % reduction occurred in the index at all concentrations tested.

Mussels (*Mytilus* sp.) were exposed to 50 ppm TSS for 30 days by Gerber et al. (1980). Growth was 75 % of that observed in control animals. It is not known, however, whether this represents a process of reversible growth retardation or irreversible growth inhibition.

Juvenile mysids were exposed to 15,000-75,000 ppm of the aqueous phase of a lignosulfonate mud for 7 days by Carr et al. (1980). On a dry-weight basis, no effect on respiration occurred. This contrasts with the increased respiration seen in shrimp exposed to 35,000 ppm of the same mud's aqueous phase and suggests that compensatory adaptation had occurred. Average dry weights were significantly lower in exposed shrimp.

When polychaetes (*Nereis* sp.) were exposed to 100,000 ppm of the aqueous phase of a lignosulfonate mud for 4 days, glucose-6-phosphate dehydrogenase activity was significantly decreased (Gerber et al., 1980). Activity recovered, however, during a 4-day depuration period.

Histologic alterations were noted following exposure of grass shrimp to 100 ppm or 500 ppm barite for 30 days (Conklin et al., 1980). Mortalities in two replicates of the experiment were 20 % for control shrimp and 60 % for exposed shrimp (no concentrations of barite given). In 40 % of the surviving shrimp, there were no histologic changes. In the remainder of surviving shrimp, a variety of changes were noted, including: absence of posterior midgut epithelia (20 % of the survivors); degenerative changes in microvilli; dilated and hypertrophied rough endoplasmic reticulum; and both nuclear and Golgi changes. Barite was also observed in statocysts. Although controls were provided with a sand substrate, exposed shrimp were not. Thus, it remains unclear whether such changes would occur in a sediment-barite mixture. Also, because of concerns over settling of barite particles, no dose-response relationship could be identified or constructed from the data.

Lobsters were exposed to a Jay field fluid (an onshore operation) for 36 days in a flow-through system by Atema et al. (1982). The exposure was nominal at 10 mg/l. However, settling of solids was noted and the actual exposure was undefined. The number of dead or damaged lobsters was not significantly different from controls. The number of dead plus damaged lobsters was significantly higher among treated animals. Although molts from larval stage IV to V were unaffected, molts from stage V to VI were delayed in exposed animals. Exposed lobsters also exhibited poor coordination and food alert suppression.

Three studies in a GOM laboratory examined the effects of drilling muds or drilling mud components oncommunity recruitment and development of benthic macrofauna (Tagatz et al., 1980; Tagatz and Tobia, 1978) andmeiofauna (Cantelmo et al., 1979). Test substances were mixed at various ratios with sediment or were applied asa covering layer over sediment in a flow-through system.

The tests conducted with drilling mud indicated that annelids were the most sensitive group, exhibiting significant reductions in abundance at 1:10 and 1:5 mixtures of mud and sediment, as well as when exposed to a covering of drilling mud (Tagatz et al., 1980). This sensitivity of annelids was also observed for a similar experiment conducted with barite as the toxicant. Coelenterate abundance was also significantly reduced by exposure to the 1:5 mixture of mud and sediment and the drilling mud covering. Arthropods were affected only by a drilling mud covering. Mollusks were not significantly affected by exposure to drilling mud but were reduced in abundance when exposed to barite covering (Tagatz & Tobia, 1978). Annelid abundance was also reduced by exposure to barite covering (Tagatz & Tobia, 1978), but no other groups were significantly affected. Exposure to barite as a mixture in sediment significantly increased the abundance of nematodes and increased total meiofaunal density, whereas barite layering slightly reduced total meiofauna density and densities of nematodes and copepods. The reduction was not statistically significant (Cantelmo et al., 1979).

Certain difficulties arise in the interpretation of these data. First, results for total abundance are apparently skewed by the greater sensitivity of a certain few predominant species. This does not affect the significance of the results within the constraints of this experiment, but may reduce the applicability of these results to areas *in situ* where community structure is not similar to those observed in this experiment. Second, any attempt to relate these studies to effects *in situ* is confounded by the absence of sediment barium levels given for these studies. Barium is the only useful tracer of drilling mud dispersion in the sediment.

5.2.4 *Metals*

The potential accumulation of metals in biota represents an issue of concern in the assessment of oil and gas impacts. Sublethal effects resulting from bioaccumulation of these highly persistent compounds are most often measured. Gross metal contamination from drilling fluids may also cause mortality, particularly in benthic species. Sources of metals include drilling fluids, produced waters, sacrificial anodes, and contamination from other minor sources. Drilling fluids and produced waters are the primary sources of the metals of concern: arsenic, barium, chromium, cadmium, copper, mercury, nickel, lead, vanadium, silver, and zinc.

Field studies of metal concentration in sediments around platforms suggest that enrichment of certain metals may occur in surface sediments around platforms (Tillery and Thomas, 1980; Mariani et al., 1980; Crippen et al., 1980; and others). In the review of these studies conducted by Petrazzuolo (1983), enrichment of metals around platforms is generally distance dependent with maximum enrichment factors seldom exceeding ten. In platforms studied, enrichment of metals that could be attributed to drilling activities was either generally distributed to 300-500 m around the platform or distributed down-current in a plume to a larger distance from the structure.

The concentrations of metals required to produce physiological or behavioral changes in organisms vary widely and are determined by factors such as the physicochemical characteristics of the water and sediments, the bioavailability of the metal, the organism's size, physiological characteristics, and feeding adaptations. Metals are accumulated at different rates and to different concentrations depending on the tissue or organ involved. Laboratory studies on metal accumulation as a result of exposure to drilling muds have been conducted by Tornberg et al. (1980), Brannon and Rao (1979), Page et al. (1980), McCulloch et al. (1980), Liss et al. (1980), and others. Data from these laboratory studies are summarized in Appendix B. Maximum enrichment factors for the metals measured were generally low (<10) with the exception of barium and chromium, which had enrichment factors of up to 300 and 36, respectively.

Depuration studies conducted by Brannon and Rao (1979), McCulloch et al. (1980), and Liss et al. (1980) have shown that organisms tested have the ability to depurate some metals when removed from a zone of contamination. In various tests, animals were exposed to drilling fluids from 4-28 days, followed by a 1-14 day depuration period. Uptake and depuration of barium, chromium, lead, and strontium were monitored and showed a 40-90% decrease in excess metal in tissues following the depuration period. Longer exposure generally meant a slower rate of loss of the metal. In addition, if uptake was through food organisms rather than a solute, release of the excess metal was slowed.

The available laboratory data on metals accumulation are difficult to correlate with field exposure and accumulation. Petrazzuolo's review (1983) notes that in the field, bioaccumulation of metals in the benthos will result from exposure to the particulate components of drilling muds. However, laboratory studies have almost always used either whole fluids or mud aqueous fractions, and thus are either over- or underestimating potential accumulation.

Field studies of metal accumulation in marine food webs off southern California have been conducted by Schafer et al. (1982) and others. These data have indicated that most metals measured (including Chromium, Copper, Cadmium, Silver, and Zinc) do not increase with trophic level either in open water or in contaminated regions such as coastal sewage outfalls.

5.3 Bioaccumulation Potential of Synthetic-Based Drilling Fluids

One factor considered in assessing the potential environmental impacts of discharged drilling fluids and drill cuttings is their potential for bioaccumulation. This section presents information concerning the bioaccumulation of oleaginous-base fluids, including the synthetic-base fluids and mineral oil.

Most of the available information has been developed by mud suppliers to provide information to government regulators to assess the acceptability of these materials for discharge into the marine environment. The available information on the bioaccumulation potential of synthetic base fluids is scant, comprising only a few studies on octanol:water partition coefficients (P_{ow}) and three on tissue uptake in experimental exposures. The P_{ow} represents the ratio of a material that dissolves or disperses in octanol (the oil phase) versus water. The P_{ow} generally increases as a molecule becomes less polar (more hydrocarbon-like). The EPA reviewed the available information on the bioaccumulation potential of synthetic-base fluids (USEPA, 2000). The review covers four types of synthetics: an ester (two studies), internal olefins (IO; four studies), and poly alpha olefins (PAO; five studies).

One study included a low toxicity mineral oil (LTMO) for comparative purposes. The types of synthetic-base fluids tested represent the more common of synthetic-base fluid types currently in use in drilling operations.

The data that the EPA identified concerning the bioaccumulation potential of synthetic base fluids are summarized in Table 5-8. Nine reports provided original information. This information consisted of P_{ow} data (based on calculated or experimental data), dispersibility data, or subchronic exposure of test organisms to yield data for calculating BCFs or assessing uptake. log P_{ow} values less than three or greater than seven would indicate that a test material is not likely to bioaccumulate (Zevallos et al., 1996).

For PAOs, the log P_{ow}s reported were >10, 11.19, 11.9, 14.9, 15.4, and 15.7 in the five studies reviewed. The four studies of IOs that were reviewed reported log P_{ow}s of 8.57 (8.6) and >9. The ester was reported to have a log P_{ow} of 1.69 in the two reports in which it was presented. The LAO log P_{ow} was cited as 7.82 and a log P_{ow} of 15.4 was reported for an LTMO. The only BCF reported was calculated for

Table 5-8. Bioaccumulation Data for Synthetic Fluids and Mineral Oil Muds

Type of Synthetic Base Fluid or LTMO	Parameter Determined	Reference
PAO	log Pow: 15.4 (calculated)	Friedheim et al., 1991
PAO	log Pow: >10 (calculated)	Leutermann, 1991
PAO	log P_{ow}: 14.9 - 15.7 (measured)	Schaanning, 1995
PAO	log P_{ow}: 11.9 (measured)	Zevallos et al., 1996
PAO	log P_{ow}: 11.19	Moran, 2000
IO	log P_{ow}: > 9	Environment & Resource Technology, Ltd., 1994a
IO	log P_{ow}: 8.57	Zevallos et al., 1996; Moran, 2000
LAO	log P_{ow}: 7.82	Moran, 2000
Ester	log P_{ow}: 1.69	Growcock et al., 1994; Moran, 2000
LTMO	log P_{ow}: 15.4	Growcock et al., 1994
Various	dispersibility: ranking = ester> di-ether >> detergent alkylate > PAO > LTMO	Growcock et al., 1994
IO	10-day uptake; 20-day depuration exposure gave log BCF: 5.37 (C16 forms); 5.38 (C18 forms)	Environment & Resource Technology, Ltd., 1994b; Moran, 2000
PAO	Uptake: no measured uptake in tissues after 30-day exposure; presence noted in 1 of 24 gut samples	Rushing et al., 1991; Moran, 2000
LTMO	Uptake: after 30-day exposure, detectable amounts in 50% of tissues analyzed (12 of 24) and 19 of 24 gut samples examined	Rushing et al., 1991
PAO	Subchronic effects: equal or better growth vs controls	Jones et al., 1991
LTMO	Subchronic effects: retarded growth vs controls	Jones et al., 1991

Type of Synthetic Base Fluid or LTMO	Parameter Determined	Reference
LAO	Mytilus edulis log BCF: 4.84	Moran, 2000

Abbreviations: PAO: poly alpha olefin; IO: internal olefin; LAO: linear alpha olefin; LTMO: low toxicity mineral oil

IOs; a value of 5.4 l/kg was determined. In 30-day exposures of mud minnows (*Fundulus grandis*) to water equilibrated with a PAO- or LTMO-coated cuttings, only the LTMO was reported to produce adverse effects and tissue uptake/occurrence. Growth retardation was observed for the LTMO and LTMO was observed at detectable levels in 50% of the muscle tissue samples examined (12 of 24) and most (19 of 24) of the gut samples examined. The PAO was not found at detectable levels in any of the muscle tissue samples and occurred in only one of twenty-four gut samples examined.

These limited data suggest that synthetic base fluids do not pose a serious bioaccumulation potential. Despite this general conclusion, existing data cannot be considered sufficiently extensive to be conclusive. This caution is specifically appropriate given the wide variety of chemical characteristics resulting from marketing different formulations of synthetic fluids (i.e., carbon chain length or degree of unsaturation within a fluid type, or mixtures of different fluid types).

6. BIOLOGICAL OVERVIEW

This chapter describes the biological communities and processes in the eastern Gulf of Mexico which may be exposed to pollutants, the presence of endangered species, any unique species or communities of species, and the importance of the receiving water to the surrounding biological communities. The species identified as threatened or endangered by the US Fish and Wildlife Service (USFWS) and National Marine Fisheries Service (NMFS) are characterized in the last section of this chapter for compliance with Section 7 of the Endangered Species Act.

6.1 Primary Productivity

Primary productivity is "the rate at which radiant energy is stored by photosynthetic and chemosynthetic activity of producer organisms in the form of organic substances which can be used as food materials" (Odum, 1971). Primary productivity is affected by light, nutrients, and zooplankton grazing, as well as other interacting forces such as currents, diffusion, and upwelling.

The producer organisms in the marine environment consist primarily of phytoplankton and benthic macrophytes. Since benthic macrophytes are depth/light limited, primary productivity in the open ocean is attributable primarily to phytoplankton. The productivity of nearshore waters can be attributed to benthic macrophytes--including seagrasses, mangroves, salt marsh grasses, and seaweeds--and phytoplankton.

There are numerous methods for estimating primary productivity in marine waters. One method is to measure chlorophyll content per volume of seawater and compare results over time to establish a productivity rate. The chlorophyll measurement, typically of chlorophyll a, gives a direct reading of total plant biomass. Chlorophyll a is generally used because it is considered the "active" pigment in carbon fixation (Steidinger and Williams, 1970). Another method, the C^{14} (radiocarbon) method, measures photosynthesis (a controversy exists as to whether "net", "gross", or "intermediate" photosynthesis is measured by this method; Kennish, 1989). The C^{14} method introduces radiolabeled carbon into a sample and estimates the rate of carbon fixation by measuring the sample's radioactivity.

The units used to express primary productivity are grams of carbon produced in a column of water intersecting one square meter of sea surface per day (g $C/m^2/d$), or grams of carbon produced in a given cubic meter per day (g $C/m^3/d$).

C^{14} uptake throughout the Gulf is 0.25 g C/m^3/hr or less, and chlorophyll measurements range from 0.05 to 0.30 mg/m^3 (ppb). Eastern regions of the GOM are generally less productive than western regions, and throughout the eastern Gulf, primary productivity is generally low. However, outbreaks of "red-tide" caused by pathogenic phytoplankton may occur in the mid- to inner-shelf. Also, depth- integrated productivity values in the area of the Loop Current (primarily the outer shelf and slope) are actually higher than western and central Gulf values. Enhanced productivity occurs in areas affected by upwelling. Near the bottom of the euphotic zone, chlorophyll and productivity values are about an order of magnitude greater, probably due to the often intruded, nutrient-rich Loop undercurrent waters (MMS, 1990).

Productivity measurements in the oceanic waters of the Gulf of Mexico include:

- 0.1 g $C/m^2/d$ yielding 17 g $C/m^2/yr$ or 86 million tons of phytoplankton biomass (MMS, 1983)
- 103-250 g $C/m^2/yr$ (Flint & Kamykowski, 1984)
- 103 g $C/m^2/yr$ (Flint & Rabalais, 1981).

Biomass (chlorophyll a) measurements in the predominantly oceanic waters of the Gulf of Mexico include:

- 0.05-0.30 mg Chl a/m^3 (MMS, 1983a)
- 0.05-0.1 mg Chl a/m^3 (Yentsch, 1982)
- 0.22 mg Chl a/m^3 (El-Sayed, 1972)
- 0.17 mg Chl a/m^3 (Trees & El-Sayed, 1986).

For comparisons, the following data on primary productivity are presented for coastal wetland systems as compiled by Thayer and Ustach (1981):

· Salt Marshes	200-2000 g $C/m^2/yr$
· Mangroves	400 g $C/m^2/yr$
· Seagrasses	100-900 g $C/m^2/yr$
· *Spartina alterniflora*	1300 g $C/m^2/yr$
· *Thalassia*	580-900 g $C/m^2/yr$
· Phytoplankton	350 g $C/m^2/yr$

For the eastern Gulf of Mexico, biomass (chlorophyll a) measurements include the following (Yoder and Mahood, 1983):

- Surface mixed layer values of 0.1 mg/m^3
- Subsurface measurements at 40-60 m ranged from 0.2 - 1.2 mg/m^3
- Average integrated values for the water column over the 100-200 m isobath was 10 mg/m^2
- Average integrated values for the water column greater than 200 m isobath was 9 mg/m^2.

6.2. Phytoplankton

6.2.1 *Distribution*

Phytoplankton distribution and abundance in the GOM is difficult to measure. Shipboard or station measurements cannot provide information about large areas at one moment in time, and satelliteimagery cannot provide definitive information about local conditions that may be important. Due to fluctuations in light and nutrient availability and the immobility of phytoplankton, distribution is temporally and spatially variable. Seasonal fluctuations in location and abundance are often masked bypatchy distributions which human sampling designs must attempt to interpret. In addition, methods for measurement of chlorophyll or uptake of carbon cannot always resolve all questions concerning variability among or within species under different conditions or concerning the effects of grazing on abundance.

As mentioned in the previous section, phytoplankton occupy a niche at the base of food chain as primary producers of our oceans. Herbivorous zooplankton populations require phytoplankton for maintenance and growth -- generally 30-50% of their weight each day and surpassing 300% of their weight in exceptional cases (Kennish, 1989). In the GOM, phytoplankton are also often closely associatedwith bottom organisms, and may also contribute to benthic food sources for demersal feeding fish.

Phytoplankton seasonality has been explained in terms of salinity, depth of light penetration, and nutrient availability. Generally, diversity decreases with decreased salinity and biomass decreases with distance from shore (MMS, 1990).

6.2.2 *Principal Taxa*

The principal taxa of planktonic producers in the ocean are diatoms, dinoflagellates, coccolithophores, silicoflagellates and blue-green algae (Kennish, 1989).

Diatoms. Many specialists regard diatoms as the most important phytoplankton group, contributing substantially to oceanic productivity. Diatoms consist of single cells or cell chains and secrete an external rigid silicate skeleton called a frustule.

In 1969, Saunders and Glenn reported the following for diatom samples collected 5.6 -77.8 km from shore in the GOM between St. Petersburg and Ft. Myers, Florida. Diatoms averaged 1.4 x $10^7 \mu^2$/l surface area offshore, 13.6 x $10^7 \mu^2$/l at intermediate locations and 13.0 x $10^8 \mu^2$/l inshore. The tenmost important species in terms of their cellular surface area were: *Rhizosolenia alata, R. setigera, R. stolterfothii, Skeletonema costatum, Leptocylindrus danicus, Rhizosolenia fragilissima, Hemidiscus hardmanianus, Guinardia flaccida, Bellerochea malleus,* and *Cerataulina pelagica*.

Dinoflagellates. Dinoflagellates are typically unicellular, biflagellated autotrophic forms that also supply a major portion of the primary production in many regions. Some species generate toxins and when blooms reach high densities, mass mortality of fish, shellfish, and other organisms can occur (Kennish, 1989). Notably, *Gymnodinium breve* is responsible for most of Florida's red tides and several of the *Gonyaulax* species are known to cause massive blooms (Steidinger and Williams, 1970). Table 6-1 lists species and varieties of dinoflagellates found to be abundant during the Hourglass Cruises (a systematic sampling program in the eastern Gulf of Mexico.)

Coccolithophores. Coccolithophores are unicellular, biflagellated algae named for their characteristic calcareous plate, the coccolith, which is embedded in a gelatinous sheath that surrounds the cell.

Phytoplankton of offshore Gulf of Mexico are reported to be dominated by coccolithophores (Iverson and Hopkins, 1981).

Silicoflagellates. Silicoflagellates are unicellular flagellated (single or biflagellated) organisms that secrete an internal skeleton composed of siliceous spicules (Kennish, 1989). Perhaps because of their small size (usually less than 30 µm in diameter) little specific information relative to Gulf of Mexico distribution and abundance, is available for this group.

Blue Green Algae. Blue green algae are prokaryotic organisms that have chitinous walls and often contain a pigment called phycocyanin that gives the algae their blue green appearance (Kennish, 1989). On the west Florida shelf, inshore blooms of the blue green algae *Oscillatoria erethraea* sometimes occur in spring or fall.

6.3 Zooplankton

Like phytoplankton, zooplankton are seasonal and patchy in their distribution and abundance. Zooplankton standing stocks have been associated with the depth of maximum primary productivity and the thermocline (Ortner et al., 1984). Zooplankton feed on phytoplankton and other zooplankton and are important intermediaries in the food chain as prey for each other and larger fish.

As in many marine ecosystems, zooplankton fecal pellets contribute significantly to the detrital pool. The ease of mixing in Gulf coastal waters may make them extremely important to nutrient circulation and primary productivity, as well as benthic food stocks. Also contributing to the detrital pool is the concentration of zooplankton in bottom waters, coupled with phytoplankton in the nepheloid layer during times of greater water stratification.

Copepods are the dominant zooplankton group found in all Gulf waters. They can account for as much as 70% by number of all forms of zooplankton found (NOAA, 1975). In shallow waters, peaks occur in the summer and fall (NOAA, 1975), or in spring and summer, (MMS, 1983a). When salinities are low, estuarine species such as *Acartia tonsa* become abundant.

The following information on zooplankton distribution and abundance in the eastern Gulf of Mexico is summarized from Iverson and Hopkins (1981).

- During Bureau of Land Management-sponsored studies, small copepods predominated in net catches over the shelf regions of the eastern and western GOM.

- During Department of Energy-sponsored studies at sights located over the continental slope of Mobile and Tampa Bays, small calanoids such as *Parcalanus*, and *Clausocalanus* and cyclopoids such as *Farralanula, Oncaea*, and *Oithona* predominated at the 0-200 m depths; and larger copepods such as *Eucalanus, Rhincalnus,* and *Pleuromamma* dominated at 1,000 m depths. Euphausiids were also more conspicuous. Night-time samples taken near Tampa showed larger crustaceans such as Lucifer and Euphasia. Biomass data for the same site revealed a decrease in zooplankton with increasing depth. The mean cumulated biomass value for the upper 1,000 m was 21.9 ml/m^2.

