EPA Contract 68-C5-0035

OCEAN DISCHARGE CRITERIA EVALUATION FOR THE NPDES GENERAL PERMIT FOR THE EASTERN GULF OF MEXICO OCS

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1. INTRODUCTION

1.1 Background

The Clean Water Act Section 402 authorizes the U.S. Environmental Protection Agency (EPA) to issue National Pollutant Discharge Elimination System (NPDES) permits to regulate discharges to the nation's waters. EPA Region 4 is issuing an NPDES general permit for waters on the Outer Continental Shelf (OCS) of the eastern Gulf of Mexico for effluent discharges associated with oil and gas exploration, development, and production activities. Sections 402 and 403 of the Clean Water Act require that NPDES permits for discharges to the territorial seas (baseline to 3 miles), the contiguous zone, and the ocean be issued in compliance with EPA's regulations for preventing unreasonable degradation of the receiving waters.

Prior to permit issuance, discharges must be evaluated against EPA's published criteria for determination of unreasonable degradation. Unreasonable degradation is defined in the NPDES regulations (40 CFR 125.121[e]) 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 determining 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 finfishing and shellfishing

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

9. Such other factors relating to the effects of the discharges as may be appropriate

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

In the event that an assessment of these 10 factors determines that unreasonable degradation may occur even with proposed technology- and water quality-based permit conditions in place, Section 403(c) authorizes the Agency to impose more stringent permit conditions and/or monitoring. If the Agency concludes that a determination cannot be made due to lack of data, an NPDES permit may not be issued.

1.2 Scope

This Ocean Discharge Criteria Evaluation (ODCE) will address the ten factors for determining unreasonable degradation as outlined above and at 40 CFR 125.122. It will also assess whether the information exists to make a "no unreasonable degradation" determination including any permit conditions that may be necessary to make that determination. The information contained in several chapters of the ODCE includes the geographic area shoreward of the 200 meter depth contour, not covered by the general permit, for completeness and to fully address the potential for impacts to these areas from oil and gas activities beyond (seaward) of the 200 meter depth contour.

Chapter 2 of this document describes the physical and chemical oceanography relevant to the coverage area, and addresses Factor 2 of the 10 factors listed above. The quantities and composition of materials that are potentially discharged from covered facilities (Factor 1) are described in Chapter 3 of this document. The fourth chapter of this ODCE describes the transport and persistence characteristics of the discharges (Factor 2). Chapter 5 summarizes the toxicity and bioaccumulation characteristics of the waste streams covered by the permit (Factors 1 and 6). The biological communities, endangered species, and the importance of the receiving waters to those species and their habitats (Factors 3 and 4) are presented in Chapter 6 of this document. Commercial and recreational fisheries are discussed in Chapter 7 (Factor 7). The OCS general permit covers only Federal waters beyond state jurisdiction; however the coastal zone management plans (CZMPs) of Florida, Alabama, and Mississippi were reviewed for consistency due to the proximity of Federal waters to state waters. Chapter 8 discusses the consistency of the general permit with those plans (Factors 5, 7, and 8). Chapter 9 compares Federal marine water quality and human health criteria and Florida, Alabama, and Mississippi state water quality standards (Factor 10) to projected water column pollutant concentrations to assess potential impacts of the discharges, both on human health (Factor 6) and on biological communities (Factors 3 and 4). Chapter 10 summarizes information regarding the potential effects of covered discharges considering all of the information presented in Chapters 3 through 9. Chapter 11 offers the basis for the Agency's determination on consistency with the 10 factors used to determine unreasonable degradation. This chapter also describes the technology-, water quality-, and 403(c)-based permit conditions.

2. PHYSICAL AND CHEMICAL OCEANOGRAPHY

To address Factor 2 (biological, physical, and chemical transport processes) of the 10 factors used to determine unreasonable degradation, the physical and chemical oceanography of the eastern Gulf of Mexico, or the receiving waters, are characterized. This general description of the oceanography is used in the examination of the fate of the discharges in Chapter 4, Transport and Persistence.

2.1 Physical Oceanography

Physical oceanography is the marine science that describes the motions of ocean waters (e.g., currents, tides, and waves) as well as the physical properties of seawater such as temperature and salinity (Kennish, 1989). The physical oceanographic conditions of the receiving waters will influence the fate of discharges and the eventual exposure of marine organisms to those discharges.

2.1.1 Circulation

Circulation patterns in the Gulf of Mexico 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 Gulf of Mexico is the Loop Current. 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 (Figure 2-1). Within this zone, short-term strong currents exist, but no permanent currents have been identified (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).

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. In general, winter surface circulation in the Mississippi/Alabama shelf area is directed along shore and westward with flow averaging 4 cm/s to 7 cm/s. During the spring and summer, the current shifts to the east with flow averaging 2 cm/s to 7 cm/s. The mean circulation on the west Florida shelf is directed southward with mean flow ranging from 0.2 cm/s to 7 cm/s (MMS, 1990).

Figures 2-2 through 2-5 illustrate wind patterns in the Gulf which are primarily anticyclonic (clockwise around high pressure areas), and tend to follow an annual cycle; winter winds from the east-northeast, spring winds from the southeast, summer winds from the southeast and south, and fall winds