Table 6-1. Significant Dinoflagellate Species of the Eastern Gulf of Mexico

Species	Biomass Value (μ^3)
Amphisolenia bidentata	67,039 - 95,406
Ceratium carriense	637,219 - 1,115,367
C. carriense var. *volans*	622,206 - 1,196,643
C. contortum var. *karstenii*	943,121 - 1,655,573
C. extensum	189,709 - 323,546
C. furca	23,157 - 43,369
C. fusus	34,463 - 154,722
C. hexacanthum	687,593 - 1,384,016
Ceratium hircus	211,709
C. inflatum	145,897 - 221,276
C. massiliense	543,762 - 1,002,222
C. trichoceros	104,110 - 357,437
C. tripos var. *atlanticum*	518,659 - 964,436
Dinophysis caudata var. *pedunculata*	92,153 - 231,405
Gonyaulax splendens	51,651
Prorocentrum crassipes	329,540
P. gracile	25,773
P. micans	65,412

Source: Steidinger & Williams, 1970.

- Studies funded by the National Science Foundation in the east-central Gulf found diurnal patterns of distribution in the upper 1,000 m--with increases in the 50-m range at night and in the 300-600-m zone during the day--most likely attributable to vertical migration. In the upper 200 m, in addition to copepods, group such as chaetognaths, tunicates, hydromedusae, and euphausiids were significant contributors to the biomass.

Icthyoplankton studies for the eastern Gulf conducted during 1971-1974 found fish eggs to be more abundant in the northern half and fish larvae to be more abundant in the southern half of the eastern Gulf. Mean abundances were 5,454 eggs/m^2 and 3,805 larvae/m^2 in the northern Gulf and 4,634 eggs/m^2 and 4,869 larvae/m^2 in the southern Gulf. Eggs were more abundant in waters less than 450 meters deep, whereas larvae were more abundant in-depth zones greater than 50 m (Houde and Chitty, 1976).

6.4 Habitats

6.4.1 *Seagrasses*

Seagrasses are vascular plants that serve a variety of ecologically important functions. As primary producers, seagrasses are a direct food source and also contribute nutrients to the water column. Seagrass communities serve as a nursery habitat for juvenile fish and invertebrates and seagrass blades provide substrate for epiphytes. Species such as *Thalassia testudinum* have an extensive root system that stabilize substrate, and broad ribbon-like blades that increase sedimentation. Seagrasses mainly occur in shallow, clear, highly saline waters. Seagrass beds do not occur in the proposed activity area (MMS, 2000).

Approximately 1.25 million acres of seagrass beds are estimated to exist in exposed, shallow, coastal/nearshore waters and embayments of the GOM**.** About 3% of these beds are in Mississippi. Florida with Florida Bay and coastal Florida accounting for more than 80%. True seagrassesthat occur in the GOM are shoal grass, paddle grass, star grass, manatee grass, and turtle grass. Although not considered a true seagrass because it has hydroanemophilous pollination (floating pollen grains) and can tolerate freshwater, widgeon grass is common in the brackish waters of the Gulf. (BOEM, 2013).

6.4.2 *Offshore Habitats*

Offshore habitats include the water column and the sea floor. The eastern Gulf benthos consist primarily of low relief live-bottom areas. Live-bottom areas contain biological assemblages consisting of such sessile invertebrates as sea fans, sea whips, hydroids, anemones, ascidians, sponges, bryozoans, seagrasses, or corals living upon and attached to naturally occurring hard or rocky formation with fishes and other fauna. Live-bottom types include pinnacle-trend, low-relief, offshore seagrasses, and coral reef communities. Coral reef communities are not found within the proposed permit coverage area and are therefore not discussed in this document. Within the eastern Gulf, live-bottom communities are scattered across the west Florida shelf and at the outer edge of the Mississippi/Alabama shelf.

Deepwater Benthic Resources

Deepwater benthic habitats, as discussed here, refer to those in water depths greater than 300 meters. These include a number of unique chemosynthetic habitat and community types occur in the deep waters of the GOM. Chemosynthetic communities consist of sessile invertebrates such as clams, mussels and tube worms and motile invertebrates similar to hydrothermal vent communities discovered inthe eastern Pacific (Corliss et al., 1979). Detailed descriptions of deepwater benthic resources in the central and eastern GOM are presented in a number of recent studies and reports including CSA International, Inc. 2007, and Brooks et. al., 2014 as well as several recent BOEM Environmental Impact Statement (EIS) documents (BOEM 2012, 2013).

Chemosynthetic communities are those that use a carbon source, from fluids venting from the seafloor, other than sun driven photosynthesis to support life. Primary production of chemosynthetic bacteria can support assemblages of higher organisms via symbiosis. The existence of deep benthic chemosynthetic communities was initially discovered in the eastern Pacific Ocean (Corliss et al., 1979). Communities using bothhydrocarbon seepage and hydrogen sulfide vents were discovered during investigations in the Gulf duringthe 1980's with most occurring within the western and central Gulf (MMS 2000b).

Chemosynthetic communities are not known to be abundant within the area of the GOM under the EPA Region 4 NPDES permitting authority. At present the only known chemosynthetic community in the Eastern PlanningArea, and the first to be discovered in the GOM in 1983, was found in an area termed the Florida Escarpment at Vernon Basin 926 block about 400 km south of Apalachicola, FL (MMS 2000b). These communities are similar to deep sea hydrothermal vent communities of the eastern Pacific. The presence of hydrogen sulfide seeps on the Escarpment indicate the potential for additional chemosyntheticcommunities in this area.

The deepwater GOM consists mainly of soft mud bottoms with occasional patches of hard substrate that support non-chemosynthetic reef communities. Wherever hard substrate exists, deepwater live bottom communities, comprised of all phyletic groups of organisms found on the continental shelf and other marine environments including coral communities, can establish. Deepwater coral communities are now known to occur in many locations in the deep GOM (>300 m; 984 ft).

Investigations of 3D seismic data revealed over 16,000 hard sonar returns, most shown to be hard bottom substrate supporting nonchemosynthetic communities and/or live bottom reef communities. This data suggests that nonchemosynthetic and coral communities are much more common in the deepwater GOM than previously known (BOEM, 2013).

6.5 Fish and Shellfish Resources

Table 2-6 on pages 2-26 to 2-31 in *Final Environmental Impact Statement, National Pollutant Discharge Elimination System permitting for Eastern Gulf of Mexico Offshore Oil and Gas Extraction* (USEPA,

1998) provide a detailed list and information on fish and shellfish resources that occupy the waters of Alabama, Florida, and Mississippi.

The distribution of fish resources in the central and eastern GOM are highly dependent on a variety of factors including habitat type, chemical and physical water quality variables, biological, and climatic factors. The Gulf contains both a temperate fish fauna and a tropical fauna arrayed into inshore and offshore habitats depending on latitude. To the south of the 20°C winter isotherm, approximately middle Florida, the more tropical fish fauna occupies inshore habitats replacing the temperate fauna. To the north the tropical fauna is pushed further offshore to avoid cold winter temperature and by increased competition by temperate species able to tolerate cooler waters. In the northern Gulf where temperate species dominate inshore, a well-developed tropical fauna occurs on offshore structures, particularly reefs (Hoese & Moore, 1977). During warm weather the early life stages of the tropical fauna move further inshore around piers and jetties.

The temperate fish and invertebrate fauna of the north-central Gulf tend to be dominated by estuary dependent species such as sciaenids (i.e., croaker, red and black drum, spotted seatrout), menhaden, shrimp, oysters and crabs. These species require the transportation of early life stages into estuaries for grow out into mature adults or juveniles and migration out to shelf environments. Shellfish resources in the Gulf tend to be more estuarine dependent than finfishes. GOM shellfish habitats range frombrackish wetlands to nearshore shelf environments. Of the 15 penaeid shrimp species found in the Gulf the brown, white and pink shrimp are the most important. Adults of these species spawn in offshore marine waters and the free-swimming post larvae move into estuaries to remain through their juvenile stages. Juvenile shrimp move back offshore to molt into adults.

Reef fish assemblages may consist of mainly temperate species in the more northern Gulf with increasing dominance of more tropical fish species, typically associated with coral reefs, further offshore and in the more southern portions of the Gulf. Natural reef habitat in the eastern Gulf ranges from low relief (>1 m) live-bottom, high relief ridge habitats along the Florida shelf break and pinnacle formations of the Florida Middle Grounds on the west Florida shelf. Man-made or artificial reef habitats also exist from oil and gasplatforms, sunken vessels and a variety of other structures placed intentionally for fisheries enhancement.These structures comprise critical habitats for many important commercial and recreational fishes such asgroupers and snappers.

Pelagic fish species are distributed by water column depth and relationship to the shore. Coastal pelagics are those that move mainly around the continental shelf year-round, singly or in schools of various size (MMS 2000b). These include some commercially important groups of fishes including sharks, anchovies, herring, mackerel, tuna, mullet, bluefish and cobia. Oceanic pelagics occur at or seaward of the shelf edge throughout the Gulf. Oceanic pelagics include many larger species such as sharks, tuna, bill fishes, dolphin and wahoo.

Deepwater Fishes

Extensive discussions of deepwater fishes are available in: *Deepwater Gulf of Mexico Environmental and Socioeconomic Data Search and Literature Synthesis, Volume 1: Narrative Report* (MMS, 2000c) and in several recent BOEM EIS documents (BOEM 2012; 2013).

Deepwater Pelagic Fishes

Mesopelagic fishes are restricted mainly to the midwater (200 - 1000 m) environment in the Gulf. These are dominated by lanternfishes (myctophids) and bristlemouths (gonostomatids). The Stomiidae (dragonfishes) with 73 species is the most diverse family of fishes known for the Gulf of Mexico (Sutton & Hopkins, 1996; McEachran & Fechhelm, 1998). The second most diverse group is the myctophids represented by 49 species in the GOM (Backus et al., 1977; Gartner et al., 1987). Mesopelagic fishes make extensive vertical migrations, from 400-800 m to near or at the surface, at night to feed in theupper portions of the water column and are important in the transfer of nutrients and energy between the mesopelagic and epipelagic (upper 200 m) zone (Hopkins & Baird, 1985).

Bathypelagic fishes live a depths greater than 1000 m and seldom move up into shallower waters. This group consists of little-know species such as slickheads, gulper eels, deep-sea anglers, whalefishes and bigscales and is not well studied in the Gulf.

Deepwater Demersal Fish

Deepwater demersal fishes are species that associate with benthic structure, living on or above it, from the shelf slope transition to the abyssal plain. In the Gulf this group consists of some 300 species (MMS 2000c). Studies by Pequegnat (1983) and Galloway et al. (1988) showed that the number of demersal species and the distribution of individuals among species declined with increasing depth. Several species of snapper, grouper and tilefish are caught commercially on demersal habitat in depths of up to 500 m.

6.8 Marine Mammals

Twenty-nine species of marine mammals (listed in EPA, 1998, Table 3-4) are known to occur in or migrate through the northern Gulf of Mexico based on sightings and/or strandings (Schmidly, 1981; Davis et al., 2000). Extensive discussions can be found in the 2016 EPA EA for the EPA Oil and Gas General NPDES Permit (EPA, 2016) and in several recent BOEM EIS documents (BOEM 2012; 2013). Cetaceans (whales, dolphins, and porpoises) are the most common. Five of the seven baleen whales in the Gulf are currently listed as threatened or endangered and of the 20 toothed whales present only the sperm whale is endangered. During 1978 - 1987, a total of 1,200 cetacean strandings/sightings was reported for Alabama, Florida and Mississippi to the Southeastern U.S. Marine Strandings Network. Ninety percent of these stranding/sighting occurred off Florida coasts (the Florida figure reflects strandings from both the Gulf and the Atlantic waters; NOAA, 1991). The cetaceans foundin the Gulf include species that occur in most major oceans and, for the most part, are eurythermic, with a broad range of temperature tolerances (Schmidly 1981). An introduced species of pinniped, the California sea lion, occurred in small numbers only in the feral condition, however no sightings of this species has been reported in the Gulf since 1990. All marine mammals are protected under the Marine Mammal Protection Act of 1972.

6.10 Endangered Species

The USFWS and NMFS evaluate the conditions of species and their populations within the United States. Those species populations considered in danger of extinction are listed as endangered species per the Endangered Species Act of 1973. In addition, Section 7(a)(2) of the Endangered Species Act requires federal agencies to ensure that their action do not jeopardize the continued existence of listed species or destroy or adversely modify critical habitat. Threatened and endangered species that occur in the Gulf of Mexico are discussed extensively in the 2016 EPA EA for the EPA Oil and Gas General NPDES Permit (EPA, 2016) and in several recent BOEM EIS documents (BOEM 2012; 2013).

Table 6-2 provides an updated list of species either listed as threatened or endangered that potentially could occur in impacted areas of the central or eastern Gulf.

Table 6.2. Federally Listed Species in the Eastern Gulf of Mexico.

Species	Scientific Name	Status
Birds		
Piping plover	*Charadrius melodus*	Threatened
Wood stork	*Mycteria americana*	Endangered
Roseate tern	*Sterna dougallii*	Threatened
Interior Least turn	*Sterna antillarum athalassos*	Endangered
Whooping crane	*Grus americana*	Endangered
Mississippi Sandhill crane	*Grus canadensis*	Endangered
Everglades snail kite	*Rostrhamus sociabilis*	Endangered
Red knot	*Calidris cantunus*	Threatened
Reptiles		
American crocodile	*Crocodylus acutus*	Threatened
Loggerhead sea turtle	*Caretta caretta*	Threatened
Kemp's Ridley sea turtle	*Lepidochelys kempii*	Endangered
Green sea turtle	*Chelonia mydas*	Threatened
Hawks bill sea turtle	*Eretmochelys imbricata*	Threatened
Leatherback sea turtle	*Dermochelys coriacea*	Endangered
Marine Mammals		
West Indian manatee	*Trichechus manatus*	Endangered
Finback whale	*Balaenoptera physalus*	Endangered
Humpback whale	*Megaptera novaeangliae*	Endangered
Right whale	*Eubalaena glacialis*	Endangered
Blue whale	*Balaenoptera musculus*	Endangered
Sei whale	*Balaenoptera borealis*	Endangered
Sperm whale	*Physeter macrocephalus*	Endangered

Terrestrial Mammals		
Choctawhatchee beach mouse	*Peromyscus polionotus allophrys*	Endangered
Alabama beach mouse	*Peromyscus polionotus ammobates*	Endangered
Perdido Key beach mouse	*Peromyscus polionotus trissyllepsis*	Endangered
Key Largo cotton mouse	*Peromyscus gossypinus allapaticola*	Endangered
Florida panther	*Puma concolor coryi*	Endangered
Key Largo woodrat	*Neotoma floridana smalli*	Endangered
Lower Keys rabbit	*Sylvilagus palustris hefneri*	Endangered
Florida salt marsh vole	*Microtus pennsylvanicus dukecampbelli*	Endangered
St. Andrew beach mouse	*Peromyscus polionotus peninsularis*	Endangered
Rice rat	*Oryzomys palustris*	Endangered
Fishes		
Gulf sturgeon	*Acipenser oxyrhynchus desotoi*	Threatened
Smalltooth sawfish	*Pristis pectinata*	Endangered
Corals		
Staghorn coral	*Acropora cervicornis*	Threatened
Elkhorn coral	*Acropora palmata*	Threatened
Lobed star coral	*Orbicella faveolata*	Threatened
Boulder star coral	*Montastraea annularis*	Threatened
Mountainous star coral	*Orbicella faveolata*	Threatened
Pillar coral	*Dendrogyra cylindricus*	Threatened
Rough cactus coral	*Mycetophyllia ferox*	Threatened

Sources: USFWS 2010. Federally Listed Wildlife and Plants Threatened by Gulf Oil Spill
http://www.fws.gov/home/dhoilspill/pdfs/FedListedBirdsGulf.pdf

USFWS 2013. Gulf Restoration. **Threatened and Endangered Species on the Gulf Coast.**
http://www.fws.gov/gulfrestoration/TandEspecies.html

NOAA. 2016. Endangered and Threatened Marine Species under NMFS' Jurisdiction
http://www.nmfs.noaa.gov/pr/species/esa/listed.htm

7.0 COMMERCIAL AND RECREATIONAL FISHERIES

7.1 Overview

Though the Gulf of Mexico Region includes Alabama, Louisiana, Mississippi, Texas, and West Florida, much of the following discussion will focus on Gulf states in the eastern portion of the GOM. Federal fisheries in this region are managed by the Gulf of Mexico Fishery Management Council (GMFMC) and NOAA Fisheries (NMFS) under seven fishery management plans (FMPs): Red Drum, Shrimp, Reef Fish, Coastal Migratory Pelagic Resources (with SAFMC), Spiny Lobster (with SAFMC), Corals, and Aquaculture. The coastal migratory pelagic resources and spiny lobster fisheries are managed in conjunction with the South Atlantic Fishery Management Council (SAFMC).

The most recent change is the development of the Aquaculture FMP to establish a regional permitting process to manage the development of an environmentally sound and economically sustainable aquaculture industry in federal waters of the GOM (NMFS, 2014). The final rule was publishedin January, 2016. More information can be found at: http://sero.nmfs.noaa.gov/sustainable_fisheries/gulf_fisheries/aquaculture/.

Several of the stocks or stock complexes covered in these fishery management plans, are currently listed as overfished: gag, gray triggerfish, greater amberjack, and red snapper. Other impacts to commercial fisheries in the GOM in recent years include a number of hurricanes, especially with major storms making landfall in Louisiana and Texas in 2005 (Hurricanes Katrina and Rita) and 2008 (Hurricanes Gustav and Ike). Locally, these storms severely disrupted or destroyed the infrastructure necessary to support fishing, such as vessels, fuel and ice suppliers, and fish houses. Current information on the status of US fisheries can be found at: http://www.nmfs.noaa.gov/sfa/fisheries_eco/status_of_fisheries/.

The Deepwater Horizon MC252 oil spill in 2010 severely affected fisheries in the Gulf. Large parts of the GOM, including state and federal waters, were closed to fishing during May through October, 2010. Both Alabama and Mississippi reported less than half and Louisiana about three quarters of their annual shrimp landings compared to the average of the previous three years. The impacts of the spill remain under study and the long term consequences of the oil spill on fish stocks and the fishing industry have yet to be fully assessed.

7.2 Commercial Fisheries

National Marine Fishery Service (NMFS 2014; 2015) data show that in 2013, commercial fishermen in the Gulf of Mexico Region landed 1.4 billion pounds of finfish and shellfish, earning $937 million in landings revenue. In 2014 1.1 billion pounds were landed at a value of over $1.0 billion. From 2003 to 2013, most of the commercial fisheries revenue and catch (91% and 96% respectively) was dominated by ten key species or species groups (Table 7-1).

Table 7-1. Key Gulf of Mexico Region Commercial Species or species groups

Shellfish	Finfish
Crawfish	Groupers
Blue crab	Menhaden
Oysters	Mullets
Shrimp	Red snapper
Stone crab	Tunas

Commercially important species groups in the GOM include oceanic pelagic (epipelagic) fishes, reef (hard bottom) fishes, coastal pelagic species, and estuarine-dependent species. Landings revenue in 2012 was dominated by shrimp ($392 million) and menhaden ($87 million). These species comprised 63% of total landings revenue, and 90% of total landings in the GOM Region. Other invertebrates such as blue crab, spiny lobster, and stone crab also contributed significantly to the value of commercial landings. Other finfish species that contributed substantially to the overall commercial value of the GOM fisheries included red grouper, red snapper, and yellowfin tuna. In terms of landing weight, Atlantic menhaden far surpassed other commercial fish species in the GOM, accounting for approximately 73% ofthe total weight of landed commercial species in 2013 (Table 7-2). However, Atlantic menhaden accounted for only about 10% of the total value of the GOM commercial fishery. The portion of commercial fishery landings that occurred in nearshore and offshore waters of the GOM States is presented in Table 7-3.

TABLE 7.2. Total Weights and Values of Key Commercial Fishery Species in the GOM Region in 2013.

Species	Weight (thousands of pounds)	Value (Thousands of dollars)	% Weight	% Value
Menhaden	1,020,244	95,277	73.3	10.2
Shrimp	204,527	503,842	14.7	53.8
Blue crab	46,543	61,264	3.3	6.5
Oyster	19,230	76,729	1.4	8.2
Crayfish	19,823	16,593	1.4	1.8
Mullets	13,482	13,222	0.01	0.01
Stone crab	3,778	24,762	0.003	2.6
Groupers	7,280	23,396	0.005	2.5
Red snapper	5,286	20,493	0.004	2.2
Tuna	2,107	7352	0.002	0.008
Total	**1,392,364**	**936,660**		

Source: NMFS 2015.

TABLE 7-3 Value of Gulf Coast Fish Landings by Distance from Shore and State for 2012 ($1,000)

	Distance from shore	
State	0-3	3-200
Florida (GOM)	64,727	75,232
Alabama	15,870	27,195
Mississippi	29,767	19,509
Louisiana	232,710	95,242
Texas	63,135	130,813

Source: https://www.st.nmfs.noaa.gov/commercial-fisheries/commercial-landings/other-specialized- programs/preliminary-annual-landings-by-distance-from-shore/index

In 2013, the eastern GOM Region's seafood industry generated $527 million in sales in Alabama, $268 million in sales in Mississippi, and $15 billion in sales in Florida Table 7-4). Florida generated the largest employment, income, and value added impacts, generating 78,000 jobs, $2.9 billion, and $5.1 billion, respectively. The smallest income impacts were generated in Mississippi ($200 million) and the smallest employment impacts were also generated in Mississippi (6,432 jobs) (NMFS 2015).

Table 7-4. 2013 Economic Impacts of the Eastern Gulf of Mexico Region Seafood Industry (thousands of dollars)

	Landings Revenue	**Jobs**	**Sales**	**Income**	**Value Added**
Alabama	55,434	12,090	526,767	200,494	265,580
Mississippi	46,618	6,432	268,367	107,340	138,779
Florida	148,058	78,378	15,319,435	2,878,309	5,136,623

Source: NMFS 2015

In 2013 1.4 billion pounds of finfish and shellfish were landed in the Gulf of Mexico Region. This was a 6.7% decrease from the 1.5 billion pounds landed in 2004 and a 7.0% increase from the 1.3 billion pounds landed in 2012. Finfish landings experienced a 9.6% decrease between 2012 and 2013 while shellfish landings experienced a 1.6% decrease over the same period (Table 7-5).

Table 7-5. Total Landings and Landings of Key Species/Species Groups From 2010 to 2013 (thousands of pounds).

	2010	**2011**	**2012**	**2013**
Total landings	1,072,068	1,792,550	1,293,195	1,392,364
Finfish & other	810,649	1,472,798	987,374	1,092,148
Shellfish	261,419	319,752	305,821	300,216

Source: NMFS 2015

From 2004 to 2013, species or species groups with large changes in landings include tunas (decreasing 46%), groupers (decreasing 39%), and oysters (decreasing 23%). Species or species groups with large changes in landings between 2012 and 2013 include crawfish (increasing 66%), and red snapper (increasing 24%) (NMFS, 2015).

The DWH event had immediate effects on the GOM fishing industry between April and November 2010, with up to 40% of Federal waters being closed to commercial fishing in June and July (CRS 2010). Portions of Louisiana, Alabama, Mississippi, and Florida State waters have also been closed. These areas are some of the richest fishing grounds in the GOM for major commercial species such as shrimp, blue crab, and oysters, and as prices for these items have increased, imports of these species have likely taken the place of lost GOM coast production. NOAA continued to reopen areas to fishing once chemical tests revealed levels of hydrocarbons or dispersants in commercial species were not of concern to human health.

It cannot be determined from these data whether the decreases in fin and shell-fish landings were the result of reduced stock sizes, changes in stock geographic distribution or changes in fishing effort, however studies are currently ongoing and it is not known at this time whether there are long term affects to fisheries due to the spill.

7.3 Recreational Fishing

The NMFS (2015) estimates that in 2013, over 3.3 million recreational anglers took 25 million fishing trips in the GOM Region. The key fish species or species groups making up most of the recreational fishery in the GOM are listed in Table 7-6.

Table 7-6. Key Gulf of Mexico Region Recreational Species

• Atlantic croaker	• Gulf and southern kingfish
• Sand and silver seatrout	• Spotted seatrout
• Sheepshead porgy	• Red drum
• Red snapper	• Southern flounder
• Spanish mackerel	• Striped mullet

Source: NMFS, 2015

Of the three eastern GOM States, western Florida had the highest number of anglers and fishing trips in 2013 (15.9 million), followed by Alabama (2.8 million), and Mississippi (1.8 million) (Table 7.7). Almost 67% of the fishing trips in the GOM coast left out of west Florida, followed by Alabama (7%), and Mississippi (5%). 41.8% of the total recreational fish landings (by weight) in the GOM occurred in Florida, 12.8% 33 in Alabama, and 5.3% in Mississippi.

In Mississippi nearly all landings were made in inland waters (98.6%). While the inland catch was important in Alabama (50.0%) and Florida (44.0%), the offshore catch was larger in these States, with 34.1% of the total catch landed up to 5 km (3 mi) from shore, and 16% at more than 5 km (3 mi) in Alabama and 28.7% at less than 16 km (10 mi), and 27.3% at more than 16 km (10 mi) in Florida.

TABLE 7.7. Estimated Number of People Participating in Eastern GOM Marine Recreational Fishing in 2013 [a] (thousands).

	Coastal	Non-coastal	Out of state	Total
West Florida	1,813	NA	2,538	4,351
Alabama	279	224	549	1,050
Mississippi	171	67	101	339
GOM Total*	2,263	291	3,098	5,740

a Coastal, non-coastal, and out-of-State refer to place of residence of participants in marine
recreation in each State.
*Texas does not collect angler data.
Source: NMFS, 2015

Recreational fishing contributes to the Gulf state economies mainly through employment, expenditures (fishing trips and durable good), and sales. Table 7-8 shows the economic impacts of recreational fisheries by Gulf state. Recreational fishing activities generated over 87,000 full- and part-time jobs in Alabama, Mississippi and West Florida, and over $10.0 billion in sales.

Table 7-8. 2013 Economic Impacts of Recreational Fishing Expenditures in the Eastern GOM (thousands of dollars)

	Trips	**Jobs**	**Sales**	**Income**	**Value Added**
Alabama	2,862	10,163	927,409	358,769	569,144
Mississippi	1,761	1,583	146,333	53,602	87,684
West Florida	15,949	76,236	9,086,311	3,423,836	5,341,420

Source: NMFS, 2015

8.0 COASTAL ZONE MANAGEMENT CONSISTENCY AND SPECIAL AQUATIC SITES

This chapter addresses two of the 10 ocean discharge criteria: (5) The existence of special aquatic sites including, but not limited to marine sanctuaries and refuges, parks, national and historic monuments, national seashores, wilderness areas and coral reefs, and (8) Any applicable requirements of an approved Coastal Zone Management plan (CZMP).

8.1 Coastal Zone Management Consistency

The Coastal Zone Management Act requires that any Federally-licensed or permitted activity affecting the coastal zone of a state that has an approved CZMP be reviewed by that state for consistency with the state's program (16 USC 1456(c)(A) Subpart D). Under the Act, applicants for Federal licenses and permits must submit a certification that the proposed activity complies with the state's approved CZMP and will be conducted in a manner consistent with the CZMP. The state then has the responsibility to either concur with or object to the consistency determination under the procedures set forth by the Act and their approved plan. For NPDES program general permits, the EPA is considered the applicant and must submit the general permit and consistency determination to the affectedstates for concurrence.

Consistency certifications are required to include the following information (15 CFR § 930.58):
A detailed description of the proposed activity and its associated facilities, including maps, diagrams, and other technical data;

A brief assessment relating the probable coastal zone effects of the proposal and its associated facilities to relevant elements of the CZMP;

A brief set of findings indicating that the proposed activity, its associated facilities, and their effects are consistent with relevant provisions of the CZMP; and

Any other information required by the state.

The States of Mississippi, Alabama, and Florida have federally approved CZMPs. Each Gulf state has specific requirements in their CZM plans that outline proceduresfor determining whether the permitted activity is consistent with the provision of the program.

Discharges covered by this OCS general permit will occur in Federal waters outside the boundaries of the coastal zones of the States of Alabama, Florida, and Mississippi. However, because these discharges could occur in close proximity to state waters, creating the potential for impacts on state waters, consistency determinations for the general permit will be prepared and submitted to the States of Alabama, Florida, and Mississippi. The following summaries describe the requirements of each state's management plan for consistency determination. The permitting agency must provide the necessary data and information for the State to determine that the proposed activities comply with the enforceable policies of the States' approved program, and that such activities will be conducted in a manner consistent with the program. (See 16 U.S.C. 1456(c)(3)(A) and 15 CFR § 930.76.)

8.2 Alabama Coastal Area Management Program

Alabama's Coastal Management Plan (ADEM Admin. Code R. 335-8-x-.xx, as revised 2013) contains a Review Process for Federally Regulated Activities (335-8-1-.09):

Pursuant to 15 CFR Part 930, Subpart D, uses which are federally licensed or permitted activities affecting the coastal area are required to be conducted in a manner consistent with the management program. The Department shall review and respond to a federal license or permit applicant's consistencycertification in accordance with the provisions of 15 CFR Part 930, Subpart D.

The [Environmental Protection Agency] federal license and permit activities which are subject to review, listed pursuant to 15 CFR Part 930, Subpart D, are: Permits and licenses required under Sections 401, 402, 403, 404 and 405 of the Federal Water Pollution Control Act of 1972, as amended.

The Alabama Coastal Area Management Program requires compliance with Federal and state statutes and regulations that relate to the development and preservation of resources within the coastal area. In order to be deemed consistent with the Program, activities must comply with the relevant substantive requirements of those Federal and state statutes and any regulations adopted pursuant to these statutes to the extent applicable under the terms of those statutes or regulations.

In addition to the data and information required to be furnished to the Department with the consistency certification pursuant to 15 CFR §§ 930.58, the following data and information must be provided:

1. An informational copy of the application for the license or permit;
2. A copy of the federal agency's written determination that the license or permit application is complete;
3. A copy of the federal agency's draft or proposed license or permit if a draft or proposed license or permit is required to be prepared by federal law or regulations;
4. A copy of any transcript of any public hearing conducted by the federal agency concerning the federal license or permit application and all written comments received by the federal agency during any comment period; and,
5. A copy of any draft Environmental Assessment or draft Environmental Impact Statement required under the National Environmental Policy Act §§ 102, 42 U.S.C. §§ 4332 or implementing federal regulations.

ADEM will issue a public notice at least 15 days prior to a decision regarding an activity requiring a federal permit to solicit public comment and may hold a public hearing on the proposed activity if any person has satisfactorily demonstrated that a relevant and significant issue cannot be effectively or fully communicated to the Department in writing or a significant public interest would be served thereby.

8.3 Mississippi Coastal Program

The Mississippi Coastal Program was approved by the Associate Administrator, Office of Coastal Zone Management, under provisions of Coastal Zone Management Act on September 30, 1980 and became effective October 1, 1980. The document entitled *Mississippi Coastal Program*, prepared by the Bureau of Marine Resources of the Mississippi Department of Wildlife Conservation, was used to prepare the following understanding of the requirements of the Mississippi Coastal Zone Management Plan. The Mississippi Commission on Wildlife Conservation (MCWC) was created by legislation in 1978 to implement the Mississippi Coastal Program.

Currently, implementation of the Mississippi Coastal Program is the primary responsibility of the Office of Coastal Resources. The Mississippi Coastal Program was legislatively mandated in Section 57-15-6 of the Mississippi Code of 1972 (MS Code Section 57-15-6, 2013).

The primary authority guiding the coastal management program is the Coastal Wetlands Protection Act. The Mississippi coastal zone includes the three coastal counties, as well as all adjacent coastal waters and the barrier islands of the coast.

In addition to coastal management responsibilities, Coastal Resources Management also administers the Coastal Preserves Program, Wetlands Permitting, and other special projects.

Coastal management consistency determination requirements are determined for coastal uses and activities based on their effect on water quality, water quantity, bottom disturbances, water pollution, sedimentation (runoff), shoreline erosion, marine aquatic life, and historical and archaeological sites. Oil and gas activities regulated under NPDES (section 402) permits are subject to management by the Mississippi Coastal Program under two sets of guidelines: wetlands management and policy coordination.

The Wetlands Management Guidelines are mainly concerned with the placing of structures and pipelines. These concerns are addressed by BOEM in lease stipulations or Army Corp. of Engineers dredge permits and are not covered under the NPDES program. The one guideline that does affect the NPDES general permit is that no discharge of cuttings, drilling fluids, produced waters, sanitary wastes, and contaminated deck drainage shall be discharged into coastal waters. The general permit does not permit discharges to state waters, and therefore, is in compliance with this guideline.

The Policy Coordination Guidelines protect the wetlands, waterfront sites, seafood, natural scenic qualities, and natural interests of publicly owned lands within the state's jurisdiction. Although the general permit covers only Federal waters, the conclusions concerning potential effects demonstrate that the permit is consistent with the policy guidelines of Mississippi.

8.4 Florida Coastal Management Program

The Florida Coastal Management Program (FCMP) was approved by NOAA in 1981 and is codified at Chapter 380, Part II, F.S. The State of Florida's coastal zone includes the area encompassed by the state's 67 counties and its territorial seas. The FCMP consists of a network of 24 state statutes administered by eight state agencies and five water management districts.

Federal consistency reviews are integrated into other review processes conducted by the state depending on the type of federal action being proposed. The Florida State Clearinghouse administered by the DEP Office of Intergovernmental Programs, is the primary contact for receipt of consistency evaluations from federal agencies. The Clearinghouse coordinates the state's review of applications for federal permits other than permits issued under Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act.

The review of federal activities is coordinated with the appropriate state agency. Each agency is given an opportunity to provide comments on the merits of the proposed action, address concerns, make recommendations, and state whether the project is consistent with its statutory authorities in the FCMP. Regional planning councils and local governments also may participate in the federal consistency review process by advising the Department of Economic Opportunity (DEO) on the local and regional impact of proposed federal actions. Comments provided by regional planning councils and local governments are considered by the DEO in determining whether the proposed federal activity is consistent with specific sections of Chapter 163, Part II, F.S., that are included in the FCMP. If a state agency determines that a proposed federal activity is inconsistent, the agency must explain the reason for the objection, identify the statutes the activity conflicts with and identify any alternatives that would make the project consistent.

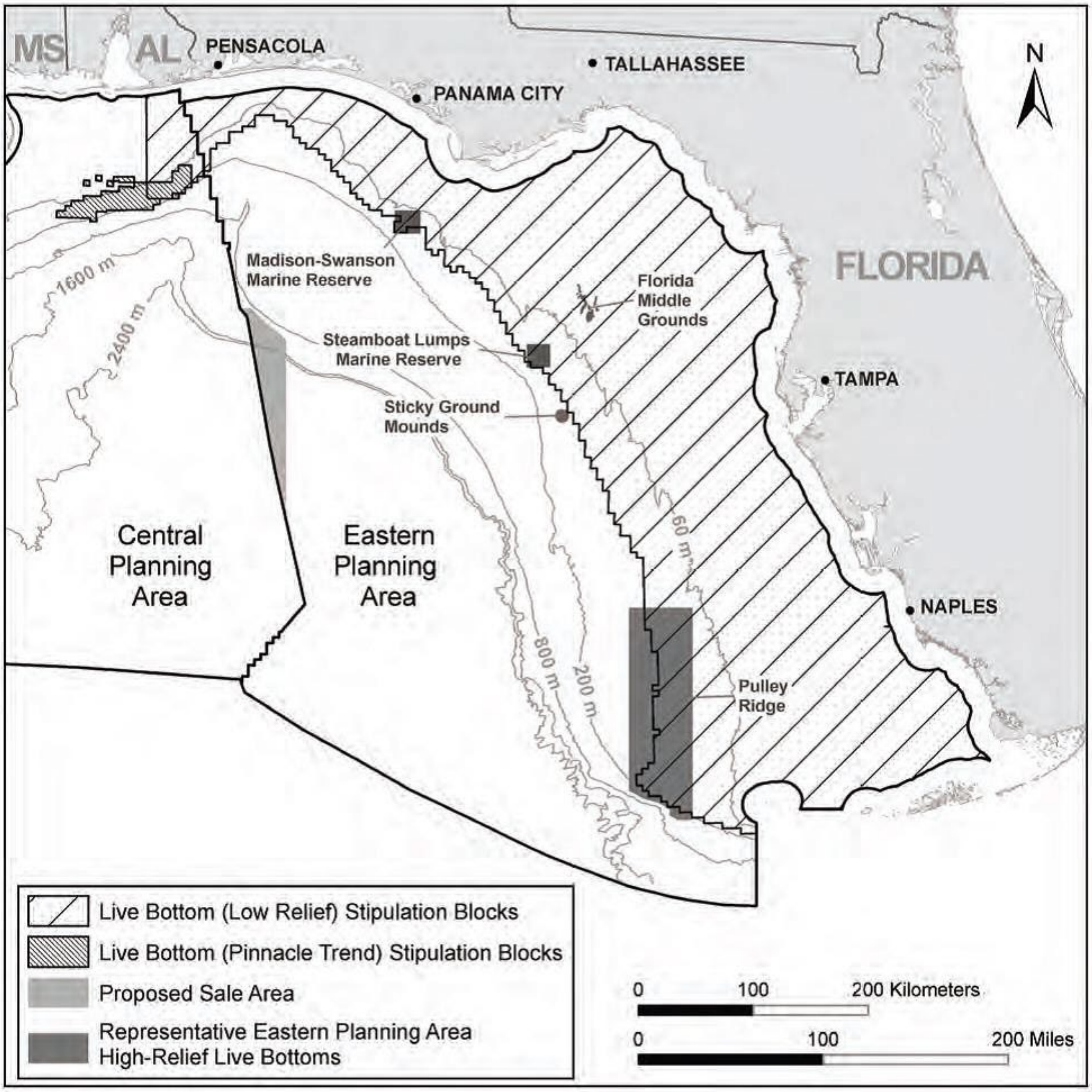
As the designated lead coastal agency for the state, the DEP communicates the agencies' comments and the state's final consistency decision to federal agencies and applicants for all actions other than permits issued under Clean Water Act Section 404 and Section 10 of the Rivers and Harbors Act.

8.5 Special Aquatic Sites

The Code of Federal Regulations, 40 CFR § 230.3 q, Defines Special aquatic sites as "geographic areas, large or small, possessing special ecological characteristics of productivity, habitat, wildlife protection, or other important and easily disrupted ecological values. These areas are generally recognized as significantly influencing or positively contributing to the general overall environmental health or vitality of the entire ecosystem of a region."

Areas of high relief outcroppings (Pinnacle Trend) occur on the outer edge of the Mississippi-Alabama shelf between the Mississippi River and De Soto Canyon (Figure 8-1). The Pinnacle Trend covers some 2,680 km^2 area in water depths of 60-200 meters. High-relief features have complex shape and structure that provide varied zones of microhabitat for attached organisms and attract large numbers of fish. Areas of high relief live bottom habitat also occur off the west Florida coast. These include the Madison-Swanson Marine Reserve, Florida Middle Grounds, Pulley Ridge, Steamboat Lumps Special Management Area, and Sticky Ground Mounds (BOEM, 2013).

Figure 8-1. High Relief Live Bottom Areas in the Central and Eastern Gulf of Mexico.



Source BOEM 2013

Various species of sessile attached reef fauna and flora grow on the exposed hard grounds. Some taller species (e.g., sea whips and other gorgonians) appear to survive this intermittent sand movement and accretion. Surveys on the southwest Florida Shelf revealed that the biotic cover on the live bottom patches is generally low and that the patches tend to be dominated by either algae or encrusting invertebrates (Woodward-Clyde Consultants and CSA, 1983).

BOEM has included a Live Bottom Stipulation in NTL No. 2009-G39 designed to protect both high and low relief live bottom areas. The Stipulation designated affected lease blocks near the Pinnacle Trends and on the West Florida Shelf out to a 100-meter depth as Live Bottom Stipulation Blocks. A lease stipulation to avoid and protect pinnacle trend features has been made a part of relevant Central Planning

Area OCS oil and gas leases since 1974. A lease stipulation to avoid and protect low relief features has been made a part of relevant OCS oil and gas leases since 1982. Both Pinnacle Trends and Low Relief Live Bottom Stipulations are intended to identify and protect these communities from bottom disturbances from activities such as platform and pipeline placement and well drilling. Requirements include preparing a live-bottom survey report containing a bathymetry map constructed from remote-sensing data and an interpretation of live-bottom area surveys that extend to at least 1,000 meters from the site of the proposed activity.

A portion of the Central Gulf of Mexico Planning Area and most of the Eastern Gulf of Mexico Planning Area is under moratoria until 2022 as part of the Gulf of Mexico Energy Security Act of 2006. The area restricted is that portion of EPA within 125 miles of Florida, all areas in the Gulf of Mexico east of the Military Mission Line (86º 41' west longitude), and the area within the CPA that is within 100 miles of Florida.

The portion of the Pinnacle Trend in the Central Planning Area under EPA Region 4 jurisdiction is shoreward of the 200 meter isobath proposed general permit coverage area. The portion of the Eastern Planning Area open to oil and gas activity are seaward of the 125 mile moratoria area that includes the high relief hardbottom features off the West Florida coast.

9. FEDERAL WATER QUALITY CRITERIA AND STATE WATER QUALITY STANDARDS

Factor 10 of the 10 ocean discharge criteria used to determine no unreasonable degradation requires the assessment of Federal marine water quality criteria and applicable state water quality standards. This chapter evaluates compliance with the Federal water quality criteria at the edge of a 100-meter mixing zone. In addition, compliance with Florida, Alabama and Mississippi water quality standards has been analyzed.

9.1 Federal Water Quality Criteria

Federal water quality criteria are established as guidelines for protection of water quality and human health. Table 9-1 presents a list of Federal water quality criteria for priority pollutants found in drilling or production discharges.

Table 9-1. Federal Water Quality Criteria

Pollutant	Marine Acute Criterion (µg/l)	Marine Chronic Criterion (µg/l)	Human Health Criterion (µg/l)
Anthracene			110,000
Antimony			640
Arsenic	69	36	0.14
Benzene			51
Benzo(a)pyrene			0.018
Cadmium	40	8.8	
Chlorobenzene			21,000
Chromium (VI)	1100	50	
Copper	4.8	3.1	
Di-n-butylphthalate			4,500
2,4-Dimethylphenol			850
Ethylbenzene			29,000
Fluorene			5,300
Lead			
Manganese			100
Mercury	210	8.1	
Nickel			
Phenol	1.8	0.94	
Selenium	74	8.2	
Silver			
Thallium	290	71	6.3
Toluene	1.9		200,000
Zinc			
	90	81	

[a] Human health criteria for consumption of organisms only; risk factor of 10^{-6} for carcinogens.
Source: EPA, 2015

9.2 Florida Water Quality Standards

Water quality standards for the surface waters of Florida are established by the Department of Environmental Regulation in the Official Compilation of Rules and Regulations of the State of Florida, Chapter 62-302 -530 Surface Water Quality Standards (effective 08/01/2013). These standards are presented in Table 9-2 for use classes applicable to the Desoto Canyon receiving water.