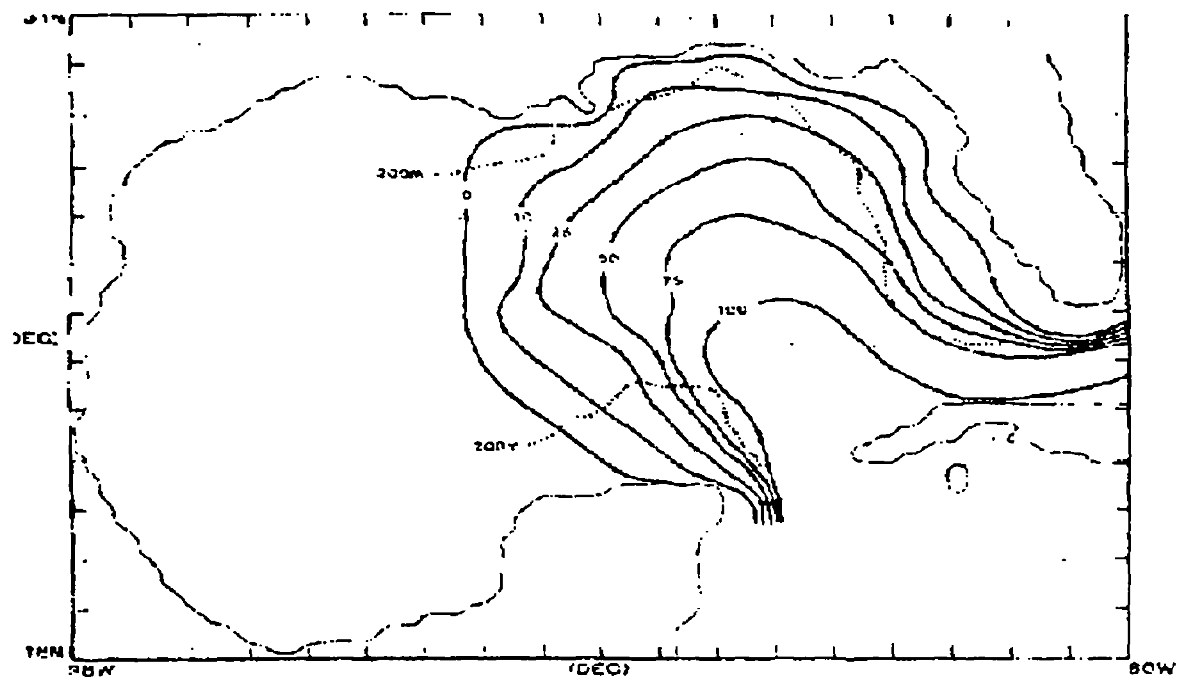

Figure 2-1. Frequency of Occurrence (%) for Loop Current Water During March
Analyzed for the period 1973 -1977, for unit 1° latitude-longitude squares based on satellite data (Vukovich et al., 1978). Of the seven months similarly analyzed (few satellite observations are useful from June to October), March displayed the apparent greatest intrusion, while November displayed the least. Source: MMS, 1986.

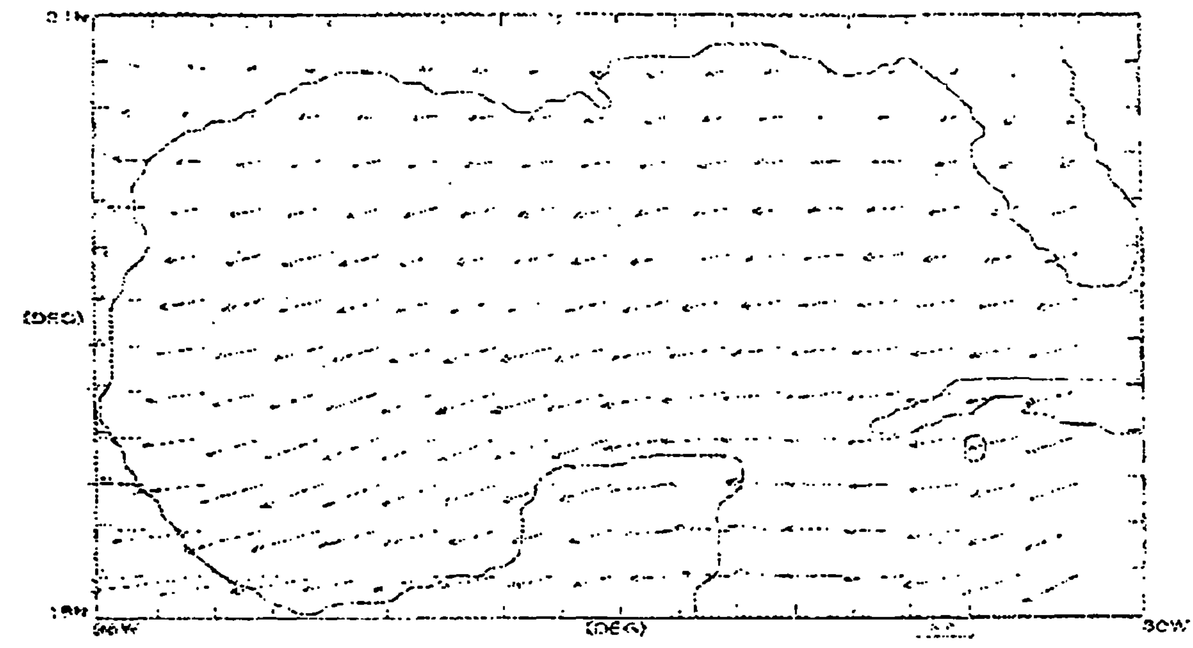

Figure 2-2. Winter Geostrophic Winds
(December - February; m/sec, average of the period 1967 - 1982) Source: MMS, 1986.