Table 9-2. Florida Water Quality Standards

Parameter	Shellfish Propagation of Harvesting (Class II) and Recreation, Fish and Wildlife (Class III-Marine) [a] (µg/l)
Aluminum	1,500
Antimony	4,300
Arsenic (total)	50
Benzene	71.28 annual average
Beryllium	0.13 annual average
Biological Integrity [b]	not reduced <75% of natural background
BOD	DO shall not drop below depressed limit for class
Cadmium	8.8
Chlorides	not more than 10% above natural background
Chlorine (total residual)	10
Chromium (VI)	50
Copper	3.7
Detergents	500
Dissolved Oxygen	5,000 daily average
Fluorides	5,000
Iron	300
Lead	8.5
Manganese	100 [c]
Mercury	0.025
Nickel	8.3
Oil and Grease	none visible
dissolved or emulsified--	5,000
pH	natural background ± .2 unit; 6.5 min. - 8.5 max.
Phenol	300
Phenolic Compounds	1.0
Radioactive Substances --radium	5 pCi/l
(226+228)--	15 pCi/l
gross alpha--	
Selenium	71
Silver	0.05
Thallium	6.3
Turbidity	≤29 NTU above natural background
Zinc	86

[a] Shall be applied to all state waters except within the zones of mixing.
[b] According to the Shannon-Weaver diversity index of benthic macroinvertebrates.
[c] Standard applies only to Class II water use

The antidegradation policy of the standards requires that new and existing sources be subject to the highest statutory and regulatory requirements under Sections 301(b) and 306 of the Clean WaterAct. In addition, water quality and existing uses of the receiving water shall be maintained and violations of water quality standards shall not be allowed.

Minimum criteria apply to all surface waters of the state and require that all places shall at all times be free from discharges that, alone or in combination with other substances or in combination with other components of discharges, cause any of the following conditions.

- Settleable pollutants to form putrescent deposits or otherwise create a nuisance
- Floating debris, scum, oil, or other matter in such amounts as to form nuisances
- Color, odor, taste, turbidity, or other conditions in such degree as to create a nuisance
- Acute toxicity (defined as greater than 1/3 of the 96-hour LC50)
- Concentrations of pollutants that are carcinogenic, mutagenic, or teratogenic to human beings or to significant, locally occurring wildlife or aquatic species
- Serious danger to the public health, safety, or welfare.

These general criteria of surface water apply to all surface waters except within zones of mixing. A mixing zone is defined as the surface water surrounding the area of discharge "within which an opportunity for the mixture of wastes with receiving waters has been afforded." Effluent limitations can be set where the analytical detection limit for pollutants is higher than the limitation based on computation of concentration in the receiving water.

9.3 Alabama Water Quality Standards

The Alabama Water Quality Criteria Standards are set forth by the Alabama Environmental Management Commission at Title 22, Chapter 335-6-10.

Toxic pollutant standards applicable to state waters are presented in Table 9-3. Alabama water quality standards provide instruction for calculating human health criteria based on pollutant-specific reference doses, bioconcentration factors, and cancer potency factors. These values used for the calculations are presented in Table 9-4.

Table 9-3. Alabama Toxic Pollutant Standards

Pollutant	Marine Acute Criteria (µg/l)	Marine Chronic Criteria (µg/l)	Human Health Criteria (µg/l)
Antimony			933
Arsenic	69	36	
Benzene			155
Benzo(a)pyrene			0.0675
Cadmium	40	8.8	
Chromium (VI)	1,100	50	
Copper	4.8	3.1	
2,4-Dimethylphenol			498
Di-n-butylphthalate			2,622
Ethylbenzene			6,222
Lead	210	8.1	
Mercury	2.1	0.025	0.121
Nickel	74	8.2	933
Phenol			1,000,000
Selenium	290	71	
Silver	1.9		
Thallium			133
Toluene			43,614
Zinc	90	81	

[a] Non-carcinogenic pollutant criteria calculated as:
[Human body weight (70 kg) x RfD]/[Fish consumption rate (0.030 kg/day) x BCF] x 1,000 µg/mg
RfD = Reference dose (Values presented in Table 9-4).
BCF = Bioconcentration factor (Values presented in Table 9-4).

[b] Carcinogenic pollutant criteria calculated as: [Human body weight (70 kg) x Risk level (1 x 10^{-5})]/[CPF x Fish consumption rate (0.030 kg/day) x BCF] x 1,000 µg/mg
CPF = Cancer potency factor (Values presented in Table 9-4).

Source: Alabama Department of Environmental Management, Water Division - Water Quality Program

Table 9-4. Reference Doses, BCFs, and Cancer Potency Factors Used to Calculate Alabama Toxic Pollutant Standards

Pollutant	Reference Dose (RfD) [mg/(kg-day)]	Bioconcentration Factor (BCF) (l/kg)	Cancer Potency Factor (CPF) [kg/day)/mg]
Antimony	0.0004	1.0	
Benzene		5.2	0.029
Benzo(a)pyrene		30	7.3
Beryllium		19	4.3
Chromium (VI)	0.005	16	
2,4-Dimethylphenol	0.02	93.8	
Di-n-butylphthalate	0.1	89	
Ethylbenzene	0.1	37.5	
Mercury	0.0001	5,500	
Nickel	0.02	47	
Phenol	0.3	1.4	
Thallium	0.000068	116	
Toluene	0.2	10.7	

Source: Alabama Department of Environmental Management Water Division, Water Quality Program, September 29, 2015.

9.4 Mississippi Water Quality Standards

The Mississippi Water Quality Criteria for Intrastate, Interstate, and Coastal Waters are set forth by the Mississippi Department of Environmental Quality as adopted June 28, 2012. The Mississippi water quality criteria general conditions require that the following be met in all waters of the state:

1. In open ocean waters there shall be no oxygen demanding substances added which will depress the dissolved oxygen content below 5.0 mg/1.
2. Although mixing zones are sometimes unavoidable they will not substitute waste treatment. Application of mixing zones shall be made on a case-by-case basis and shall only occur in cases involving large surface water bodies in which a long distance or large area is required for the wastewater to completely mix with the receiving water body.
3. The location of a mixing zone shall not significantly alter the designated uses of the receiving water outside its established boundary. Adequate zones of passage for the migration and free movement of fish and other aquatic biota shall be maintained. Toxicity and human health concerns within the mixing zone shall be addressed as specified in the *Environmental Protection Agency Technical Support Document* for Water Quality-Based Toxics Control (EPA-505/2-90-001, March 1991) and amendments thereof. Under no circumstances shall mixing zones overlap or cover tributaries, nursery locations, locations of threatened or endangered species, or other ecologically sensitive areas.

Minimal conditions that are applicable to all waters include the following:

Waters shall be free from substances attributable to municipal, industrial, agricultural, or other discharges that will settle to form putrescent or otherwise objectionable sludge deposits.

Waters shall be free from floating debris, oil, scum, and other floating materials attributable to municipal, industrial, agricultural, or other discharges in amounts sufficient to be unsightly or deleterious.

Waters shall be free from materials attributable to municipal, industrial, agricultural, or other discharges producing color, odor, taste, total suspended or dissolved solids, sediment, turbidity, or other conditions in such degree as to create a nuisance, render the waters injurious to public health, recreation, or to aquatic life and wildlife, or adversely affect the palatability of fish, aesthetic quality, or impair the waters for any designated use. Except as prohibited in Rule 2.1.H. above, the turbidity outside the limits of a 750-foot mixing zone shall not exceed the background turbidity at the time of discharge by more than 50 Nephelometric Turbidity Units (NTU). Exemptions to the turbidity standard may be granted under the following circumstances:

(a) in cases of emergency to protect the public health and welfare
(b) for environmental restoration projects which will result in reasonable and temporary deviations and which have been reviewed and approved by the Department of Environmental Quality.

Waters shall be free from substances attributable to municipal, industrial, agricultural, or other discharges in concentrations or combinations that are toxic or harmful to humans, animals, or aquatic life. Specific requirements for toxicity are found in Rule 2.2.F.

Municipal wastes, industrial wastes, or other wastes shall receive effective treatment or control in accordance with Section 301, 306, and 307 of the Federal Clean Water Act. A degree of treatment greater than defined in these sections may be required when necessary to protect legitimate water uses. Mississippi numerical standards are presented in Table 9-5.

Table 9-5. Mississippi Toxic Pollutant Standards

Pollutant	Marine Acute Criteria (µg/l)	Marine Chronic Criteria (µg/l)	Human Health Criteria (µg/l)
Arsenic	69	36	0.14
Cadmium	40	8.8	168
Chromium (III)			140,468
Chromium (VI)	1,100	50	1470
Copper	4.8	3.1	1,000
Lead	210	8.1	
Mercury			0.153
Nickel	75	8.3	4,600
Phenol	300	58	860,000
Selenium	290	71	4200
Silver	1.9		
Zinc	90	81	26,000

Source: State of Mississippi Water Quality Criteria for Intrastate, Interstate, and Coastal Waters, Adopted June 28, 2012. Mississippi Department of Environmental Quality.

9.5 Compliance with Federal Water Quality Criteria

9.5.1 *Water Based Drilling Fluids Discharges*

Federal water quality criteria are compared to effluent concentrations projected for the edge of a 100-m mixing zone to determine the ability of drilling fluid discharges to achieve sufficient mixing and occur at concentrations below criteria in the surrounding waters. Table 9-6 presents the results of calculating the minimum number of dilutions that will ensure that all criteria are met by drilling fluid discharges at 100 meters from the discharge point. The minimum number of dilutions to achieve sufficient mixing for drilling fluids is projected to be 118 (the number of dilutions required to meet the arsenic human health criterion). Compared to drilling fluids modeling results presented in Chapter 4, there appears to be significant probability that the criteria can be met by the edge of a 100-m mixing zone.

For comparison, the preferred option of the MMS EIS for this development and production project specifies a maximum 400 bbl/hr discharge rate; water depths for the proposed activity area rangefrom approximately 30 m to 150 m. For the generalized drilling fluid modeling approach that had been performed for EPA Region 10, a 500 bbl/hr discharge in a water depth of 20 m resulted in a minimum projected dilution of 1,035; even at a 1,000 bbl/hr discharge rate the available dilution is 655 at a water depth of 20 m and 731 at a water depth of 40 m. For a 1,000 bbl/hr discharge in a 70-m water depth, the dilutions achieved at 100 meters is 1,721, 10-fold greater than the amount required to meet the most stringent Federal water quality criteria in the Desoto Canyon area.

Table 9-6. Comparison of Federal Water Quality Criteria to Projected Drilling Fluids Pollutant Concentrations at 100 Meters

Pollutant	Effluent Conc. [a] (mg/l)	Leach Factor [b]	Federal Criteria (µg/l) Marine Acute	Marine Chronic	Human Health	Minimum Dilutions Required [c]
Antimony	2,592	11%			110,000	<1
Arsenic	3,228	0.51%	69	36	0.14	118
Cadmium	0.50	11%	42	9.3		6
Chromium	109	3.4%	1,100	50		74
Copper	8.50	0.63%	4.8	3.1		17
Lead	15.9	2.0%	210	8.1		39
Mercury	0.045	1.8%	1.8	0.94	0.051	16
Nickel	6.138	4.3%	74	8.2	4,600	32
Selenium	0.50	11%	290	71	11,000	<1
Silver	0.318	11%	1.9			18
Thallium	0.546	11%			6.3	10
Zinc	91.16	0.41%	90	81	69,000	5

[a] See Table 3-3.

[b] The leach factor for metals for which no value was available is assumed to be 11%, equal to the highest value reported (cadmium).

[c] Calculated for each pollutant as: [(Effluent conc. x 1000 µg/mg) x leach factor]/lowest criterion value.

For the project-specific modeling approach, the minimum available dilutions under the most conservative scenario modeled was 150, which although closer to the required minimum dilution still affords an excess dilution under the least probable set of operational and environmental conditions. The occurrence of non-compliance with Federal water quality criteria appears to be highly unlikely based on the results of either modeling approach. And although the project-specific modeling approach and results have yet to be reviewed and verified by the EPA, the comparability of the results lends some re-assurance to the likelihood that the project-specific approach will be found to be technically sound.

9.5.2 *Synthetic Based Drilling Fluids Discharges*

Assessments of water quality impacts from the discharge of cuttings with adhered synthetic based fluids (SBF-cuttings) rely on modeling data presented in a study (Brandsma, 1996) of the post-discharge transport behavior of oil and solids from cuttings contaminated with oil-based fluids (OBF-cuttings). Due to the similar hydrophobic and physical properties between SBFs and OBFs, the EPA assumes that above 5% retention, that dispersion behavior of SBF-cuttings is similar to that of OBF-cuttings when discharged following shale shaker only (i.e. baseline technology) treatment of cuttings. However, at controlled discharge levels reflecting best-available technology treatment the cuttings are expected to disperse similar to WBF-cuttings.

The analyses in this chapter are somewhat conservative due to the assumption that discharged pollutants immediately leach into the water column. In the water column, total organic pollutant discharge concentrations are assumed to represent the soluble concentration. Metals are assumed to leach immediately into the water column at pollutant-specific amounts determined for mean seawater pH (as derived in Avanti Corporation, 1993).

To evaluate the relative water quality impacts of the current industry practice and regulatory options, the EPAestimates the water column concentration of pollutants present in SBF drilling discharges under regulatory discharge options and compares them to Federal water quality criteria/toxic values. This comparative analysis applies only to those pollutants found in SBF discharges, and for which the EPA has published numeric criteria, as presented in Table 9-1. Note that there are no criteria for the synthetic-based fluid compounds themselves.

In order to determine the water column pollutant concentrations, the EPA used data regarding thetransport of discharged drill solids and corresponding oil concentration in the water column. The study was performed by Brandsma (1996) and the data are published in the E&P Forum Summary Report No. 2.61/202 (1996). Following is a description of the Brandsma (1996) study from that E&P report.

Brandsma modeled the discharge of nine treatments of cuttings obtained from a North Sea drilling platform to obtain: (1) a maximum deposition density (g/m^2) of cuttings and oil; (2) water column concentrations of suspended solids and oil; (3) the maximum thickness (cm) of cuttings deposited on the seabed; and (4) the seabed area (ha) that would achieve a 100 ppm oil content threshold in the upper 4 cm or 10 cm of the sediment.

The treatment technologies included: (1) no treatment (lab formulated control), (2) untreated cuttings from shale shakers, (3) centrifugation, (4) solvent extraction, (5) thermal treatment, and (6) water washing. The bulk densities of the cutting ranged from 1,830 - 2,430 g/l; oil content for the six typesof cuttings ranged from 0.02% (dry weight basis) to 19.6%.

The author simulated four sites in the North Sea: Southern (30 m water depth and depth-averaged, root mean-squared current speed of 0.37 m/s); Central (100 m water depth and current speed of 0.26 m/s); Northern (150 m water depth and current speed of 0.22 m/s); and Haltenbanken (250 m water depth and current speed of 0.10 m/s).

The Offshore Operators Committee (OOC) drilling and production discharge model was used to simulate the concentrations and deposition of discharged cuttings. The OOC model utilized a mixture of 12 profile size classes of mud and cuttings particles (with adsorbed oil) and water. All other discharge conditions were fixed. All discharges simulated a 68.5-hour discharge of 152 m^3 of cuttings from a 0.3 m diameter pipe shunted to a depth of 15.2 m below mean sea level. This cuttings volume is the volume expected from a single well section of OBF-cuttings. Results presented are based on these 152 m^3 model efforts, however, results are scaled up to a 300 m^3 volume which was later determined by the project steering committee to be more representative of actual OBF-cuttings volumes generated using OBFs (representing two well sections).

Hydrographic conditions were conservatively selected to maximize predicted cuttings deposition on the seabed by choosing the minimum water column stratification at each site. The result is no density gradient at all sites but the Haltenbanken site which exhibited only a weak (0.0016 $kg/m^3/m$) gradient.

Water column results were determined at a radial distance of 1000 m downstream. For untreated and centrifuged OBF-cuttings, projected water column oil concentrations at 1000 m were below maximum North Sea background levels at all four sites; all other treatments resulted in projected 1000 m oil concentrations that exceeded maximum background levels (except through treatment at the Haltenbanken site). The explanation for this phenomenon is that while treatments other than centrifugation also reduce oil content (from an untreated level of 15.8% [w/w] to a range of 0.3- 5.1%), these treatments also generate cuttings with finer particle sizes. Thus, according to the model, the untreated and centrifuged

OBF-cuttings would not reach the 1000 m mark to the same extent that the treated OBF-cuttings would because the finer particles created by the treatment have lower settling velocities and are transported farther in the water column (Brandsma, 1996).

Although Brandsma (1996) does not present oil concentration data for a radial distance of 100 m (the edge of the mixing zone established for U.S. offshore discharges by CWA Section 403, Ocean Discharge Criteria, as codified at 40 CFR 125 Subpart M), the study does present data on suspended solids and oil concentration as a function of transport time. Using current speeds representative of each geographic area (GOM; Cook Inlet, Alaska; and offshore California) and the transport times reported by Brandsma, EPA derived the corresponding oil concentrations and dilutions at 100 m. For example, assuming a mean current speed of 15 cm/s as representative of the Gulf of Mexico, a transport time of approximately 11 minutes is derived as the time required for the plume to reach 100 m (100 m/0.15 m/sec). Using data obtained from Brandsma's 1996 study, the EPA conducted a regression analysis to determine the oil concentration at selected transport times. Based on the mean initial oil concentration of the 9 cuttings cases presented in the study (5.5% in water-washed cuttings), the dilutions achieved can be estimated for a selected time (i.e., distance) in the following manner. The 5.5% (w/w) oil content converts to 55 g oil/kg wet cuttings. Based on a reported mean OBF-cuttings density of 2.050 kg wet cuttings/l, the initial oil concentration of 112,750 mg oil/l (55 g/kg x 2.050 kg/l) is used to determine the dilutions achieved. For the GOM example, the oil concentration at 11 minutes of 3.0 mg/l is used to calculate a 37,425-fold dilution (112,750 mg/3.0127 mg) at 11 minutes (Bowler, 1999). As described above, 11 minutes represents the estimated time at which the plume would reach the edge of themixing zone at 100 meters.

Projected water column pollutant concentrations at the edge of a 100-m mixing zone are calculated by dividing the drilling waste pollutant concentration by the dilutions available. The effluent concentrations for metals are further adjusted by a leach factor to account for the portion of the total metal pollutant concentration that is dissolved and therefore available in the water column. In terms of metal concentrations, this analysis is conservative in that it assumes that all leachable metals are immediately leached into the water column.

When comparing the Federal water quality criteria to the SBF concentration in the water column at 100 meters from the discharge, no exceedances of any of the Federal water quality criteria occurred for any model wells in the GOM using the current technology, nor under either the discharge or zero discharge options.

9.6 Compliance with State Water Quality Standards

9.6.1 *Water Based Drilling Fluids Discharges*

Tables 9-7 and 9-8 respectively summarize the state water quality standards and the minimum dilutions required for drilling fluid discharges to achieve them for Florida and Alabama. State standards for Florida and Alabama are the same for 7 of 12 common pollutants (Cadmium, Chromium, Copper, Mercury, Nickel, Selenium, and Zinc).

Alabama standards for antimony and arsenic (933 and 36 mg/l, respectively) are more stringent than Florida; Florida's standards for Lead, Silver, and Tthallium are more stringent than Alabama's standards. Florida also lists three pollutants that are not listed in Alabama - Aluminum, Beryllium, and Iron. From thetables, it is readily apparent that, based on comparisons of dispersion/dilution projections and the requireddispersions/dilutions listed in these tables, complying with all Alabama standards is highly likely.

In contrast, the minimum dispersions/dilutions required to meet Florida standards are greater than the minimum available dispersions/dilutions projected by either the generalized modeling approach or the project-specific approach in certain areas. Beryllium and Aluminum, respectively, require 269 and 302 dispersions/dilutions; silver requires 700 and iron requires 2,558 dispersions/dilutions to meet state standards.

Table 9-7. Comparison of Florida State Water Quality Standards to Projected Drilling Fluids Pollutant Concentrations at 100 Meters

Pollutant	Effluent Conc. [a] (mg/l)	Florida Standard (µg/l)	Minimum Dilutions Required
Aluminum	4,124	1,500	302
Antimony	2,592	4,300	>1
Arsenic	3,228	50	>1
Beryllium	0.318	0.13	269
Cadmium	0.50	9.3	6
Chromium	109	50	74
Copper	8.50	2.9	18
Iron	6,976	300	2,558
Lead	15.9	5.6	57
Mercury	0.045	0.025	32
Nickel	6.138	8.3	32
Selenium	0.50	71	1
Silver	0.318	0.05	700
Thallium	0.546	6.3	10
Zinc	91.16	86	4

[a] See Table 3-3.

Table 9-8. Comparison of Alabama Water Quality Standards to Projected Drilling Fluids Pollutant Concentrations at 100 Meters

Pollutant	Effluent Conc. [a] (mg/l)	Alabama Standards (µg/l) Marine Acute	Marine Chronic	Human Health	Minimum Dilutions Required
Antimony	2,592			933	<1
Arsenic	3,228	69	36		<1
Cadmium	0.50	43	9.3		6
Chromium	109	1,100	50		74
Copper	8.50	2.9	2.9		18
Lead	15.9	220	8.5		37
Mercury	0.045	2.1	0.025		32
Nickel	6.138	75	8.3		32
Selenium	0.50	300	71		<1
Silver	0.318	2.3			15
Thallium	0.546			133	<1
Zinc	91.16	95	86		4

[a] See Table 3-3.

Using the generalized modeling approach, the projected minimum available dispersions/dilutions required for all pollutants but iron are sufficient to comply with Florida standards at the edge of the 100-m mixing zone. Only in the case of iron, which requires 2,552 dispersions/dilutions to achieve the state standard, is there an issue with respect to compliance with state standards. The results of the project-specific analysis indicate that for worst case analyses, the dilutions available are not sufficient to comply with Florida's standards for four pollutants (Be, Al, Ag, and Fe). For modeling scenarios other than those for which the minimum dispersion/dilution is projected, again, only iron remains a potential issue.

Several factors mitigate the potential water quality non-compliance projected above. First, these non-compliance issues occur for worst case conditions, which requires a set of assumptions that are not likely to be encountered except rarely. Second, for iron, which is the pollutant with the largest exceedances, a surrogate leach factor is used (11%) based on the most mobile trace metal (Cadmium) because no leach data areavailable for Iron. Related to this factor, iron is expected to have a low leach factor; it has low solubility in seawater due to its ability to form precipitates from several anions that are in abundance in seawater. Third, compliance with state standards is being assessed at the edge of the 100-m mixing zone. While appropriate for discharges in state waters, this project is located some 16 miles from the state waters of Florida. It is expected that no state water quality standards will be violated within the territorial seas of the State of Florida.