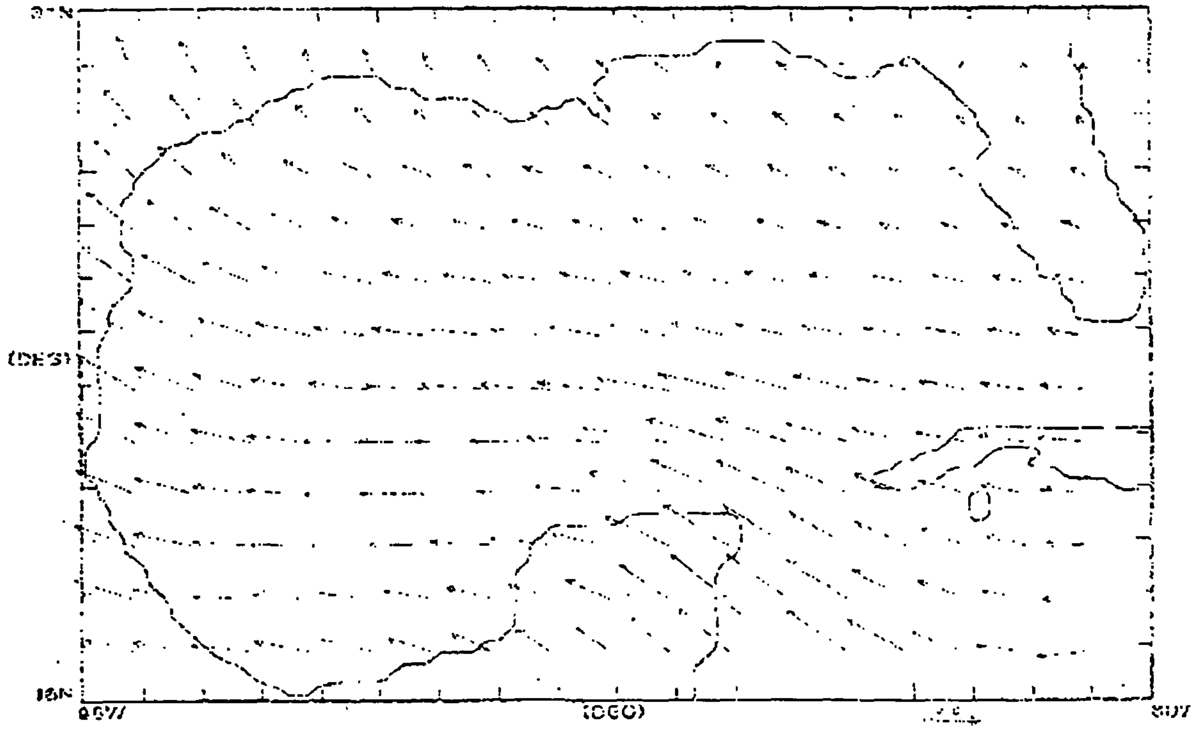

Figure 2-3. Spring Geostrophic Winds
(March - May; m/sec, average of period 1967 - 1982) Source: MMS, 1986

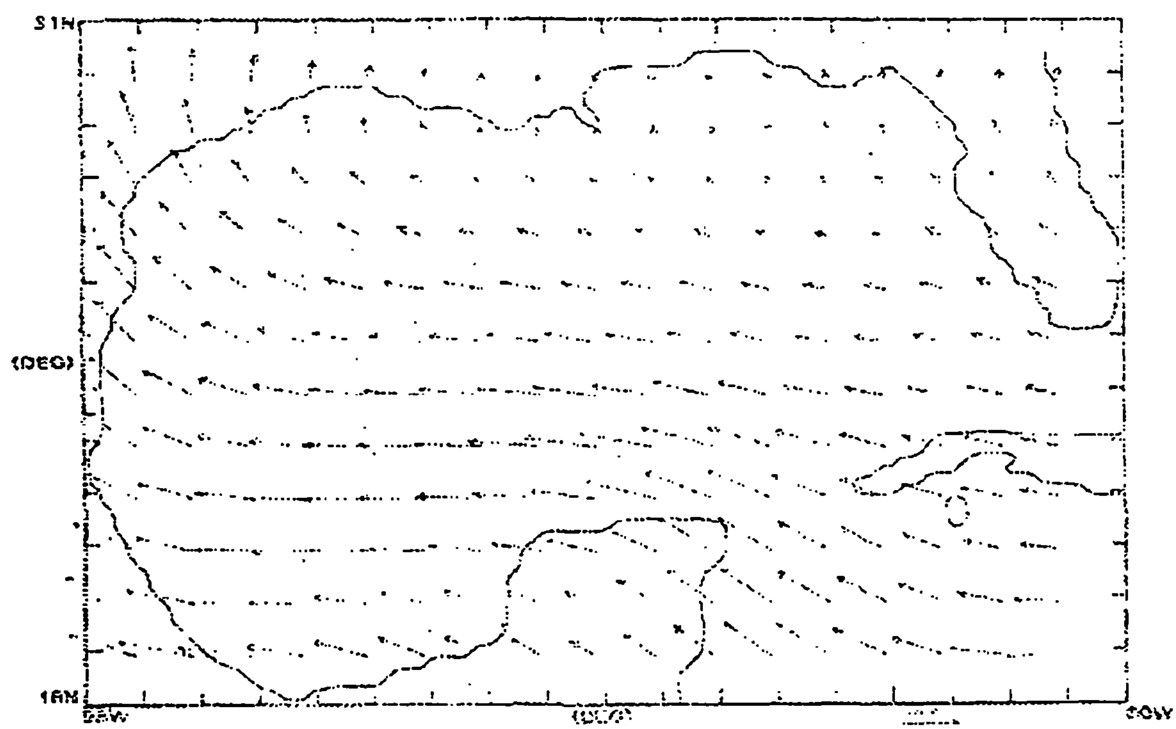

Table 2-4. Summer Geostrophic Winds
(June - August; m/sec, average of period 1967 - 1982) Source: MMS, 1986

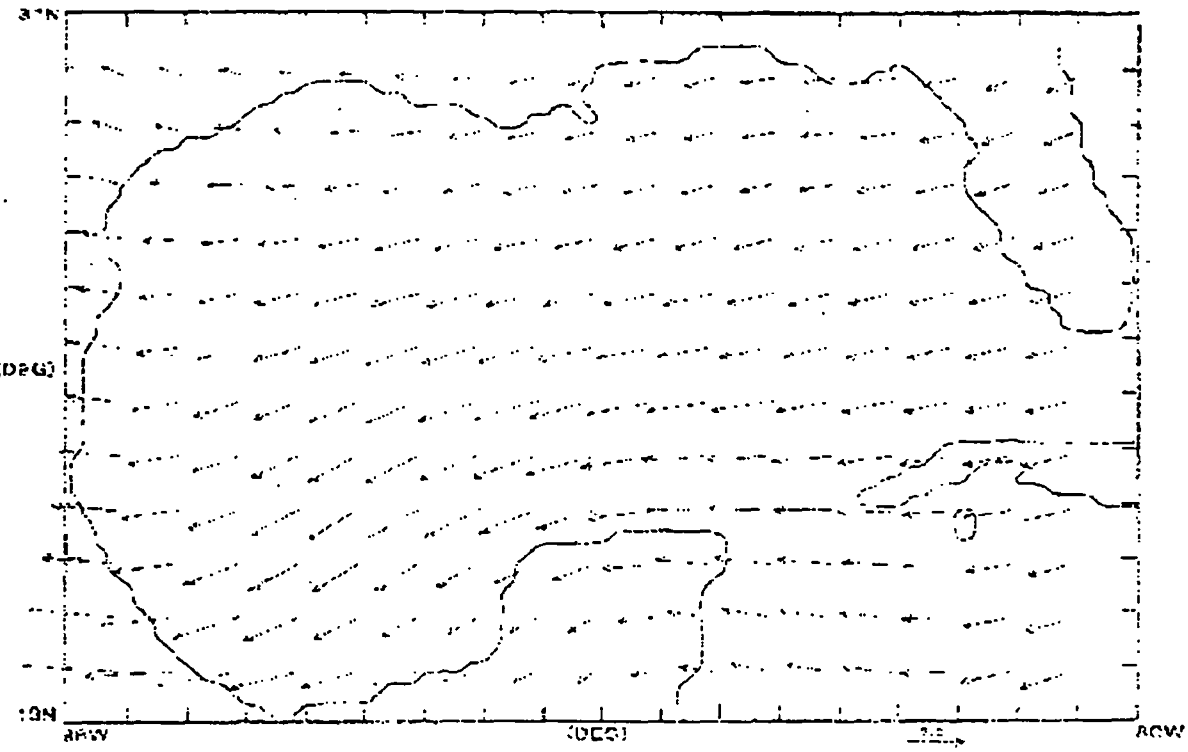

Figure 2-5. Fall Geostrophic Winds
(September - November; m/sec, average of period 1967 - 1982) Source: MMS, 1986

shifting back to the east-northeast (MMS, 1990). 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 meters to 1.2 meters, depending on the location and time of year. The Gulf has three types of tides, which vary throughout the area: diurnal, semidiurnal, and mixed (both diurnal and semidiurnal). These are illustrated in Figure 2-6. 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 (18+ meters per second), high waves (7+ meters), and storm surge (3 to 7.5 meters). Winter storm systems also may cause moderately high winds, waves, and storm conditions that mask local tides.

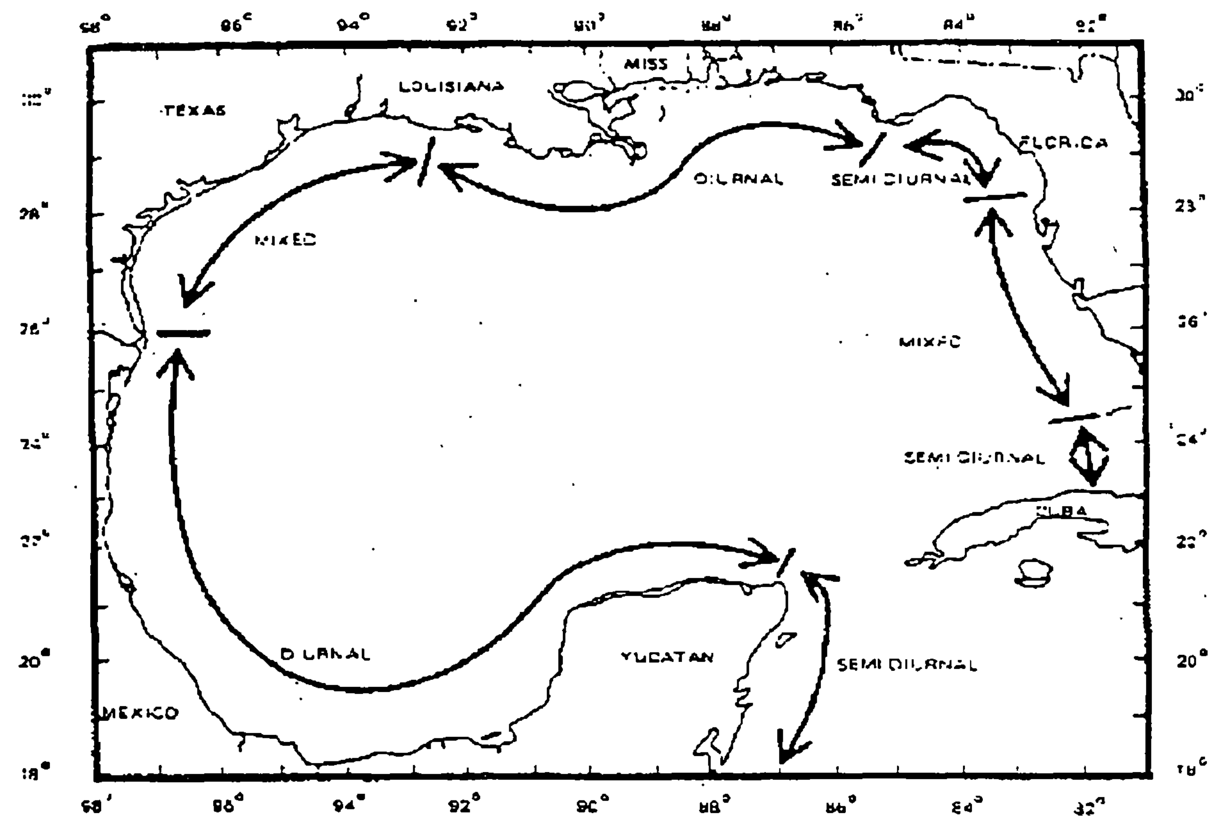

Figure 2-6. Gulf of Mexico Tidal Regimes
(Source: Eleuterius, 1979)

2.1.2 Temperature and Salinity

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).