In Mississippi, the projected maximum drilling fluid discharge rate would not cause any exceedances of the state water quality standards (Table 9- 8).

Table 9-9. Comparison of Mississippi Water Quality Standards to Projected Drilling Fluid Pollutant Concentrations at 100 meters (in µg/l)

Pollutant	Effluent Concentrations[a]	Extraction Factors[b]	Concentration at 100 meters			State Standard[e]		
			15 m water depth[c]	40m water depth[c]	70m water depth[c]	Marine Acute	Marine Chronic	Human Health
Arsenic	3,228	0.51%	0.029	0.021	0.010	69	36	0.14
Cadmium	500	11 %	0.098	0.070	0.032	43	9.3	168
Chromium VI	109,116	3.4%	6.60	4.714	2.156	1,100	50	3,365
Copper	8,502	0.63%	0.095	0.068	0.031	2.9	2.9	1,000
Lead	15,958	2.0%	0.568	0.406	0.185	140	5.6	
Mercury	45	1.8 %	0.001	0.001	0.0005			0.153
Nickel	6,138	4.3 %	0.470	0.335	0.153	75	8.3	4,584
Selenium	500	100 %	0.890	0.635	0.290	300	71	
Silver	318	100%	0.566	0.404	0.185	2.3		
Zinc	91,157	0.41 %	0.665	0.475	0.217	95	86	5,000

[a]See Table 3-3.
[b]The extraction factors represent the trace metal leach percentages from barite and drilling fluids.
[c]The average OOC Model run dilution results were used for each of the water depths (See Table 4-7). For 15m, dilution = 562, 40m = 787, and 70m = 1,721.
[d]See Table 9-5.
Source: Avanti, 1993.

10. REFERENCES

Alabama Bureau of Marine Resources (BMR) and Dept. of Wildlife Conservation (DWC). 1988. Mississippi Coastal Program. Biloxi, MS. October, 1988.

Alabama Department of Economic and Community Affairs. 1999. Alabama Coastal Area Management Plan, ACAMP III. Coastal Programs Office, currently in the Department of Conservation and Natural Resources. January 1999. 103 pp.

Anderson, J.W. 1982. The transport of petroleum hydrocarbons from sediments to benthos and the potential effects. Pages 165-179 In: G.F. Mayer (ed.), Ecological Stress and the New York Bight: Science and Management. Estuarine Research Federation, Columbia, SC.

American Petroleum Institute. 2015. Offshore well control and well stimulation technology. Briefing Paper. DM2015-027. 2pp.

Andreasen, J.K. and R.W. Spears. 1983. Toxicity of Texan petroleum well brine to the sheepshead minnow (*Cyprinodon variegatus*) a common estuarine fish. *Bull. Environ. Contam. Toxicol.* 30:277-283.

Armstrong, H.W., K. Fucik, J.W. Anderson, and J.M. Neff. 1979. Effects of oil field brine effluent on sediments and benthic organisms in Trinity Bay, TX. *Mar. Environ. Res.* 2:55-69.

Armstrong, R.S. 1981. Transport and dispersion of potential contaminants. p. 403-419. In: B. Middleditch (ed.). Environmental Effects of Offshore Oil Production. The Buccaneer Gas and Oil Field Study. Plenum Press, NY.

Atema, J., E.B. Karnofsky, S. Olszko-Szuts, and B. Bryant. 1982. Sublethal effects of number 2 fueloil on lobster behavior and chemoreception. Report to U.S. EPA, Environmental Research Lab, Gulf Breeze, FL. EPA-600/S3-82-013.

Atlantic Richfield Co. (ARCO). 1978. Drilling Fluid Dispersion and Biological Effects Study for the Lower Cook Inlet C.O.S.T. Well. Prepared by Dames and More. 309 pp. In: Petrazzuolo, G. 1983. Environmental Assessment of Drilling Fluids and Cuttings Discharge on the OCS. Draft Final Report. U.S. EPA, Office of Water Enforcement and Permits, Washington, DC.

Auble, G.T., A.K. Andrews, R.A. Ellison, D.B. Hamilton, R.A. Johnson, J.E. Roelle, and D.R. Marmorek. 1982. Results of an Adaptive Environmental Assessment Modeling Workshop Concerning Potential Impacts of Drilling Muds and Cuttings on the Marine Environment. Prepared for U.S. FWS, Fort Collins, CO. 64 pp.

Augenfield, J.M., J.W. Anderson, R.G. Riley, and B.L. Thomas. 1982. The fate of polyaromatic hydrocarbons in an intertidal sediment exposure system: bioavailability to *Macoma inquinata* (Molluska: Pelecypoda) and *Abarenicola pacifica* (Annelida: Polychaetea). *Mar. Environ. Res.* 7:31-50.

Austin, H. 1970. Florida Middle Ground. *Int. Poll. Bull.* 2(2):71-72.

Avanti Corporation. 1992. Characterization of Produced Water Discharges to Coastal Waters of Louisiana and Texas. Draft prepared for U.S. EPA Region 6, Water Management Division.

Avanti Corporation. 1993. Biological Assessment for the NPDES General Permit for Oil and Gas Exploration, Development, and Production Activities on the Eastern Gulf of Mexico OCS. Submitted to U.S. EPA Region 4, Water Management Division.

Avanti Corporation. 1993. Environmental Analysis of the Final Effluent Guidelines, Offshore Subcategory, Oil and Gas Industry, Volume I- Modeled Impacts. Prepared for U.S. EPA Office of Science and Technology, Standards and Applied Science Division, January 14, 1993.

Ayers, R.C., Jr. 1981. Fate and effects of drilling discharges in the marine environment. Proposed North Atlantic OCS oil and gas lease sale 52. Statement delivered at public hearing Boston, MA. Nov. 19, 1981. BLM, U.S. DOI.

Ayers, R.C., Jr., T.C. Sauer, Jr., D.O. Stuebner, and R.P. Meek. 1980a. An environmental study to assess the effect of drilling fluids on water quality parameters during high rate, high volume discharges to the ocean. In: Symposium on research on environmental fate and effects of drilling fluids and cuttings. Lake Buena Vista, FL, September 1980. API, Washington, DC. pp. 351-381.

Ayers, R.C., Jr., T.C. Sauer, Jr., R.P. Meek, and G. Bowers. 1980b. An environmental study to assess the impact of drilling discharges in the Mid-Atlantic. I. Quantity and Fate of Discharges. In: Symposium on research on environmental fate and effects of drilling fluids and cuttings. Lake Buena Vista, FL, September 1980. API, Washington, DC. pp. 382-418.

Backus, R.H., J.E. Craddock, R.L. Haedrick and B.H. Robinson. 1977. Atlantic mesopelagic zoogeography. In: Fishes of the western north Atlantic, Part 7. Mem. Sears Found. Mar. Res. 1:266-287.

Baggett, H.D. 1982. Schaus' Swallowtail. In: P. Pritchard, Ed., Rare and Endangered Biota of Florida, Volume Six, Invertebrates. University Presses of Florida. Gainesville, FL.

Bielsa, L.M., W.H. Murdich and R.F. Labisky. 1983. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (South Florida)--Pink Shrimp. Prepared for U.S. Army Corps of Engineers and U.S. FWS. FWS/OBS-82/11.17, TR EL-82-4.

BOEM. 2012. Outer Continental Shelf Oil and Gas Leasing Program: 2012-2017. Final Programmatic Environmental Impact Statement. U.S. Department of the Interior. Bureau of Ocean Energy Management. OCS EIS/EA BOEM 2012-030.

BOEM. 2013. Eastern Planning Area Lease Sales 225 and 226. Final Environmental Impact Statement. Volume I. Oil and Gas Lease Sales: 2014 and 2016. U.S. Department of the Interior. Bureau of Ocean Energy Management. Gulf of Mexico OCS Region. Gulf of Mexico OCS. OCS EIS/EA. BOEM 2013-200

Boesch, D.F. and N.N. Rabalais, eds. 1985. The long-term effects of offshore oil and gas development: an assessment and a research strategy. NOAA, National Marine Pollution Program Office. 738 pp.

Boesch, D.F. and N.N. Rabalais. 1989a. Produced waters in sensitive coastal habitats: an analysis of impacts, central coastal Gulf of Mexico. Prepared under MMS Contract 14-12-001-30325. New Orleans, LA: U.S. Dept. of the Interior, MMS, Gulf of Mexico OCS Region. OCS Study/MMS 89-0031. 157 pp.

Boesch, D.F. and N.N. Rabalais. 1989b. Environmental Impact of Produced Water Discharges in Coastal Louisiana. Final Rept. to Louisiana Div. of Mid-Continent Oil and Gas Assoc., Louisiana Universities Marine Consortium, Chauvin, Louisiana.

Bookhout, C.G., R. Monroe, R. Forward, and J.D. Costlow, Jr. 1984. Effects of soluble fractions of drilling fluids on development of crabs, *Rhithropanopeus harrisii* and *Callinectes sapidus*. *Water, Air, Soil Pollut.* 21:183-197.

Boothe, P.N. and B.J. Presley. 1985. Distribution and Behavoir of Drilling Fluids and Cuttings Around Gulf of Mexico Drilling Sites. Final Report to API. Texas A&M University.

Brandsma, M.G., L.R. Davis, R.C. Ayers Jr., T.C. Sauer Jr. 1980. A Computer Model to Predict the Short-term Fate of Drilling Discharges in the Marine Environment. In: Symposium on research on the environmental fate and effects of drilling fluids and cuttings. Lake Buena Vista, FL, January 1980. API, Washington, DC.

Brandsma Engineering. 1991. Simulations of Discharge Scenarios on the Alaskan Outer Continental Shelf. Prepared for *Avanti* Corporation for submission to U.S. EPA, Region 10, Water Management Division. 43 pp.

Brandsma, M.G. and J.P. Smith. 1996. Dispersion modeling perspectives on the environmental fate of produced water discharges. In: M. Reed and S. Johses, Eds., Produced Water 2: Environmental Issues and Mitigation Technologies. Plenum Press, New York (in press).

Brannon, A.C. and K.R. Rao. 1979. Barium, Strontium, and Calcium Levels in the Exoskeleton, Hepatopancreas and Abdominal Muscle of the Grass Shrimp *Palaemontes pugio*: Relation to Molting and Exposure to Barite. Comp. Biochem. and Phys., Vol. 63A, pp. 261-274.

Brendenhaug, J., S. Johnson, K.H. Bryne, A.L Gjøse, T.H. Eide, and E. Aamot. 1992. Toxicity Testing and Chemical Characterization of Produced Water - A Preliminary Study. In: J.P. Ray and F.R. Engelhardt (Eds.) Produced Water Technological/Environmental Issues and Solutions. PennWell Books, New York, NY. pp. 245-256.

Breteler, R.J., P.D. Boehm, J.M. Neff, and A.G. Requejo. 1983. Acute toxicity of drilling muds containing hydrocarbon additives and their fate and partitioning between liquid, suspended and solid phases. Draft final report to API, Washington, DC. 93 pp.

Brooks, J.M., E.L. Estes, D.A. Wisenburg, C.R. Schwab, and H.A. Abdel-Reheim. 1980. Investigations of Surficial Sediments, Suspended Particulates and Volatile Hydrocarbons at Buccaneer Gas and Oil Field. In: Volume I - Environmental Assessment of Buccaneer Gas and

Oil Field in the Northwestern Gulf of Mexico, 1975-1980. Edited by W.B. Jackson and E.P. Wilkins. NOAA Technical Memorandum NMFS-SEFC-47, Washington, DC.

Brooks, J.M., C. Fisher, H. Roberts, B. Bernard, I. McDonald, R. Carney, S. Joye, E. Cordes, G. Wolff, E. Goehring. 2014. Investigations of chemosynthetic communities on the lower continental slope of the Gulf of Mexico: Volume I: Final report. U.S. Dept. of the Interior, Bureau of Ocean Energy Management, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study BOEM 2014-650. 560 pp.

Bryan, G.W. 1983. The biological availability and effects of heavy metals in marine deposits. In: Proc. Ocean Dumping Symposium. Wiley Interscience, New York.

Burk, C.J. and J.A. Veil. 1995. Potential Environmental Benefits from Regulatory Consideration of Synthetic Drilling Muds. Argonne National Laboratory Technical Memorandum ANL/EAD/TM-43, February 1995.

Burns and Roe Industrial Services Corporation. 1983. Data Report for EPA Priority Pollutant Sampling Program Offshore Oil and Gas Program. Prepared for U.S. EPA Effluent Guidelines Division. Evaluation of Analytical Data; Revision February 1983, Vols. I and II.

Candler, J.E., A.J.J. Leuterman, and J.H. Rushing. 1993. "Synthetic-Based Mud Systems Offer Environmental Benefits Over Traditional Mud Systems," SPE 25993 presented at SPE/EPA Exploration & Production Environmental Conference held in San Antonio, TX, March 7-10, 1993.

Candler, J., R. Herbert and A.J.J. Leuterman. 1997. Effectiveness of a 10-day ASTM Amphipod Sediment Test to Screen Drilling Mud Base Fluids for Benthic Toxicity. SPE 37890 Society of Petroleum Engineers Inc. March 1997. 19 pp.

Cantelmo, F.R., M.E. Tagatz, and K.R. Rao. 1979. Effect of Barite on Meiofauna in a Flow-Through Experimental System. *Marine Environmental Research*, pp. 301-309.

Capuzzo, J.M. and J.G.S. Derby. 1982. Drilling fluid effects to developmental stages of the American lobster. Report to U.S. EPA, Environmental Research Lab., Gulf Breeze, FL, EPA-600/S4-82-039.

Carls, M.G. and S.D. Rice. 1980. Toxicity of oil well drilling fluids to Alaskan larval shrimp and crabs. Research Unit 72. Final Rept. Proj. No. R7120822, Outer Continental Shelf Environmental Assessment Program. U.S. Dept. of Interior, BLM, 29 pp.

Conklin, P.J., D.G. Doughtie and K.R. Rao. 1980. Effects of barite and used drilling fluids on crustaceans, with particular reference to the grass shrimp, *Palaemonetes pugio*. In: Symposium on research on environmental fate and effects of drilling fluids and cuttings. Lake Buena Vista, FL, January 1980. API, Washington, DC. pp. 723-738.

Conklin, P.J., D. Drysdale, D.G. Doughtie, K.R. Rao, J.P. Kakareka, T.R. Gilbert and R.F. Shokes. 1983. Comparative toxicity of drilling fluids: role of chromium and petroleum hydrocarbons. *Marine Environmental Research*. 10:105-125.

Continental Shelf Associates (CSA). 1983. Monitoring study of exploratory drilling activity at High Island Block A-384. Final Report to Conoco Oil Company.

Corliss, J.B., J. Dymond, L. Gordon, J.M. Edmund, R.P. von Herzen, R.D. Ballard, K. Green, D. Williams, A. Bainbridge, K. Crane, and T.H. Van Adel. 1979. Submarine thermal springs on the Galapagos Rift. Science. 203: 1073-1083.

CSA. 1986. Southwest Florida Shelf Regional Biological Communities Survey, Marine Habitat Atlas-Year 3, Vol. I Maps. OCS Study/MMS 86-0072.

CSA. 1993. Measurement of Naturally Occurring Radioactive Materials at Two Offshore Production Platforms in the Northern Gulf of Mexico. Final Report to the American Petroleum Institute, Washington, DC.

CSA. 2007. Characterization of northern Gulf of Mexico deepwater hard bottom communities with emphasis on *Lophelia* coral. U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2007-044. 169 pp. + app.

Crawford, R.B. and J.D. Gates. 1981. Effects of drilling fluids on the development of a teleost and an echinoderm. *Bull. Environ. Contam. Toxicol*. 26:207-212.

Crippen, R.W., S.L. Hood and G. Green. 1980. Metal levels in sediment and benthos resulting from a drilling fluid discharge into the Beaufort Sea. In: Symposium on research on environmental fate and effects of drilling fluids and cuttings. Lake Buena Vista, FL, January 1980. API, Washington, DC. pp. 636-669.

Ditton, R.B. and A.R. Graefe. 1978. Recreational fishing use of artificial reefs on the Texas coast. College Station, TX: Texas A & M University, Department of Recreation and Parks. 155 pp.

Dodge, R.E. 1982. Effects of Drilling Muds on the Reef-Building Coral *Montastrea annularis*. *Marine Biology*. 71:141-147.

DOE. 1997. Levels of Naturally Occurring Radioactive Materials, Metals, and Organic compounds in Produced Water, Produced Sand, Receiving Water, Ambient water, Sediment, and Biota on the Texas/Louisiana Shelf. Draft Report to US Dept. of Energy, Barlesville, OK.

Doneker, R.L. and G.H. Jirka. 1990. Expert System for Hydrodynamic Mixing Zone Analysis of Conventional and Toxic Submerged Single Port Discharges (CORMIX1). Prepared by Cornell University for U.S. EPA, Environmental Research Laboratory, Athens, GA. EPA/600/3-90/012.

Doneker, R.L. and G.H. Jirka. 1993. Cornell Mixing Zone Expert System (CORMIX v. 2.10). Prepared by Cornell University for U.S. EPA, Environmental Research Laboratory, Athens, GA. May 1993.

Drake, D.E. 1976. Suspended sediment transport and mud deposition on continental shelves. In: Stanley, D.J. and D.J.P. Swift (eds). Marine Sediment Transport and Environmental Management. John Wiley & Sons, New York, NY, p. 127-158. In: Houghton, J.P., K.R. Critchlow, D.C. Lees, R.D. Czlapinski. 1981. Fate and Effects of Drilling Fluids and Cuttings Discharges in Lower Cook Inlet, Alaska, and on Georges Bank - Final Report. NOAA, and BLM, Washington, DC.

Dribus, John R.; Jackson, Martin P.A.; Kapoor, Jerry and Smith, Martiris F. 2008. The prize beneath the salt. Oilfield Review. 14pp.

Dugas, R., V. Guillory and M. Fischer. 1979. Oil rigs and offshore fishing in Louisiana. *Fisheries* 4(6):2-10.

Duke, T.W. and P.R. Parrish. 1984. Results of the Drilling Fluids Program Sponsored by the Gulf Breeze Research Laboratory, 1976-1984, and their Application to Hazard Assessment. U.S. EPA, Environmental Research Laboratory, Gulf Breeze, FL. EPA/600/4-84-055.

Dutton, Shirley P. and. Loucks, Robert G. 2014. Reservoir quality and porosity-permeability trends in on-shore Wilcox sandstones, Texas and Louisiana Gulf Coast: Application to deep Wilcox plays, offshore Gulf of Mexico. GCAGS Journal. Vol 3. 33pp.

Ecomar, Inc. 1978. Tanner Bank fluids and cuttings study. Conducted for Shell Oil Company, January through March, 1977. Ecomar, Inc. Goleta, CA. 95 pp. In: Houghton, J.P., K.R. Critchlow, D.C. Lees and R.D. Czlapinski. 1981. Fate and Effects of Drilling Fluids and Cuttings Discharges in Lower Cook Inlet, Alaska, and on Georges Bank - Final Report. NOAA and BLM, Washington, DC.

EG&G. 1982. A study of environmental effects of exploratory drilling on the Mid-Atlantic OCS - Final Report of the Block 684 Monitoring Program. EG&G, Environmental Consultants, Waltham, MA. Prepared for OOC, Environmental Subcommittee, New Orleans, LA.

Eleuterius, C.K., and S.L. Beaugez. 1979. Mississippi Sound, a hydrographic and climatic atlas. Mississippi-Alabama Sea Grant Consortium MASGP-79-009. Gulf Coast Research Lab, Ocean Springs, MS. 136pp.

El-Sayed, S.Z. 1972. Primary productivity and standing crop of phytoplankton in the Gulf of Mexico. In: El-Sayed, S.Z. et al., eds. Chemistry, primary productivity and benthic algae of the Gulf of Mexico. Serial atlas of the marine environ., Folio 22. New York, NY: American Geographic Society. pp. 8-13.

Elliott, E.G., Ettinger, A.S, Brian P. Leaderer, B.P., Michael B. Bracken, M.B., and Nicole C. Deziel, N.C. 2016. A systematic evaluation of chemicals in hydraulic-fracturing fluids and wastewater for reproductive and developmental toxicity. Journal of Exposure Science and Environmental Epidemiology (2016), 1–10.

ERT (Environment & Resource Technology Ltd). 1994a. Bioaccumulation potential of ISO-TEQ base fluid. ERT 94/209. Report to Baker Hughes INTEQ, Houston, TX.

ERT (Environmental & Resource Technology Ltd.). 1994b. Bioconcentration assessment report. Assessment of the bioconcentration factor (BCF) of ISO-TEQ base fluid in the blue mussel *Milts elude*s. ERT 94/061. Report to Baker Hughes INTEQ, Houston, TX.

Flint, R.W. and D. Kamykowski. 1984. Benthic nutrient regeneration in South Texas coastal water. *Estuar. Coast. Shelf. Sci.* 18(2):221-230.

Flint, R.W. and N.N. Rabalais. 1981. Environmental Studies of a Marine Ecosystem: South Texas Outer Continental Shelf. Univ. Texas Press, Austin. 272 pp.

Florida Department of Community Affairs (DCA). 1997. Florida Coastal Management Program, 1997 Revision, Florida Coastal Program Guide and Reference Book. Tallahassee, FL.

Fowler, S.W. 1982. Biological Transfer and Transport Processes. In: Pollutant Transfer and Transport in the Sea, G. Kullenberg, ed. CRC Press, Inc., Boca Raton, FL.

Friedheim, J.E., G.J. Hans, A. Park and C.R. Ray. 1991. An environmentally superior replacement for mineral-oil drilling fluids. SPE 23062. Pages 299-311 In: The Offshore Europe Conference. Aberdeen, 3-6 September 1991. Society of Petroleum Engineers, Inc. Richardson, TX.