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).

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 offshelf waters 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.

Salinity

Characteristic salinity in the open Gulf is generally between 36.4 and 36.5‰. 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‰. High freshwater input conditions (spring-summer months) are characterized by strong horizontal gradients and inner shelf salinity values of less than 20‰ (MMS, 1990).

Density Profile

The density stratification was characterized for areas where production discharges are occurring. The stratification profile is used in this assessment as input for discharge modeling (Chapter 4) and for the water quality analysis (Chapter 9). Data for water offshore Alabama were obtained from Temple et al. (1977). The data for the 7 meter and 14 meter contours are provided in Table 2- 1.

Sigma-t/m (the density gradient per meter) calculated for the 0-3 meter interval of the 7 meter depth averages 0.692 kg/m^3 (n=6). For the 0- 11 meter interval of the 14 meter depth, the average sigma-t/m is 0.163 kg/m^3 (n=5).

2.2 Chemical Oceanography

The Gulf of Mexico is a semi-enclosed system with oceanic input through the Yucatan Channel and principal outflow through the Straits of Florida. Runoff from approximately two-thirds of the U.S. and more than one-half of Mexico empties into the Gulf (MMS, 1990).

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,

Table 2-1. Temperature and Salinity Data for Offshore Alabama

Day	Month	Temperature (°C)				Salinity (‰)			Density (kg/m³)			Sigma-t		
		0 m	3 m	11 m	Bottom	0 m	3 m	11 m	0 m	3 m	11 m	0 m	3 m	11 m
Transect 1 E-37 (Alabama)														
26	2	13.8	13.8		13.8	35.5	35.5		1.027	1.027		26.60	26.55	
26	4	22.4	22.6		18.3	28.4	31.0		1.019	1.021		19.10	21.03	
19	6	25.6	25.5		20.6	30.5	32.3		1.020	1.021		19.79	21.22	
21	8	28.6	28.6		27.2	23.4	32.9		1.014	1.021		13.57	20.60	
25	10	24.1	24.3		24.4	30.8	33.3		1.020	1.022		20.45	22.33	
14	12	14.9	14.9		15.5	33.5	33.7		1.025	1.025		24.88	25.01	
Transect 1 E-38 (Alabama)														
26	2	12.9	12.9	12.9	12.9	35.2	0.0	35.1	1.027		1.027	26.58		26.51
25	4	23.0	22.4	17.8	17.8	30.5	31.1	35.1	10.21	1.021	1.025	20.54	21.16	25.43
19	6	25.1	24.9	21.7	21.7	32.7	32.8	35.9	1.022	1.022	1.025	21.60	21.69	25.03
21	8	0.0	0.0	0.0	0.0	27.4	33.3	35.3						
25	10	24.4	24.3	24.2	24.2	34.0	33.7	34.6	1.023	1.023	1.023	22.83	22.58	23.34
14	12	15.2	15.2	15.4	15.9	34.1	34.1	34.5	1.025	1.025	1.025	25.24	25.26	25.47

Source: Temple et al., 1977.

chlorine, sodium, magnesium, calcium, potassium, silicon, zinc, copper, iron, manganese, and cobalt (Smith, 1981). In addition to dissolved materials, trace metals, nutrient elements, and dissolved atmospheric gases comprise the chemical make-up of seawater.

2.2.1 Trace Metals

Trace metals commonly found in seawater include antimony, arsenic, cadmium, lead, mercury, nickel, and silver. The average seawater concentrations of these metals and other metals characteristically found in drilling and production discharges from oil and gas facilities are presented in Table 2-2.

2.2.2 Micronutrients

In Gulf of Mexico 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 ppm to 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 ppm to 0.14 ppm, averaging 0.014 ppm; silicates range predominantly from 0.048 ppm to 1.9 ppm, with open Gulf values tending to be lower than shelf values.

Table 2-2. Average Trace Metal Concentrations in Seawater

Constituent	Concentration Range (μg/l)
Aluminum	0 - 7
Antimony	0.18 - 1.1
Arsenic	2 - 35
Barium	5 - 93
Cadmium	0.02 - 0.25
Chromium	0.04 - 0.43
Copper	0.2 - 27
Iron	0 - 62
Lead	0.02 - 0.4
Manganese	0.2 - 8.6
Mercury	0.03 [a]
Nickel	0.13 - 43
Radium	5 - 15 x 10^{-8}
Selenium	0.052 - 0.50
Silver	0.055 - 1.5
Thallium	< 0.01 [a]
Vanadium	2.0 - 3.0
Zinc	1 - 48.4

The value is an average as reported in the source table.
Source: Adapted from Kennish, 1989.

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).

2.2.3 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 water masses 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 mg/1 through the mixed layer (MMS, 1990). In some offshore areas in the northern Gulf of Mexico, hypoxic (<2.0 mg/1) and occasionally anoxic (<0.1 mg/1) 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

The quantity and composition of the discharges covered under the general permit are a consideration under Factor 1 of the 10 factors used to determine unreasonable degradation. The potential for bioaccumulation or persistence of the pollutants in these discharges is addressed in Chapter 5, Toxicity and Bioaccumulation.

3.1 Discharges Covered Under the General 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.

Drilling Fluids
Drill Cuttings
Deck Drainage
Produced Water
Produced Sand
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 (also known as drilling muds or muds) are suspensions of solids and dissolved materials in a water or oil base that are used in rotary drilling operations. The rotary drill bit is rotated by a hollow drill 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 create the necessary properties. The primary functions of a drilling fluid include the following.