Gallaway, B.J. 1980. Pelagic, reef and demersal fishes and macrocrustaceans/ biofouling communities. In: Jackson, W.B. and E.O. Wilkens (eds). Environmental assessment of Buccaneer gas and oil field in the northwestern Gulf of Mexico, 1975-1978. NOAA technical memorandum NMFS-SEFC-48. Galveston, TX: U.S. DOC, NMFS. 82 pp.

Gallaway, B.J. 1988. Northern Gulf of Mexico continental slope study, Final report, Year 4. Volume II, Synthesis report. Prepared for the U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Regional Office, New Orleans, Louisiana. OCS Study MMS 88-053.

Gartner, J.V., T.L. Hopkins, R.C. Baird, and D.M. Milliken. 1987. The lanternfishes of the eastern Gulf of Mexico. Fish. Bull. 85: 81-98.

Gerber, R.P., E.S. Gilfillan, B.T. Page, D.S. Page, and J.B. Hotham. 1980. Short- and long-term effects of used drilling fluids on marine organisms. In: Symposium on research on environmental fate and effects of drilling fluids and cuttings. Lake Buena Vista, FL, January 1980. API, Washington, DC. pp. 882-911.

Gerber, R.P., E.S. Gilfillan, J.R. Hotham, L.J. Galletto, and S.A. Hanson. 1981. Further studies on the short- and long-term effect of used drilling fluids on marine organisms. Unpublished. Final Report, Year II to API, Washington, DC., 30 pp.

Gettleson, D.A. and C.B. Laird. 1980. Benthic barium in the vicinity of six drill sites in the Gulf of Mexico. In: Symposium on research on environmental fate and effects of drilling fluids and cuttings. Lake Buena Vista, FL, January 1980. API, Washington, DC.

Gilbert, T.R. 1981. A study of the impact of discharged drilling fluids on the Georges Bank environment. New England Aquarium, H.E. Edgerton Research Laboratory. Progress Report No. 2 to U.S. EPA, Gulf Breeze, FL, 98 pp.

Gilbert, T.R. 1982. A survey of the toxicities and chemical compositions of used drilling muds. Annual Report to U.S. Environmental Research Laboratory, Gulf Breeze, FL from Edgerton Research Lab., New England Aquarium, Boston, MA, 31 pp.

Ground Water Protection Council & Interstate Oil and Gas Compact Commission. 2016. Hydraulic Fracturing: The Process. https://fracfocus.org/hydraulic-fracturing-how-it-works/hydraulic-fracturing-process.

Growcock, F.B., S.L. Andrews, and T.P. Frederick. 1994. Physicochemical properties of synthetic drilling fluids. IADC/SPE 27450. Pages 181-190 In: 1994 IADC/SPE Drilling Conference. Dallas, TX, 15-18 February 1994. International Association of Drilling Contractors/Society of Petroleum Engineers, Inc. (IADC/SPE). Richardson, TX.

Hall, C.A.S., R.G. Howarth, B, Moore, III, ad C.J. Vorosmarty. 1978. Environmental Impacts of Industrial Energy Systems in the Coastal Zone. Annual Review of Energy. 3:395-475.

Hamilton, P. Donohue, K., Hall, C., Leben,R., Quian, H., Sheinbaum, J., & Watts, D. R. (2014). Observations and dynamics of the Loop Current. US Department of Interior, Bureau of Ocean Energy Management, Gulf of Mexico OCS Region. OCS Study BOEM 2015-006. Observations and Dynamics of the Loop Current (boem.gov)

Higashi, R.M., G.N. Cherr, C.A. Bergens, and T.W.M. Fan. 1992. An Approach to Toxicant Isolation from a Produced Water Source in the Santa Barbara Channel. In: J.P. Ray and F.R. Engelhardt (Eds.) Produced Water Technological/Environmental Issues and Solutions. PennWell Books, New York, NY. pp. 223-233.

Hoese, H.D. and R.H. Moore. 1977. Fishes of the Gulf of Mexico, Texas, Louisiana, and Adjacent Waters. Texas A7M University Press. 327 pp.

Holtzman, R.B. 1969. Concentrations of the naturally occurring radionuclides ^{226}Ra, ^{210}Po in aquatic fauna. In: Proc. 2nd Nat. Symp. Radioecology, U.S. Atomic Energy Commission, Conf. 670503. pp. 535-546.

Hopkins, T.S. and R.C. Baird. 1985. Feeding ecology of four hatchetfishes (Sternoptychidae) in the eastern Gulf of Mexico. Bull. Mar. Sci. 36: 260-277.

Houde, E.D. and N. Chitty. 1976. Seasonal Abundance and Distribution of Zooplankton, Fish Eggs, and Fish Larvae in the Eastern Gulf of Mexico, 1972-1974. Prepared for NMFS, Seattle, WA. NMFS SSRF-701. 18 pp.

Houghton, J.P., D.L. Beyer, and E.D. Thielk. 1980. Effects of oil well drilling fluids on several important Alaskan marine organisms. In: Symposium on research on environmental fate and effects of drilling fluids and cuttings. Lake Buena Vista, FL, January 1980. API, Washington, DC. pp. 1017-1043.

Houghton, J.P., K.R. Critchlow, D.C. Lees, R.D. Czlapinski. 1981. Fate and Effects of Drilling Fluids and Cuttings Discharges in Lower Cook Inlet, Alaska, and on Georges Bank - Final Report. U.S. DOC, NOAA, and the U.S. Department of Interior, BLM, Washington, DC.

Houghton, J.P., R.P. Britch, R.C. Miller, A.K. Runchal, and C.P. Falls. 1980. Drilling Fluid Dispersion Studies at the Lower Cook Inlet C.O.S.T. Well. In: Symposium on research on environmental fate and effects of drilling fluids and cuttings. Lake Buena Vista, FL, January 1980. API, Washington, DC.

Hudson, J.H. and D.M. Robbin. 1980. Effect of Drilling Mud on the Growth Rate of the Reef-Building Coral, *Montastrea annularis*. In: Symposium on research on environmental fate and effects of drilling fluids and cuttings. Lake Buena Vista, FL, January 1980. API, Washington, DC.

Hunt, C.D. and D.L. Smith. 1983. Remobilization of metals from polluted marine sediments. *Can. Journal Fish Aquat. Sci.* 40:132-142.

Iverson, R.L. and T.L. Hopkins. 1981. A summary of knowledge of plankton production in the Gulf of Mexico: Recent Phytoplankton and Zooplankton research. Proceedings of a Symposium on Environmental Research Needs in the Gulf of Mexico (GOMEX), Key Biscayne, FL, 30 September

- 5 October, 1979.
Jenne, E.A. and S.N. Luoma. 1977. Forms of trace elements in soils, sediments, and associated waters: An overview of their determination and biological availability. Pages 110-143. In: H. Drucker and R.E. Wildung (eds.), Biological Implications of Metals in the Environment.

Jensen, A., Eimhjellen, K., Raasok, K., Saetersdal, G., Wedege, N.P., and Ostvedt, O.J. 1984. The fate of oil and its effect in the sea: summary of final report from the Norwegian marine pollution research and monitoring programme. Oslo, Norway: Harald Lyche & Co. A.S. 20 pp.

Jones, F.V., J.H. Rushing, and M.A. Churan. 1991. The chronic toxicity of mineral oil-wet and synthetic liquid-wet cuttings on an estuarine fish, *Fundulus grandi*s. SPE 23497. Pages 721-730 In: The First International Conference on Health, Safety and Environment. Hague, The Netherlands, 10-14 November 1991. Society of Petroleum Engineers, Inc. Richardson, TX.

Kendall, J.J., Jr., E.N. Powell, S.J. Connor and T.J. Bright. 1983. The Effects of Drilling Fluids (muds) and Turbidity on the Growth and Metabolic State of the Coral *Acropora cervicornis* with Commentson Methods of Normalization for Coral Data. *Bull. Mar. Sci.*, 33(2):336-352.

Kennish, M.J. (ed.). 1989. Practical Handbook of Marine Science. CRC Press Inc. Boca Raton, FL. 710 pp.

King, George E. 2012. Hydraulic Fracturing 101: What every representative, environmentalist, regulator, reporter, invertor, university researcher, neighbor and engineer should know about estimating frac risk and improving frac performance in unconventional oil and gas wells. Society of Petroleum Engineers. SPE Hydraulic Fracturing Technology Conference, TX. SPE 152596. 80pp.

Krause, P.R., C.W. Osenberg, and R.J. Schmitt. 1992. Effects of Produced Water on Early Life Stages of a Sea Urchin: Stage-Specific Responses and Delayed Expression. In: J.P. Ray and F.R. Engelhardt, Eds. Produced Water. Plenum Press, New York. pp. 431-444.

Krone, M.A. and D.C. Biggs. 1980. Sublethal Metabolic Responses of the Hermatypic Coral *Madracis decactis* Exposed to Drilling Mud Enriched with Ferrochrome Lignosulfonate. In: Symposium on research on environmental fate and effects of drilling fluids and cuttings. Lake Buena Vista, FL, January 1980. API, Washington, DC.

Leipper, D.F., 1970. A sequence of current patterns in the Gulf of Mexico. Jour. Geo. Res. 75(3): 637-657.

Leuterman, A.J.J. 1991. Environmental considerations in M-I product development. Novasol/Novadril. M-I Drilling Fluids Co., Houston, TX.

LimnoTech, Inc. 1993. Recommendation of Specific Models to Evaluate Mixing Zone Impacts of Produced Water Discharges to the Western Gulf of Mexico Outer Continental Shelf. Prepared for U.S. EPA Office of Wastewater Enforcement and Compliance. 22 pp.

Lindberg, W.J. and M.J. Marshall. 1984. Species Profile: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Gulf of Mexico)--Stone Crab. Prepared for U.S. Army Corps. of Engineers and U.S. FWS. FWS/OBS-82/11.21, TR EL-82-4.

Liss, R.G., F. Knox, D. Wayne, and T.R. Gilbert. 1980. Availability of Trace Elements in Drilling Fluids to the Marine Environment. In: Symposium on research on environmental fate and effects of drilling fluids and cuttings. Lake Buena Vista, FL, January 1980. API, Washington, DC.

Luoma, S.N. 1983. Bioavailability of trace metals to aquatic organisms: A review. *Sci. Tot. Environ.* 28:1-22.

Lyes, M.C. 1979. Bioavailability of hydrocarbon from water and sediments to the marine worm *Arenicola marina*. *Mar. Biol.* 55: 121-127.

Mariani, G.M., L.V. Sick, and C.C. Johnson. 1980. An Environmental Monitoring Study to Assess the Impact of Drilling Discharges in the Mid-Atlantic. Report 3, Chemical and Physical Alterations in the Benthic Environment. In: Symposium on research on environmental fate and effects of drilling fluids and cuttings. Lake Buena Vista, FL, January 1980. API, Washington, DC.

Marine Mammal Commission. 1988. Annual Report of the Marine Mammal Commission, Calendar Year 1987, A Report to Congress. Washington, DC. 209 pp.

Marx, J.M. and W.F. Herrnkind. 1986. Species Profile: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Gulf of Mexico)--Spiny Lobster. Prepared for U.S. Army Corps of Engineers and USFWS. Biological Report 82(11.61), TR EL-82-4.

Maul, G.A., 1977. The annual cycle of the Gulf Loop Current, Part 1: Observations during a one-year time series. *Jour. Mar. Res*. 35(1):29-47.

McCain, B.B., H.O. Hodgins, W.D. Gronlund, J.W. Hawkes, D.W. Brown, M.S. Myers, and J.J. Vandermuelen. 1978. Bioavailability of crude oil from experimentally oiled sediments to English sole (*Parophrus vetulus*), and pathological consequences. *J. Fish. Res. Board Canada.* 35:657-664.

McCulloch, W.L., J.M. Neff, and R.S. Carr. 1980. Bioavailability of Selected Metals from Used Offshore Drilling Muds to the Clam *Rangia cuneata* and the Oyster *Crassostrea gigas*. In: Symposium on research on environmental fate and effects of drilling fluids and cuttings. Lake Buena Vista, FL, January 1980. API, Washington, DC.

Meade, R.H. 1972. Transport and Deposition of Sediments in Estuaries. Environmental Framework of Coastal Plain Estuaries. Geol. Society Am. Mem., B. Nelson (ed) 33:91-120.

Means, J.C., C.S. Milan, and D.J. McMillin. 1990. Hydrocarbon and trace metal concentrations in produced water effluents and proximate sediments. pp. 94-199 In: K.M. St. Pe, Ed., An Assessment of Produced Water Impacts to Low-Energy, Brackish Water Systems in Southeast Louisiana. Report to Louisiana Dept. of Environmental Quality, Water Pollution Control Div., Lockport, LA.

Meek, R.P., and J.P. Ray. 1980. Induced sedimentation, accumulation, and transport resulting from exploratory drilling discharges of drilling fluids and cuttings. In: Symposium on research on environmental fate and effects of drilling fluids and cuttings. Lake Buena Vista, FL, January 1980. API, Washington, DC. pp. 259-284.

Menzie, C.A. 1982. The environmental implications of offshore oil and gas activities. Environ. Sci. Technol. 16:454A-472A.

Menzie, C.A., D. Maurer, and W.A. Leatham. 1980. An Environmental Monitoring Study to Assess the Impact of Drilling Discharge in the Mid-Atlantic. Report 4, The Effects of Drilling Fluids and

Cuttings. In: Symposium on research on environmental fate and effects of drilling fluids and cuttings. Lake Buena Vista, FL, January 1980. API, Washington, DC.

Middle East and Asia Reservoir Review. 2007. Frac Packing: Fracturing for sand control. No. 8. 7pp.

Middleditch, B.S. 1980. Hydrocarbons, Biocides, and Sulfurs. In: Volume 5 - Environmental Assessment of Buccaneer Gas and Oil Field in the Northwestern Gulf of Mexico, 1975-1980, edited by W.B. Jackson and E.P. Wilkins. NOAA Technical Memorandum NMFS-SEFC-47, NOAA, Washington, DC.

Middleditch, B.S. 1981. Environmental Effects of Offshore Oil Production - The Buccaneer Gas and Oil Field Study. Plenum Press, NY. 446 pp.

Middleditch, B.S. 1984. Ecological effects of produced water discharges from offshore oil and gas production platforms. Final Report on API Project No. 248. API, Washington, DC. 160 pp.

Minerals Management Service (MMS). 1982. Draft regional environmental impact statement, Gulf of Mexico. U.S. DOI, MMS, Gulf of Mexico OCS Region, Metairie, LA. 735 pp.

MMS. 1983. Final regional environmental impact statement. Proposed OCS oil and gas lease sales 72, 74, and 79 (Central, Western, and Eastern Gulf of Mexico). Vol. 1, PB84-102805. U.S. Department of the Interior, Washington, DC. xxxv + 527 pp.

MMS. 1986. "Physical Oceanography of the Gulf of Mexico." Visual No. 7, Figures 5A; 6A-D; and 9A, B, and E.

MMS. 2000. Gulf of Mexico OCS Oil and Gas Lease Sale 181 Eastern Planning Area, Draft Environmental Impact Statement. Gulf of Mexico Regional Office. MMS 2000-077.

MMS. 2000. Environmental Assessment. Gulf of Mexico Deepwater Operations and Activities. Gulf of Mexico OCS Region Office. MMS 2000-001.

Mobil Oil Corporation. 1978. Monitoring Program for Wells #3 and #4 Lease OCG-G-2759, Block A-389 High Island Area, East Addition South Extension. Prepared by Continental Shelf Assoc. Volume I Technical Section. 162 pp.

Moffitt, C.M., M.R. Rhea, P.B. Dorn, J.F. Hall, J.M. Bruney, and S.H. Evans. 1992. Short-Term Chronic Toxicity of Produced Water and its Variability as a Function of Sample Time and Discharge Rate. In: J.P. Ray and F.R. Engelhardt (Eds.) Produced Water Technological/Environmental Issues and Solutions. PennWell Books, New York, NY. pp. 235-244.

Montgomery, R.M. 1987. Personal communication concerning research conducted at U.S. EPA/ERL Gulf Breeze. Seven drilling fluid samples submitted from coastal TX and LA.

Moore, P.L. 1986. Drilling Practices Manual. Second Edition. PennWell Books, Tulsa, OK. 586 pp.

Moore, W.S., S. Krishmaswami and S.G. Bhat. 1973. Radiometric determination of coral growth rates. *Bull. Mar. Sci*. 23:157-176.

Mullen, Mike; Svatek, Kevin; Sevadjian, Emile; Vitthal, Sanjay and Grigsby, Tommy. 2003. Deepwater Reservoirs Requiring High Rate/High-Volume Frac Packing Continue to Stretch Downhole Tool Capabilities – Latest Tool Design and Qualification Testing Results. American Association of Drilling Engineers. AADE-03-NTCE-18. 15pp.

NAS (National Academy of Sciences). 1975. Petroleum in the marine environment: Workshop on inputs, fates and the effects of petroleum in the marine environment. Airlie, VA; May 1973. NAS, Washington, DC. 107 pp.

National Oceanic and Atmospheric Administration (NOAA). 1961-1986. Data Service, National Climate Center. U.S. Department of Commerce, NOAA.

NOAA. 1975. Environmental Studies of the South Texas Outer Continental Shelf, 1975. Report to the BLM, I.A. #08550-IA5-19. Volume I.

NOAA. 2016. Endangered and Threatened Marine Species under NMFS' Jurisdiction http://www.nmfs.noaa.gov/pr/species/esa/listed.htm

NMFS. 2010. Fisheries of the United States, 2009. U.S. Department of Commerce, NOAA Current Fishery Statistics No.2009. Available at: https://www.st.nmfs.noaa.gov/commercial-fisheries/fus/fus09/index

NMFS. 2014. Fisheries Economics of the United States, 2012. U.S. Dept. Commerce, NOAA. Tech. Memo. NMFS-F/SPO-137, 175p. Available at: https://www.st.nmfs.noaa.gov/st5/publication/index.html.

NMFS. 2014. Fisheries of the United States, 2013. U.S. Department of Commerce, NOAA Current Fishery Statistics No.2013. Available at: https://www.st.nmfs.noaa.gov/commercial-fisheries/fus/fus13/index

NMFS. 2015. Fisheries of the United States, 2014. U.S. Department of Commerce, NOAA Current Fishery Statistics No.2014. Available at: https://www.st.nmfs.noaa.gov/commercial-fisheries/fus/fus14/index

NMFS. 2013. Fisheries Economics of the United States NOAA Technical Memorandum NMFS-F/SPO-159. October 2015.

National Research Council (NRC). 1983. Drilling Discharges into the Marine Environment. National Academy Press, Washington, DC. 180 pp.

Neff, J.M., R.S. Foster, and J.F. Slowey. 1978. Availability of sediment-adsorbed heavy metals to benthos with particular emphasis on deposit feeding infauna. Technical Report D-78-42 to U.S. Army Engineer Waterways Experiment Station, Dredge Material Program, Vicksburg, MS. 286 pp.

Neff, J.M. 1979. Polycyclic Aromatic Hydrocarbons in the Aquatic Environment: Sources, Fates, and Biological Effects. Applied Science Publ., Barking Essex, England. 262 pp.

Neff, J.M. 1980. Effects of Used Drilling Fluids on Benthic Marine Animals. Publ # 4330. API, Washington, DC.

Neff, J.M. 1982. Accumulation and release of polycyclic aromatic hydrocarbons from water, food, and sediment by marine animals. pp. 282-320. In: N.L. Richards and B.L. Jackson (eds.) Symposium: Carcinogenic Polynuclear Aromatic Hydrocarbons in the Marine Environment. USEPA, Gulf Breeze, FL. EPA-600/9-82-013.

Neff, J.M. 1985. Biological effects of drilling fluids, drill cuttings, and produced waters. in: D.F. Boesch and N.N. Rabalais (eds.). The Long-Term Effects of Offshore Oil and Gas Development: An Assessment and Research Strategy. Report to NOAA, National Marine Pollution Program Office for the Interagency Committee on Ocean Pollution Research, Development, and Monitoring. Prepared by LUMCON, Chauvin, LA.

Neff, J.M., R.E. Hillman, B. Leczynski, and T. Berner. 1986. Final Report on Bioavailability of Trace Metals from Barite to Benthic Marine Organisms. Prepared for the OOC. 41 pp.

Neff, J.M., T.C. Sauer, N. Maciolek. 1988. Fate and Effects of Produced Water Discharges in Nearshore Marine Waters. Final Report to API, Washington, DC. 300 pp.

Neff, J.M., W.E. Hillman, and J.J. Waugh. 1989. Bioaccumulation of trace metals from drilling mud barite by marine animals. In: F.R. Engelhardt, J.P. Ray, and A.H. Gillam, Eds. Drilling Wastes. Elsevier Applied Science Publishers, London. pp. 461-479.

Neff, J.M., T.C. Sauer, Jr., and N. Maciolek. 1992. Composition, ate and effects of produced water discharges to nearshore marine waters. pp. 371-386 In: J.P. Ray and F.R. Engelhardt, Eds., Produced Water: Technological/Environmental Issues. Plenum Press, New York.

Neff, J.M. 1997. Metals and Organic Chemicals Associated with Oil and Gas Well Produced Water: Bioaccumulation, Fates, and Effects in the Marine Environment. Draft Report to the OOC, New Orleans, LA. As cited in OOC comments on propose permit.

Neff, J.M., S. McKelvie and R.C. Ayers, Jr. 2000. Environmental Impacts of Synthetic Based Drilling Fluids. Report prepared by Robert Ayers & Associates, Inc. August 2000. U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico Region, New Orleans, LA. OCS Study MMS 2000-64. 118 pp.

Nelson, D.A., et al. 1976. Biological effects of heavy metals on juvenile bay scallops, *Argopecten irradians*, in short term exposures. *Bull. Environ. Contam. Toxicol.* 16:275. In: U.S. EPA. 1985. Ambient Water Quality Criteria for Arsenic - 1984. U.S. EPA, Washington, D.C. EPA 440/5-84-033.