- Transport drill cuttings to the surface
- Control subsurface pressures
- Lubricate the drillstring
- 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 percent by weight of the materials that compose drilling muds (EPA, 1993):

- Barite
- Clay
- Lignosulfonate
- Lignite
- Caustic soda.

Barite

Barite is a chemically inert mineral that is heavy and soft. In water-based muds, barite is composed of over 90 percent 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 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). EPA currently regulates cadmium and mercury concentrations in barite and refers to the stock barite that meets 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 to 25 lb/bbl. In the presence of concentrated brine, or formation waters, attapulgite or sepiolite clays (10 to 30 lb/bbl) are substituted for bentonite (Perricone, 1980).

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 to 15 lb/bbl. It is made from the sulfite pulping of wood chips used to produce paper and cellulose. Ferrochrome lignosulfonate, the

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	Reduce relationship between viscosity and solids concentration; Vary the gel strength; and 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 Mean 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.

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 to 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 muds (WBM), 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 to 90 percent water by volume, with additives comprising the rest.

WBMs 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. Lightlv 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 (OBM) 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.

Synthetic-based drilling fluids or synthetic-based muds (SBM) represent a new technology which developed in response to the widespread permit discharge bans of oil-based drilling fluids. An SBM 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 (EPA, 1996).

SBMs are reported to perform as well as or better than OBMs 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 SBM, compared to WBM the quantities of muds and cuttings waste generated is reduced, reportedly in some cases by as much as 70 percent (Burke and Veil, 1995; Candler et al., 1993).

The pollutants of concern from muds discharges are primarily metals, most of which are associated with the barite added to the mud system. The pollutant concentrations in drilling fluid discharges characteristic of offshore operations are presented in Table 3-3.

For a 10,000- and 18,000-foot well, respectively, the estimated volume of drilling fluid discharged is 5,349 bbl and 10,486 bbl (EPA, 1993). These volumes represent 43% and 47% of the total drilling fluid generated to drill the well.

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.

Table 3-3. 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.

The shale shaker, a vibrating screen, removes large particles from the fluid. If the shaker is damaged or a bypass problem occurs, the cuttings are removed by gravitational settling. A series of solids control equipment (SCE) components progressively remove finer and finer particles. SCE components include desolvers, desilters, and centrifuges. After removal, the cuttings are discharged from the rig near or below the water surface. The solids discharged at this point mainly consist of: drill cuttings, wash solution, and drilling mud that still adheres to the cuttings. The cuttings, when discharged, can contain as much as 60% by volume drilling fluids (U.S. EPA, 1985a). The composition of a shale-shaker discharge is presented in Table 3-4.

The rate of discharge of drill cuttings can vary from 1 to 10 bbl/hr. Discharge is greater when the well is shallower as drilling is faster and a larger bit is used. Ayers (1981) estimates that 3,000 to 6,000 bbl of wet solids are discharged over the life of a well, and EPA (1993) estimates the volume as 1,430 to 2,781 bbl for 10,000- and 18,000-foot wells, respectively.

Table 3-4. 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. (1983b); 65% solids, density 1.7 g/cm^3.

3.4 Deck Drainage

The general permit defines deck drainage as 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.

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 to the drilling mud system, or transported to shore. The liquid effluent, primarily washwater and rain water, is discharged.

EPA (1993) estimates the average discharge of deck drainage for platforms in the Gulf of Mexico as 50 bbl/day. The oil and grease levels reported for these deck drainage discharges are 28 mg/l monthly average and 75 mg/l daily maximum.

3.5 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 3-5.

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 to 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 and 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 to 393 pCi/liter and Ra-228 concentrations of 170 to 570 pCi/liter (U.S. EPA, 1978). After treatment using gas flotation, produced water radium concentrations are reduced by 10% (EPA, 1993).

Table 3-5. Produced Water Pollutant Concentrations

Pollutant	Concentration (μg/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	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.

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 reports estimated discharge rates at 134 bbl/day to 150,000 bbl/day for offshore platforms in the central and western Gulf of Mexico (Burns and Roe, 1983). Currently, there are three platforms discharging produced water in the eastern Gulf. They are producing approximately 2 bbl/day, 160 bbl/day, and 240 bbl/day. Other facilities are presently piping to shore for treatment and discharge.

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. Under the expiring permit, produced water from the last stage of processing must meet a 48/72 mg/l oil and grease content limitation (monthly average/daily maximum). Under the proposed permit, this limitation is revised to be consistent with the final effluent guidelines as 29/42 mg/l (monthly average/daily maximum). The new limitation is based on the use of gas flotation for oil-water separation.

3.6 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 (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.

3.7 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 (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 3-6.

Table 3-6. Garbage Discharge Regulations

Garbage Type	Fixed or Floating Platforms & Associated Vessels[a] (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 [b]	Disposal prohibited
Victual waste not comminuted or ground	Disposal prohibited
Victual waste comminuted or ground[b]	Disposal prohibited less than 12 miles from nearest land and in navigable waters of the U.S.
Mixed garbage types	See footnote c

[a] 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.

[b] 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).

[c] When garbage is mixed with other harmful substances having different disposal requirements, the more stringent disposal restrictions shall apply.

Source: EPA, 1993.

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. The amount of cement used for each well depends on the well depth and the volume of the annular space. Additives are used to compensate for site-specific temperature and salt water conditions.

3.10 Well Treatment, Workover, and Completion Fluids

The following definitions are from the Development Document for the final effluent guidelines (EPA, 1993).

> Well treatment fluids are any fluid used to restore or improve productivity by chemically or 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. Workover and completion fluids remain within the wellbore. Therefore, the volume generated is approximately one well volume of fluid. Treatment fluids can react with or be lost to the formation. The total volume generated is 1 to 3 well volumes of fluid (EPA, 1993). The volumes of well treatment, workover and completion fluids discharged are presented in Table 3-7.