New England Aquarium (NEA). 1984. A Survey of Toxicity of Chemical Composition of Used Drilling Muds. Final Report to the U.S. EPA. Coop. Agreement No. CR806776. January 1984.

Ng, A. and C.C. Patterson. 1982. Changes of lead and barium with time in California offshore basin sediments. Geochem. Cosmochem. Acta. 46(11):2307-2321.

Northern Technical Services. 1983. Open-water drilling effluent disposal study. Tern Island, Beaufort Sea, Alaska. Report for Shell Oil Co. from Northern Technical Services, Anchorage, AK. 87 pp.

Nulton, C.P. and D.E. Johnson. 1981. Aromatic Hydrocarbons in Marine Tissues from the Central Gulf of Mexico. *Journal of Environmental Science and Health*, A16(37):271-288.

Odum, E.P. 1971. Fundamentals of Ecology, 3rd Edition. W.B. Saunders, Philadelphia, PA. In: Kennish, M.J. (ed.). 1989. Practical Handbook of Marine Science. CRC Press Inc. Boca Raton, FL. 710 pp.

Olla, B.L., W.W. Steiner, and J.J. Luczkovich. 1982. Effects of drilling fluids on the behavior of the juvenile red hake, *Urophycis chuss* (Walbaum). II. Effects on established behavioral baselines. Progress Report to U.S. EPA, Gulf Breeze, Florida. Report No. SHL 82-15 from NOAA/NMFS, Northeast Fisheries Center, Sandy Hook Laboratory, NJ.

Ortner, P.B., R.L. Ferguson, S.R. Piotrowicz, L. Chesal, G. Berberian, and A.V. Palumbo. 1984. Biological consequences of hydrographic and atmospheric advection within the Gulf Loop Intrusion. Deep-Sea Research. Vol. 31, no. 94:1101-1120.

Page, O.S., B.T. Page, J.R. Hotham, E.S. Gilfillan and R.P. Gerber. 1980. Bioavailability of Toxic Constituents of Used Drilling Muds. In: Symposium on research on environmental fate and effects of drilling fluids and cuttings. Lake Buena Vista, FL, January 1980. API, Washington, DC.

Pequegnat, W.E. 1983. The ecological communities of the continental slope and adjacent regimes of the northern Gulf of Mexico. A final report by TerEco Corporation for the U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Regional Office, New Orleans, Louisiana. Contract No. AA851-CTI-12.

Perricone, C. 1980. Major Drilling Fluid Additives--1979. In: Symposium on Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. Lake Buena Vista, FL. January, 1980. API, Washington, DC. pp. 15-29.

Petrazzuolo, G. 1981. An Environmental Assessment of Drilling Fluids and Cuttings Released onto the OCS for the Gulf of Mexico - Draft. U.S. EPA, Office of Water Enforcement and Permits, Washington, DC.

Petrazzuolo, G. 1983. Environmental Assessment of Drilling Fluids and Cuttings Discharge on the OCS. Draft Final Report. U.S. EPA, Office of Water Enforcement and Permits, Washington, DC.

Powell, E.N., M. Kasschau, E. Che, M. Loenig, and J. Peron. 1982. Changes in the free amino acid pool during environmental stress in the gill tissue of oyster, *Crassostrea virginica*. Comp. Biochem. Physiol. 71A:591-598.

Rabalais, N.N., 1986. Oxygen-depleted waters on the Louisiana continental shelf. Proceedings of the MMS, Information Transfer Meeting, November 4-6, 1986. 4 pp.

Rabalais, N.N., M.J. Dagg, and D.F. Boesch, 1985. Nationwide Review of Oxygen Depletion and Eutrophication in Estuarine and Coastal Waters: Gulf of Mexico (Alabama, Mississippi, Louisiana and Texas). Report to NOAA, Ocean Assessments Division. 60 pp.

Rabalais, N.N., B.A. McKee, D.J. Reed, and J.C. Means. 1991. Fate and effects of nearshore discharges of OCS produced waters. Vol. 1: Executive Summary. Vol. 2: Technical Report. Vol. 3: Appendices. OCS Studies MMS 91-004, MMS 91-005, and MMS 91-006. USDOI, MMS, Gulf of Mexico OCS Regional Office, New Orleans, LA.

Rabalais, N.N., B.A. McKee, D.J. Reed, and J.C. Means. 1992. Fate and Effects of Produced Water Discharges in Coastal Louisiana, Gulf of Mexico, USA. In: J.P. Ray and F.R. Engelhart (Eds.). Produced Water Technological/Environmental Issues and Solutions. Plenum Press, New York, NY. pp. 355-369.

Rabke S. et al. 1998a. Interlaboratory Comparison of a 96-hour *Mysidopsis bahia* Bioassay Using a Water Insoluble Synthetic-Based Drilling Fluid. Presented at 19th Annual Meeting of Society of Environmental Toxicology and Chemistry Charlotte NC 1998.

Ray, J.P. and R.P. Meek. 1980. Water Column Characterization of Drilling Fluids Dispersion from an Offshore Exploratory Well on Tanner Bank. In: Symposium on research on environmental fate and effects of drilling fluids and cuttings. Lake Buena Vista, FL, January 1980. API, Washington, DC.

Renaud, M.L., 1985. Hypoxia in Louisiana coastal waters during 1983: Implications for fisheries. *Fishery Bulletin* 84(1):19-26.

Roach, R.W., R.S. Carr, and C.L. Howard. 1992. An Assessment of Produced Water Impacts at Two Sites in the Galveston Bay System. U.S. Fish and Wildlife Service, Division of Ecological Services, Houston, TX.

Robinson, M.K. 1973. Atlas of monthly mean sea surface and subsurface temperature and depth of the top of the thermocline Gulf of Mexico and Caribbean Sea. Scripps Inst. of Ocean., Reference 73-8, 12 pp + 93 figures. In: MMS. 1990. Draft environmental impact statement. Gulf of Mexico Sales 131, 135, and 137: Central Western and Eastern Planning Areas. Gulf of Mexico OCS Region Office. MMS 90-0003.

Roesijadi, G., J.W. Anderson, and J.W. Blaylock. 1978. Uptake of hydrocarbons from marine sediments contaminated with Prudoe Bay crude oil: Influence of feeding type of test species and availability of polycyclic aromatic hydrocarbons. J. Fish. Res. Bd. Canada. 35:608-614.

Roithmayr, C.M., and R.A. Waller. 1983. Seasonal occurrance of *Brevoortia patronus* in the northern Gulf of Mexico. *Trans. Am. Fish. Soc.* 92(3):301-302.

Rose, C.D., and T.J. Ward. 1981. Acute toxicity and aquatic hazard associated with discharge formation water. Pages 301-328 In: B.S. Middleditch (ed.), Environ. Effects of Offshore Oil Production. The Buccaneer Gas and Oil Field Study. Plenum Press, NY.

Rossi, S.S. 1977. Bioavailability of petroleum hydrocarbon from water, sediments, and detritus to the marine annelid *Neanthes arenaceodentata*. In: Proceedings 1977 Oil Spill Conference (Prevention, Behavior, Control, Cleanup). API, Washington, DC. pp. 621-626.

Rubenstein, N.I., R. Rigby, and C.N. D'Asaro. 1980. Acute and sublethal effects of whole used drilling fluids on representative estuarine organisms. In: Symposium on research on environmental fate and effects of drilling fluids and cuttings. Lake Buena Vista, FL, January 1980. API, Washington, DC. pp. 828-848.

Rushing, J.H., M.A. Churan, and F.V. Jones. 1991. Bioaccumulation from mineral oil-wet and synthetic liquid-wet cuttings in an estuarine fish, *Fundulus grandi*s. SPE 23350. Pages 311-320 In: The First International Conference on Health, Safety and Environment. The Hague, The Netherlands, 10-14 November 1991. Society of Petroleum Engineers, Inc. Richardson, TX.

Sauer, T.C., Jr., T.J. Ward, J.S. Brown, S. O'Neill, and M.J. Wade. 1978. Volatile liquid hydrocarbons in the surface coastal waters of the Gulf of Mexico. Mar. Chem. 7:1-16.

Sauer, T.C., Jr. 1980. Volatile liquid hydrocarbons in waters of the Gulf of Mexico and Caribbean Sea. Limnol. Oceanog. 25:338-351.

Sauer, T.C., Jr., T.J. Ward, J.S. Brown, S. O'Neill, and M.J. Wade. 1992. Identification of Toxicity in Low-TDS Produced Waters. In: J.P. Ray and F.R. Engelhardt (Eds.) Produced Water Technological/Environmental Issues and Solutions. PennWell Books, New York, NY. pp. 209-222.

Saunders, R.P., and D.A. Glenn. 1969. Diatoms. Mem. Hourglass Cruises. Florida Marine Research Publications Series. 119 pp.

Schaanning, M.T. 1996. Environmental Fate of Synthetic Drilling Fluids from Offshore Drilling Operations. NIVA rapport nr. 3429-96.

Schafer, H.A., G.P. Hershelman, D.R. Young, and A.J. Mearns. 1982. Contamination in ocean food webs. p. 17-28. In: W. Bascom (ed.) SCCWRP Biennial Rep. 1981-1982.

SAIC. 1991. Descriptive Statistics and distributional Analysis of Cadmium and Mercury Concentrations in Barite, Drilling Fluids, and Drill Cuttings from the API/USEPA Metals Database. Prepared for Industrial Technology Division, U.S. Environmental Protection Agency, February 1991.

SAIC. 1992. Discharge Characterization Spreadsheets. Submitted to Office of Science and Technology, U.S. EPA, Washington, DC.

Sharp, J.R., R.S. Carr, and J.M. Neff. 1984. Influence of used chrome lignosulfonate drilling and fluids on the early life history of the mummichog *Fundulus heteroclitus*. In: Proc. Ocean Dumping Symposium. John Wiley & Sons, New York. 14 pp.

Shonkoff S.B., Hays J, Finkel M.L. 2014. Environmental public health dimensions of shale and tight gas development. Environ Health Perspect 122:787–795; http://dx.doi.org/10.1289/ehp.1307866

Smith, G.G. (ed.) 1981. Cambridge Encyclopedia of Earth Sciences. Cambridge University Press, Cambridge. In: Kennish, M.J. (ed.). 1989. Practical Handbook of Marine Science. CRC Press Inc. Boca Raton, FL. 710 pp.

Smith, J.P. 1993. Field Observations of Dilution of Radium-226 from Produced Water Discharges - Comparison with Dispersion Model Predictions. Report to the Offshore Operators Committee.

Smith, J.P., H.L. Mairs, M.G. Brandsma, R.P. Meek, and R.C. Ayers. 1994. Field Validation of the Offshore Operators Committee (OOC) Produced Water Discharge Model. SPE Paper 28350. SPE 69th Annual Technical Conference and Exhibit, New Orleans, LA. Society of Petroleum Engineers, Richardson, TX.

Somerville, H.J., D. Bennett, J.N. Davenport, M.S. Holt, A. Lymes, A. Mahieu, B. McCourt, J.G. Parker, R.R. Stephenson, R.J. Watkinson, and T.G. Wilkinson. 1987. Environmental effects of produced water from North Sea oil operations. Mar. Pollut. Bull. 18:549-558.

Stephenson, M.T., R.C. Ayers, L.J Bickford, D.D. Caudle, J.T. Cline, G. Cranmer, A. Duff, E. Garland, T.A. Herenius, R.P.W.M. Jacobs, C. Inglesfield, G. Norris, J.D. Petersen, and A.D. Read. 1994. North Sea produced water: fate and effects in the marine environment. Report No. 2.62/204. E&P Forum, London, England. 48 pp.

Steidinger, K.A., and J. Williams. 1970. Dinoflagellates. Mem. Hourglass Cruises. Florida Marine Research Publications Series. 225 pp.

Steinhauer, M., E. Crecelius, and W. Steinhauer. 1994. Temporal and spatial changes in the concentrations of trace metals in the vicinity of an offshore oil-production platform. Mar. Environ. Res. 37:129-163.

Stevens, L. 1993. Letter to H.J. Mueller, U.S. EPA, Region 4 regarding endangered species in Mississippi, Alabama, and Florida from L. Stevens, NMFS. March 25, 1993.

Strømgren, T., S.E. Sørstrøm, L. Schou, I. Kaarstad, T. Aunaas, O.G. Brakstad, and Ø. Johansen. 1995. Acute toxic effects of produced water in relation to chemical composition and dispersion. Mar. Environ. Res. 40:147-169.

Sutter, F.C., R.S. Waller, and T.D. McIlwain. 1986. Species Profile: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Gulf of Mexico)--Black Drum. Prepared for U.S. Army Corps of Engineers and U.S. FWS. Biological report 82(11.51), TR EL-82-4.

Sutton, T.T. and T.L. Hopkins. 1996. Species composition, abundance and vertical distribution of the stomiid (Pices: Stomiiformes) fish assemblage of the eastern Gulf of Mexico. Bull. Mar. Sci. 59: 530-542.

Tagatz, M.E., J.M. Ivey, H.K. Lehman, M. Tobia, and J.L. Oglesby. 1980. Effects of Drilling Mud on Development of Experimental Estuarine Macrobenthic Communities. In: Symposium on research on environmental fate and effects of drilling fluids and cuttings. Lake Buena Vista, FL, January 1980. API, Washington, DC.

Tagatz, M.E. and M. Tobia. 1978. Effect of Barite ($BaSO_4$) on Development of Estuarine Communities. Estuarine and Coastal Marine Science, 7:401-407.

Technical Resources, Inc. 1988. Analysis of Effluent Dispersion Models Potentially Applicable to Shallow Water Discharges from Oil and Gas Activities. Prepared for U.S. EPA, Region 6, Dallas, TX. 43 pp.

Temple, R.F., D.L. Harrington, and J.A. Martin. 1977. Monthly Temperature and Salinity Measurements of Continental Shelf Waters of the Northwestern Gulf of Mexico, 1963-1965. NOAA Tech. Rep. SSRF-707. 29 pp.

Terrens, G.W. and R.D. Tait. 1993. Effects on marine environment of produced formation water discharges from Esso/BHPP's Bass Strait Platforms. Esso Australia Ltd., Melbourne, Australia. 25 pp.

Terrens, G.W. and R.D. Tait. 1996. Monitoring ocean concentrations of aromatic hydrocarbons from produced formation water discharges to Bass Strait, Australia. SPE 36033. Proceedings of the International Conference on Health, Safety & Environment. Society of Petroleum Engineers, Richardson, TX.

Texas A&M University. 1991. Mississippi-Alabama Continental Shelf Ecosystem Study, Data Summary and Synthesis. Prepared for MMS Gulf of Mexico OCS Region. MMS 91-0064.

Thayer, G.W., and J.F. Ustach. 1981. Gulf of Mexico Wetlands: Value, state of knowledge and research needs. In: Proceedings of a Symp. on Environ. Res. Needs in the Gulf of Mexico (GOMEX), Key Biscayne, FL, September 1979. Atwood, D.K. (ed). Vol. IIB: 2-19.

Thomas, R.E. and S.D. Rice. 1979. The Effect of Exposure Temperatures on Oxygen Consumption and Operation Breathing Rates of Pink Salmon Fry Exposed to Toluene, Naphthalene, and Water-Soluble Fractions of Cook Inlet Crude Oil and No. 2 Fuel Oil. In: Marine Pollution: Functional Response. Academic Press, Inc.

Thompson, J.H., Jr. and T.J. Bright. 1977. Effect of drilling mud on clearing rates of certain hermatypic corals. Proceedings of the Oil Spill Conference (Prevention, Behavior, Control, Clean-up). March 8-10, 1977. New Orleans. pp. 495-498. In: Petrazzuolo, G. 1983. Environmental Assessment of Drilling Fluids and Cuttings Discharge on the OCS. Draft Final Report. U.S. EPA, Washington, DC.

Thompson, J.H., Jr. and T.J. Bright. 1980. Effects on an Offshore Drilling Fluid on Selected Corals. In: Symposium on research on environmental fate and effects of drilling fluids and cuttings. Lake Buena Vista, FL, January 1980. API, Washington, DC.

Tillery, J.B. and R.E. Thomas. 1980. Heavy Metals Contamination from Petroleum Production Platforms in the Central Gulf of Mexico. In: Symposium on research on environmental fate and effects of drilling fluids and cuttings. Lake Buena Vista, FL, January 1980. API, Washington, DC.

Tornberg, L.D., E.D. Thielk, R.E. Nakatani, R.C. Miller, and S.O. Hillman. 1980. Toxicity of Drilling Fluids to Marine Organisms in the Beaufort Sea, Alaska. In: Symposium on research on environmental fate and effects of drilling fluids and cuttings. Lake Buena Vista, FL, January 1980. API, Washington, DC.

Trees, C.C., and S.Z. El-Sayed. 1986. Remote sensing of chlorophyll concentrations in the northern Gulf of Mexico. Proceedings of SPIE, the International Society for Optical Engineering: Ocean Optics Viii. M. Blizzard (ed). Vol. 637, pp 328-334.

Trefry, J.H., R. Trocine, and D. Meyer. 1981. Tracing the Fate of Petroleum Drilling Fluids in the Northwest Gulf of Mexico. *Oceans*, September 1981. pp. 732-736.

Trefry, J.H., R.P. Trocine, S. Metz and M.A. Sisler. 1986. Forms, Reactivity and Availability of Trace Metals in Barite. Draft Final Report to OOC.

Trocine, R.P., J.H. Trefry and D.B. Meyer. 1981. Inorganic tracers of petroleum drilling fluid dispersion in the northwest Gulf of Mexico. Reprint Extended Abstract. Div. Environ. Chem., ACS Meeting, Atlanta, GA, March-April, 1981.

U.S. Environmental Protection Agency (U.S. EPA). 1978. Natural Radioactivity Contamination Problems. EPA 520/4-77-015.

U.S. EPA. 1985. Development Document for Effluent Limitations, Guidelines, and Standards for the Offshore Segment of the Oil and Gas Extraction Point Source Category. EPA 440/1-85-055.

U.S. EPA. 1993. Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Offshore Subcategory of the Oil and Gas Extraction Point Source Category. Office of Water. EPA 821-R-93-003.

U.S. EPA. 1996. Development Document for Final Effluent Limitations Guidelines and Standards for the Coastal Subcategory of the Oil and Gas Extraction Point Source Category. EPA-821-R-96-023.

U.S. EPA. 1998. Final Environmental Impact Statement, National Pollutant Discharge Elimination System permitting for Eastern Gulf of Mexico Offshore Oil and Gas Extraction. EPA-904/9-98-003.

U.S. EPA. 1997. Letter from Alexandra Tarnay, U.S. EPA to Nerija Orentas, *Avanti* Corporation, regarding Current Federal Water Quality Criteria, February 20, 1997.

U.S. EPA. 1999. Development Document for Proposed Effluent Limitations Guidelines and Standards for Synthetic-Based Drilling Fluids and other Non-Aqueous Drilling Fluids in the Oil and Gas Extraction Point Source Category. EPA-821-B-98-021.

U.S. EPA, Region 10. 1984. Final Ocean Discharge Criteria Evaluation, Diapir Field. OCS LeaseSales 87 and State Lease Sales 39, 43, and 43a. Prepared by Jones and Stokes Assoc., Inc. andTetra Tech, Inc.

U.S. EPA. 2000. Environmental Assessment of Final Effluent Limitations Guidelines and Standards for Synthetic-Based Drilling Fluids and other Non-Aqueous Drilling Fluids in the Oil and Gas Extraction Point Source Category. Office of Water. EPA-821-B-00-014

U.S. EPA. 2002. National Recommended Water Quality Criteria: 2002. Office of Water. EPA-822-R-02-047.

U.S. EPA. 2015. Technical Development Document for Effluent Limitations Guidelines and Standards for Oil and Gas Extraction. EPA-821-R-15-003. 205pp.

U.S. EPA. 2016. Draft Environmental Assessment, National Pollutant Discharge Elimination System (NPDES) Permit for Eastern Gulf of Mexico Offshore Oil and Gas Exploration, Development, and Production. EPA-904-P-001.

USFWS 2010. Federally Listed Wildlife and Plants Threatened by Gulf Oil Spill http://www.fws.gov/home/dhoilspill/pdfs/FedListedBirdsGulf.pdf

USFWS 2013. Gulf Restoration. Threatened and Endangered Species on the Gulf Coast. http://www.fws.gov/gulfrestoration/TandEspecies.html

van der Borght, O. 1963. Accumulation of radium-226 by the freshwater gastropod *Lymnaea stagnolis* L. *Nature* 197:612-613.

Veil, J.A., Kimmell, T.A., Rechner, A.C. 2005. Characteristics of Produced Water Discharged to the Gulf of Mexico Hypoxic Zone. U.S. Dept. of Energy. Contract W-31-109-Eng-38. 74pp.

Versar. 1992. Aquatic and Human Health Toxicity Data for Produced Water Pollutants, Draft. Memorandum from L. Wilson, March 2, 1992.

Vik, E.A., S. Dempsey, B. Nesgard. 1996. Evaluation of Available Test Results from Environmental Studies of Synthetic Based Drilling Muds. OLF Project, Acceptance Criteria for Drilling Fluids. Aquateam Report No. 96-010.

Vukovich, F.M., B.W. Crissman, M. Bushnell, and W.J. King. 1978. Sea-surface temperature variability analysis of potential OTEC sites utilizing satellite data. Research Triangle Institute, Research Triangle Park, NC. 153 pp.

Wheeler, R.B., J.B. Anderson, R.R. Schwarzer, and C.L., Hokanson. 1980. Sedimentary processes and trace metal contaminants in the Buccaneer oil/gas field, northwest Gulf of Mexico. *Environ. Geol*. 3:163-175.

Woodward-Clyde Consultants and CSA, Inc. 1984. Southwest Florida Shelf Ecosystems Study-Year 2. Report to MMS. 14-12-0001-29144.

Wright, S.J. 1993. Analysis of CORMIX1 and UM/PLUMES Predictive Ability for Buoyant Jets in a Density-Stratified Flow. Prepared for U.S. EPA Office of Wastewater Enforcement and Compliance.

Yentsch, C.S. 1982. Satellite observation of phytoplankton distribution associated with large scale oceanic circulation. NAFO Sci. Counc. Stud. No. 4. pp. 53-59.

Yoder, J.A. and A. Mahood. 1983. Primary Production in Loop Current Upwelling. In: Univ. of Maryland Eastern Shore. 1985. Federal OCS Oil and Gas Activities: A Relative Comparison of Marine Productivity Among the OCS Planning Areas. Draft report prepared for MMS. Coop. Agree. No. 14-12-0001-30114. 1,450 pp.

Zein-Eldin, Z.P., and P.M. Keney. 1979. Bioassay of Buccaneer oil field effluents with penaeid shrimp. Pages 2.3.4-1 to 2.3.4-25. In: Environmental Assessment of an Active Oil Field in the Northwestern Gulf of Mexico, 1977-1978. Volume II: Data Management and Biological Invest. NOAA, NMFS, Galveston, TX.

Zevallos, M.A.L., J. Candler, J.H. Wood, and L.M. Reuter. 1996. Synthetic-based fluids enhance environmental and drilling performance in deepwater locations. SPE 35329. Pages 235-242 In: SPE International Petroleum Conference & Exhibition of Mexico. Villahermosa, Tabasco, Mexico, 5-7 March 1996. Society of Petroleum Engineers, Inc. Richardson, TX.

Zingula, R.P. 1975. Effects of Drilling Operations on the Marine Environment. In: Conference Proceedings on Environmental Aspects of Chemical Use in Well-Drilling Operations, Houston, TX, May 21-23, 1975. EPA-550/1-75-004, 443-450. U.S. EPA, Washington, DC.

Updated materials

REGIONAL DIRECTOR'S NOTE (boem.gov)

Appendix A. Acute Lethal Toxicities of Used Drilling Fluids and Components to Marine Organisms

Test Organism	Fluid Description[a]	Criterion Value (ppm)	Toxicity Ratin
	USED DRILLING FLUIDS		
ALGA	Imco LDLS/SW	1,325-4,700 (96-h EC50)	4
Skeletonema costatum	Imco Lime/SW	1,375 (96-h EC50)	4
	Imco non-dispersed/SW	5,700 (96-h EC50)	4
	Lightly treated LS/SW-FW	3,700 (96-h EC50)	4
COPEPODS	Imco LDLS/SW	5,300-9,300	4
Acartia tonsa	Imco Lime/SW	5,600	4
	Imco non-dispersed/SW	66,500	5
	Lightly treated LS/SW-FW	10,000	5
	FCLS/FW	100-230	3
	Saltwater Gel	100	3
ISOPODS	FCLS/FW	70,000	5-6
Gnorimosphaeroma	XC-Polymer/Unical	314,000-500,000	6
oregonsis *Saduria*	CMC-Resinex Tannathin-Gel	530,000-600,000	6
entomon			
AMPHIPODS	FCLS/FW	10,000-50,000	5
Anisogammarus	FCLS/FW	10,000-200,000 (48-h	5-6
confervicolus	XC-Polymer/Unical	LC50)	6
	Spud mud	200,000-436,000	6
Onisimus sp./*Boekisima*	MDLS	100,000	5
sp. *Gammarus locusta*	MDLS (MAF)	74,000-90,000	6
	HDLS	100,000	5
	HDLS (MAF)	28,000-88,000	6
		100,000	
GASTROPODS	CMC-Resinex Tannathin-Gel	600,000-700,000	6
Nautica clausa, Neptuna	LDLS (MAF)	100,000	6
sp., & *Buccinum* sp.	LDLS	83,000	5
Littorina littorea	LDLS (MAF)	100,000	6
Thais lapillis	LDLS (suspended WM)	15,000	5
	MDLS	100,000	6
	MDLS (MAF)	100,000	6
	HDLS	100,000	6
	HDLS (MAF)	100,000	6
DECAPODS-SHRIMP	FCLS/FW	100,000 (48-h LC50)	6
Artemia salina	FCLS/FW	32,000-150,000	5-6
Pandalus hypsinotus		50,000-100,000 (48-h	5
	Spud mud (MAF)	LC50) 100,000	6
Crangon septemspinosa	Seawater LS (MAF)	100,000	6
	LDLS	71,000	5
	LDLS (suspended WM)	15,000	5
	LDLS (MAF)	98,000-100,000	5
	MDLS	82,000	5

Test Organism	Fluid Description[a]	Criterion Value (ppm)	Toxicity Ratin
	MDLS (suspended WM)	15,000	5
	MDLS (MAF)	17,000	5
	MDLS (FMAF)	19,000	5
	HDLS	92,000	5
	HDLS (suspended WM)	15,000	5
	HDLS (MAF)	100,000	6
	HDLS (FMAF)	100,000	6
	HDLS (MAF)	65,000	5
Pandalus borealis	HDLS (FMAF)	55,000	5
Stage I larvae	Spud Mud (MAF)	100,000	6
Palaemonetes pugio	Seawater-chrome LS (MAF)	27,500	5
Stage I zoeae	MDLS (MAF)	35,000	5
Adults	HDLS (MAF)	18,000	5
	HDLS (SPP)	11,800	5
	Spud Mud (MAF)	100,000	6
	Seawater-chrome LS (MAF)	92,400	5
	MDLS (MAF)	91,000	5
Stage III zoeae	HDLS (MAF)	100,000	6
Late premolt stage	Lightly treated LS	201	3
D_2 - D_4	HDLS (SPP)	11,700-13,200	5
Palaemonetes pugio	Mobile Bay fluid	318-863	3
larvae	Mobile Bay fluid	360-14,560	3-5
	Seawater LS	1,706-28,750	4-5
	Lightly treated LS	142	3
	Freshwater LS	4,276-4,509	4
	Lime	658	3
	FW/SW-LS	3,570	4
	Non-dispersed	100,000	6
	LTLS	35,420	5
Penaeus aztecus	Seawater-K-polymer	2,557	4
juvenile	Seawater-chrome LS (MAF)	41,500	5
Orchestia traskiana	MDLS (MAF)	16,000	5
	Seawater-polymer	230,000	6
	Pelly gel Chemical XC	80,000	5
	KCI-XC-Polymer	14,000	5
	Weighted shell polymer	34,000	5
	Gel-SX-polymer	420,000-500,000	6
	Imnak gel-XC-polymer	560,000	6
DECAPODS-CRABS	LDLS	89,100	5
Carcinus maenus	LDLS (suspended WM)	15,000	5
	LDLS (MAF)	100,000	6
	MDLS	68,000-100,000	5-6
	MDLS (suspended WM)	15,000	5
	MDLS (MAF)	100,000	6
	HDLS (MAF)	100,000	6
	Seawater-chrome LS (MAF)	28,700	5
Clibanarius vittatus	MDLS (MAF)	34,500	5
	HDLS (MAF)	65,600	5
	Seawater polymer	530,000	6
Hemigrapsus nudus	Shell Kipnik-KCL polymer	53,000	5

Test Organism	Fluid Description[a]	Criterion Value (ppm)	Toxicity Ratin
	Pelly gell chemical XC	560,000	6
	KCI-XC-polymer	78,000	5
	Weighted shell polymer	62,000	5
	Pelly weighted gel-XC-polymer	560,000	6
	Imnak gel-XC-polymer	560,000	6
DECAPODS-LOBSTER			
Homarus americanus	LDLS (MAF)	5,000	5
Stage V larvae	MDLS	100,000	6
	MDLS (MAF)	29,000	5
Adult	LDLS	19,000-25,000	5
	LDLS (MAF)	100,000	6
Larvae	Mobile Bay/Jay fluids	73.8-500 ppm	2-3
BIVALVES	FCLS/FW	30,000	5
Modiolus		30,000 (14 day LC50)	5
	Spud mud (MAF)	100,000	6
Mytilus edilus	Seawater LS (MAF)	100,000	6
	MDLS (MAF)	100,000	6
	MDLS (suspended WM)	15,000	5
	HDLS (MAF)	100,000	6
	HDLS (suspended WM)	15,000	5
Macama balthica	LDLS	100,000	6
	LDLS (MAF)	100,000	6
	LDLS (suspended WM)	15,000	5
	HDLS	100,000	6
	HDLS (MAF)	100,000	6
	HDLS (FMAF)	100,000	6
	LDLS	49,000	5
Placopecten	MDLS	3,200	4
magellanicus	Spud mud (SPP)	100,000	6
Crassostrea gigas	MDLS (SPP)	50,000-53,000	5
	HDLS (SPP)	73,000-74,000	5
	Spud mud (SPP)	100,000	6
Donax variabilis	Seawater-chrome LS (SPP)	53,700	5
texasiana	MDLS (SPP)	29,000	5
	HDLS (SPP)	56,000	5
	Seawater polymer	320,000	6
	Kipnik-KC1 polymer	42,000	5
Mya arenaria	Polly gel chemical XC	560,000	6
	KC1-XC-polymer	56,000	5
	Weighted shell polymer	10,000	5
	Weighted gel XC-polymer	560,000	6
	Weighted KC1-XC-polymer	560,000	6
	Imnak gel-XC-polymer	560,0008	6
Mercenaria Larvae	Seawater LS (LP)	7-3,000	2-4
	Seawater LS (SPP)	117-3,000	3-4
	LTLS (LP)	719-3,000	3-4
	LTLS (SPP)	122-2,889	3-4
	FWLS (LP)	319-330	3
	FWLS (SPP)	158-338	3

Test Organism	Fluid Description[a]	Criterion Value (ppm)	Toxicity Ratin
	FW/SW LS (LP)	380	3
	FW/SW LS (SPP)	82	2
	Lime (LP)	682	3
	Lime (SPP)	64	2
	Low solids non-dispersed (LP)	3,000	4
	Low-solids non-dispersed (SPP)	3,000	4
	Potassium polymer (LP)	269	3
	Potassium polymer (SPP)	220	3
ECHINODERMS	LDLS	55,000	5
Strongylocentrotus	LDLS (MAF)	100,000	6
droebachiensis	MDLS	100,000	6
	MDLS (MAF)	100,000	6
MYSIDS			
Neomysis integer	FCLS/FW	10,000-200,000 (48-h	5-6
		LC50)	5-6
Mysis sp.	CMC-Gel	10,000-125,000	6
	CMC-Gel-Resinex	142,000-349,000	5
	XC-polymer (supernatant)	58,000-93,000	6
Mysidopsis almyra	XC-polymer	250,000	5-6
	Spud mud (MAF)	50,000-170,000	6
	Seawater-chrome LS (MAF)	100,000	5
	MDLS (MAF)	27,000	5
	HDLS (MAF)	12,800-13,000	5
	MDLS (SPP)	16,000-32,500	5
	MDLS (MAF)	32,000	5
	MDLS (MAF) (static test)	26,800-66,300	5-6
	Reference mud (MAF) (static test)	72,100-113,000	6
		100,000	
Mysidopsis bahia	Seawater LS	429-1,557	3-4
	Seawater LS (LP)	150,000	6
	Seawater LS (SPP)	15,123-19,825	5
	Seawater LS (SP)	50,000	5
	LTLS	14-1,958	2-4
	LTLS (LP)	150,000	6
	LTLS (SPP)	1,641-50,000	3-5
	LTLS (SP)	1,246-2,437	3
	FWLS	301-1,500	3-4
	FWLS (LP)	97,238-121,476	5-6
	FWLS (SPP)	14,068-29,265	5
	Lime	87-98	2
	Lime (SPP)	650-791	3
	Lime (SP)	8,213-1,369,393	4-6
	FW/SW-LS	115-379	3
	FW/SW-LS (LP)	150,000	6
	FW/SW-LS (SPP)	11,380-38,362	5
	FW/SW-LS (SP)	50,000	5
	Low-solids non-dispersed	1,500	4
	Low-solids non-dispersed (LP)	150,000	6
	Low-solids non-dispersed (SPP)	50,000	5

Test Organism	Fluid Description[a]	Criterion Value (ppm)	Toxicity Ratin
	Low-solids non-dispersed (SP)	50,000	5
	Potassium polymer	1,500	4
	Potassium polymer (LP)	150,000	6
	Potassium polymer (SPP)	26,025-28,070	5
POLYCHAETES	CMC-Resinex-Tannathin	600,000	6
Melaenis loveni	CMC-Resinex-Tannathin-Gel	700,000	6
	Spud mud (MAF)	100,000	6
Nereis virens	Seawater-LS (MAF)	100,000	6
	LDLS	100,000	6
	LDLS (MAF)	100,000	6
	MDLS	100,000	6
	MDLS (MAF)	100,000	6
	HDLS	100,000	6
	HDLS (MAF)	100,000	6
	Spud mud (MAF)	100,000	6
Ophryotrocha labronica	Seawater-chrome LS (MAF)	100,000	6
	MDLS (MAF)	60,000	5
	HDLS (MAF)	100,000	5
	Seawater polymer	220,000	6
Neveis vexillosa	Kipnik-KC1 polymer	37,000	5
	Gel chemical XC	560,000	6
	KC1-XC-polymer	41,000	5
	Weighted shell polymer	23,000	5
	Weighted gel XC-polymer	320,000-560,000	6
	Imnak gel-XC-polymer	200,000	6
TELEOST FISH	Imco LDLS/SW	56,500-175,000	5-6
Menidia	Imco Lime	43,000-53,000	5
	Imco non-dispersed	345,000-385,000	6
	Saltwater gel	100,000	6
	LDLS-SW/FW	48,500	5
	FCLS	100,000	6
	FCLS/FW	3,000-29,000	4-5
Oncorhynchus gorbuscha	FCLS/FW	100,000-200,000	6
Leptocuttus armatus	CMC-Gel	120,000	6
Myoxocephalus	CMC-Gel-Resinex	50,000-70,000	5
quadricornis	XC-Polymer	50,000-215,000	5-6
	XC-Polymer (supernatant)	250,000	6
	Lignosulfonate	350,000	6
	CMC-Gel	200,000	6
	XC-Polymer	57,000-370,000	5-6
Coregonus nasus	XC-Polymer (supernatant)	100,000-250,000	6
	Lignosulfonate	0-100,000	6
	CMC-Gel	170,000-300,000	6
	XC-Polymer	250,000	6
Elegonus naraga	Lignosulfonate	200,000-250,000	6
Boreogodus saida	Lignosulfonate	85,000-1,000,000	6
	Spud mud (MAF)	100,000	6
Coregonus autumnalis	Seawater-LS (MAF)	100,000	6
Fundulus heteroclitus	MDLS (suspended whole mud)	15,000	5

Test Organism	Fluid Description[a]	Criterion Value (ppm)	Toxicity Ratin
	MDLS (MAF)	100,000	6
	HDLS (suspended whole mud)	15,000	6
	HDLS (MAF)	100,000	6
	Kipnik-KC1 polymer	24,000-42,000	5
Salmo gairdneri (juvenile)	Seawater polymer	130,000	6
	KC1-XC polymer	34,000	5
	Weighted shell polymer	16,000	5
	Pelly gel chemical-XC	42,000	5
	Weighted gel XC-polymer	18,000-48,000	5
	Imnak-Gel XC-polymer	42,000	5
	Kipnik-KC1 polymer	29,000	5
	Seawater polymer	130,000	5
Oncorhynchus kisutch (juvenile)	KC1-XC polymer	20,000-23,000	5
	Weighted shell polymer	4,000-15,000	4-5
	Pelly Gel chemical-XC	28,000-130,000	5-6
	Weighted gel XC-polymer	24,000-190,000	5-6
	Imnak-Gel XC-polymer	23,000-30,000	5
	Kipnik-KC1 polymer	24,000	5
O. keta (juvenile) *O. gorbuscha* (juvenile)	Kipnik-KC1 polymer	41,000	5
	DRILLING FLUID COMPONENTS		
Skeletonema costatum	Barite	385-1,650	3-4
	Aquagel	9,600	4
Arcartia tonsa	Barite	590	3
	Aquagel	22,000	5
Pandalus hypsinotus	Barite	100,000	6
	Aquagel	100,000	6
Molliensias latipinna	Barite	100,000	6
	Calcite	100,000	6
	Siderite	100,000	6
	Chrome lignosulfonate	7,800-12,200	4-5
	Quebracho	135-158	3
	Lignite	15,500-24,500	5
	Sodium acid pyrophosphate	1,200-7,100	4
Penaeus setiferus	Hemlock bark extract	265	3
	Polyacrylate	3,500	4
	$CaCO_3$ workover additive	1,925	4
	Chrome-treated lignosulfonate	465	3
	Lead-treated lignosulfonate	2,100	4

Table footnotes and references appear on following page.

Appendix A. Footnotes and References

[a] Drilling fluids abbreviations (test fractions in parenthesis):

WM = Whole mud
MAF = Mud aqueous fraction
FMAF = Filtered mud aqueous fraction

SW = Saltwater dispersed
FW = Freshwater dispersed
LS = Lignosulfonate

SPP = Suspended particulate phase
SP = Solid phase
LP = Liquid phase

LDLS = Low-density lignosulfonate
MDLS = Medium-density lignosulfonate
HDLS = High-density lignosulfonate
LTLS = Lightly-treated lignosulfonate
FCLS = Ferrochrome lignosulfonate

[b] Toxicity ratings as per Hocutt & Stauffer, 1980.

1. Very toxic (1 ppm)
2. Toxic (1-100 ppm)
3. Moderately toxic (100-1,000 ppm)
4. Slightly toxic (1,000-10,000 ppm)
5. Practically non-toxic (10,000-100,000 ppm)
6. Non-toxic (100,000 ppm)

[c] References:

1. IMCO Services, 1977.
2. Shell Oil Co., 1976.
3. Atlantic Richfield, 1978.
4. Tornberg et al., 1980.
5. Gerber et al., 1980.
6. Neff et al., 1980.
7. Conklin et al., 1980.
8. Environmental Protection Service, 1976.
9. Conklin et al., 1983.
10. Capuzzo and Derby, 1982.
11. Duke et al., 1984.
12. Carr et al., 1980.
13. Grantham and Sloan, 1975.
14. Hollingsworth and Lockhart, 1975.
15. Chesser and McKenzie, 1975.

Appendix B. Metal Enrichment Factors in Shrimp, Clams, Oysters, and Scallops Following Exposure to Drilling Fluids and Drilling Fluid Components

Test Organism	Test Substance Concentration (ppm)	Exposure Period (days)	Metals Enrichment Factor [a]				
			Ba	Cr	Pb	Sr	Zn
Palaemonetes pugio [b]	Barite						
Whole animal not	5	7, 48-hr replacement	150			1.3	
gutted	50	(after 14-d depuration)	350			1.9	
	5	(after 14-d depuration)	2.2			1.8	
	50		29			2.2	
	Barite	8 days post-ecdysis,					
Carapace	(500)	range = 8-21	7.7			1.2-2.5	
Hepatopancreas	(500)	(48-hour replacement)	13			1.9-2.8	
Abdominal muscle	(500)		12			1.5-2.8	
	Barite	106					
Carapace	(500)		60-100			1.6-7.4	
Hepatopancreas	(500)		70-300			0.03	
Abdominal muscle	(500)		50-120			0.71	
Rangia cuneata [c]	12.7 lb/gal						
(soft tissue)	lignosulfonate fluid	4, static		1.4	1.7		
	(50,000 MAF)	(after 4-dy depuration)		1.1	1.2		
	13.4 lb/gal	16, static		2.5			
	lignosulfonate fluid	(after 1-dy depuration)		1.7			
	(100,000 MAF)	(after 14-dy depuration)		1.6			
		4, daily replacement					
	Layered solid phase	(after 1-dy depuration)		4.3			
				2.0			
Crassostrea gigas [c]	9.2 lb/gal spud fluid						
(soft tissue)	(40,000 MAF)	10, static			2.1		1.1
	(10,000 SPP)	4, 24-hr replacement		2.5			
	(20,000 SPP)			3.0			
	(40,000 SPP)			3.0			
	(60,000 SPP)			5.5			
	(80,000 SPP)			7.4			

Source: Adapted from Petrazzuolo, 1983; footnotes at end of table.

Appendix B. Metal Enrichment Factors in Shrimp, Clams, Oysters, and Scallops Following Exposure to Drilling Fluids and Drilling Fluid Components (cont.)

Test Organism	Test Substance Concentration (ppm)	Exposure Period (days)	Metals Enrichment Factor [a]				
			Ba	Cr	Pb	Sr	Zn
Crassostrea gigas	12.7 lb/gal						

Test Organism (soft tissue cont.)	Test Substance Concentration (ppm)	Exposure Period (days)	Metals Enrichment Factor [a]				
			Ba	Cr	Pb	Sr	Zn
	lignosulfonate fluid						
	(40,000 MAF)	10, static			2.3		1.4
	(20,000 MAF)	14		2.9			
	(40,000 MAF)	14		3.9			
	(10,000 SPP)	4, 24-hr replacement		2.2			
	(20,000 SPP)			4.4			
	(40,000 SPP)			8.6			
	(60,000 SPP)			24			
	(80,000 SPP)			36			
	17.4 lb/gal lignosulfonate fluid						
	(40,000 MAF)	10, static			0.56		1.0
	(20,000 MAF)	14		2.1			
	(40,000 MAF)	14		2.2			
Placopecten magellanicus [d]	Uncirculated lignosulfonate fluid						
Kidney Adductor	(1,000)	28	8.8	2.6			
muscle	(1,000)	28	10	1.2			
	Low density lignosulfonate fluid						
Kidney Adductor	(1,000)	14		1.6			
		27		2.1			
		(after 15-dy depuration)		2.3			
muscle	(1,000)	14		2			
		27		2			
		(after 15-dy depuration)		2			
	FCLS (30)	14		5.7			
		(after 15-dy depuration)		3.2			
	(100)	14		6.0			
		(after 15-dy depuration)		5.2			
	(1,000)	14		7.2			
		(after 15-dy depuration)		6.0			

[a] Enrichment factor = concentration in exposed group/concentration in controls.
[b] Source: Brannon and Rao, 1979.
[c] Source: McCulloch et al., 1980.
[d] Source: Liss et al., 1980.