Well treatment fluids are acid in water solutions (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 percent) to force the hydrocarbons into the formation; an acid solution; and a post-flush of ammonium chloride the remains in the formation for 12 to 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 antisludging agents are often added to treatment fluid solutions. The pollutant concentrations for a well treatment fluid used in two wells at a THUMS facility in California are presented in Table 3-8.

Table 3-7. Typical Volumes from Well Treatment, Workover, and Completion Operations

Operation	Type of Material	Volume Discharged (bbl)
Completion and Workover	Packer Fluids	100 to 1,000
	Formation Sand	1 to 50
	Metal Cuttings	< 1
	Completion/Workover Fluids	100 to 1,000
	Filtration Solids	10 to 50
	Excess Cement	< 1
Well Treatment	Neutralized Spent Acids	10 to 500
	Completion/Workover Fluids	10 to 200

Source: EPA, 1993.

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

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

Source: EPA, 1993.

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.

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 psi. Proper fracturing accomplishes the following:

- Creates reserve 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.

Over a period of time the fractures may close up. Materials can be introduced into the fissures to keep them open. Typical materials used include sand, ground walnut shells, aluminum spheres, glass beads, and other inert particles. These "propping agents" are carried into the fractures by the workover fluid.

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.

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.

3.11 Blowout Preventer Fluids

A vegetable or mineral oil solution or antifreeze (polyaliphatic glycol) is used as a hydraulic fluid in 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 periodically to the seafloor during testing of the blowout preventer device. The volume of BOP fluid discharge ranges from 67 to 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 barrels per 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 (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 to 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 Source Water and Sand

Discharges of source water and sand consist of water from non-hydrocarbon bearing formations used for the purpose of pressure maintenance or secondary recovery, including the entrained solids.

3.18 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

Factor 2 of the 10 factors used to determine no unreasonable degradation requires the assessment of the transport and fate of the discharged material through physical, chemical, and biological processes. This chapter describes these processes and the modeling used to assess their potential water quality and human health impacts (Chapter 9).

4.1 Drilling Fluids

Drilling fluids contain quantities of coarse material, fine material, dissolved solids, and free liquids. 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 meters below the surface in a water depth of 23 meters. 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 of neutral 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 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 in soft or hard tissues, fecal agglomeration and settling of materials, and physical reworking to mix solids into the sediment (bioturbation).

[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. Dispersion refers to the behavior of the plume with respect to its solids content; dilution refers to plume behavior and is intended to apply to soluble components of drilling fluids. The term "dispersion" not only refers to settling and removal of solids from the water column as they settle on the seafloor, but also refers to the concentration of solids in the water column.

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, topography of the ocean bottom, bottom currents, and turbulence caused by platform wake. These factors influence dispersion of effluents in the water column, and resuspension and transport of 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 to 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 and 45 cm/sec (0.076 and 1.48 ft/sec).

Physical Transport Processes Affecting the Upper Plume

The materials contained in the upper plume are transported at the speed and direction of prevailing currents. 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 Gulf of Mexico.

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 to 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 Gulf of Mexico, Ayers et al. (1980b) estimated upper plume volume and found that a 275 bbl/hr drilling fluid discharge exhibited a 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 only somewhat from those influencing the upper plume. The lower plume appears to have 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

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

Dilution	Distance Required (m)[a]		
	Current Speed (cm/sec)		
	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] Ranges in distances represent discharge rates of 21 to 1,200 bbl/hr.
Source: Petrazzuolo, 1983.

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).

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 mm-2 mm) deposited within 125 m 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 μm-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

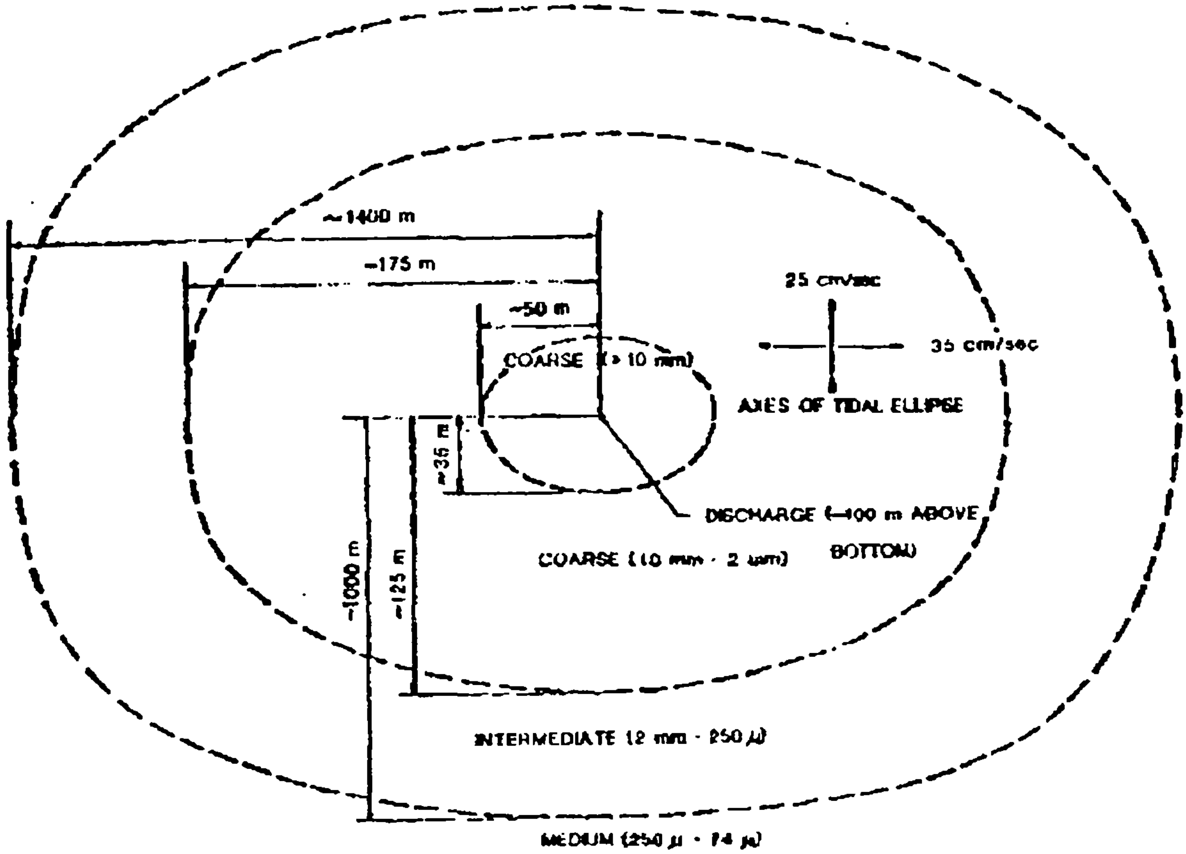

Figure 4-1. Approximate Pattern of Initial Particle Deposition (Houghton et al., 1981)

been discharged over an 85-day period (Ray and Meek, 1980). Size analysis also indicated little change in the grain size distribution.

Low-energy environments, however, are not 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 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 has not been well-described. Petrazzuolo (1983) cites a Gulf of Mexico 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 Sediment Reworking

Another pathway of biological removal of pollutants involves benthic organisms reworking sediment and mixing surface material into deeper sediment layers. This process is known as bioturbation. 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 Bioaccumulation

The majority of research of metal accumulation from drilling activities has focused on barite (barium) and ferrochrome lignosulfonate (chromium). Liss et al. (1980) examined chromium accumulation in sea scallops. The study states that chromium was found not to concentrate in the abductor muscle, but to concentrate in the kidney. In general, most of these studies represent the results of exposures of small sample sizes, ranging from three to six individuals. McCulloch et al. (1980) noted the accumulation of chromium in clams after exposure to used drilling fluids for 4 and 16 days. The four day exposure resulted in little net accumulation after depuration in clean seawater for 24 hours. The 16 day exposure resulted in a maximum chromium concentration of 19 ppm. This was reduced to 11 ppm after 24 hours of depuration and remained at that level for the remainder of the 11-day depuration period.

Neff et al. (1986) examined uptake of metals from 13-week exposures to low concentrations of barite in several marine organisms and concluded that metal associated with impure grades of barite are virtually nonavailable for accumulation in marine organisms. Neff et al. (1989) exposed four species of marine animals in flow-through mesocosms to natural marine sediments containing approximately 100,000 mg/kg (2.5- to 4-times higher than concentrations of barium expected to accumulate in sediments at a development well outfall) of either a relatively pure grade of barite or an impure barite. The pure barite contained much lower concentrations of arsenic, cadmium, copper, lead, and zinc (0.03 to 6.8 mg/kg) compared to the impure barite (15 to 664 mg/kg of these metals). Winter flounder, *Pseudopleuronectes americanus,* failed to accumulate any metals during exposure. There was some indication that soft shell clams, *Mya arenaria,* accumulated small amounts of cadmium and lead from the impure barite. In tissues of sand worms *(Nereis virens)* and grass shrimp *(Palaemonetes pugio)* exposed to both forms of barite, concentrations of cadmium, copper, and lead increased slightly. Increases were not statistically significant. Correlation analysis of the concentrations of the five metals indicated to the authors that these metals were still associated with barite particles, probably in unassimilated form in the gut. The authors concluded that metals associated with drilling mud barite are virtually nonavailable for bioaccumulation by marine organisms that might come in contact with discharged drilling fluid solids.

U.S. EPA (1985) evaluated bioaccumulation data for drilling fluids and components; based on this review and more recent data, the following can be concluded.

- Several metals can be accumulated, including barium, cadmium, chromium, lead, strontium, and zinc.
- Enrichment factors are generally very low to low (barium and chromium excluded), depuration release levels are high, and no gross functional alterations, resulting from metal accumulation following high exposures to drilling fluids or compounds, have been reported.
- However, test results indicate uptake kinetics are not simple, with saturation plateaus beyond the scope of most studies. Test design problems contribute also to equivocal interpretations and poor utility in hazard assessment analyses. These problems include: choice of inappropriate drilling fluid fractions as test substances; use of only one effective exposure concentration for fluid solids exposures; choice of tissues for analyses that are inappropriate for the species; and significant washout of drilling fluid components in long-term, flow-through tests.

4.1.5 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 maker, 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 Gulf of Mexico 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 concentrations of 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 Gulf of Mexico platform study, brine (formation water) discharges were identified as an additional 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 Gulf of Mexico. One industry-sponsored analysis indicates that 49 percent of discharged barium is dispersed beyond a radius of 1,250 m from the platform (Mobil Oil Corporation, 1978). Another analysis of these data indicates that 78 percent of the barium is located within a 1,000-m radius, and essentially all of the barium (calculated as 111 percent) is located within 1,250 m.

Boothe and Presley (1985) conducted a survey of sediment chemistries around six platforms in the Gulf of Mexico. 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 the discharge 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 (1985). 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 make 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 and Presley, 1985).

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

Location	Trace Metal[a]								
	As	Cd	Cr	Cu	Hg	Ni	Pb	V	Zn
Gulf of Mexico, Mustang Island Area									
suspended sediment	ND	-	+(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] 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

Source: Adapted from Tillery and Thomas (1980); Mariani et al. (1980); Crippen et al. (1980) in Petrazzuolo (1983).

4.2 Discharge Modeling - Drilling Fluids

Two sets of Offshore Operator's Committee (OOC) Mud Discharge Model runs were evaluated, using a broad set of environmental and operational conditions. One set of OOC model scenarios was conducted previously for EPA Region 10 (U.S. EPA Region 10, 1984) and 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 1.2Γ, 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 appropriate to the present Gulf of Mexico 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 meters and at the maximum discharge rate authorized in the Gulf of Mexico 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-meter, 40-meter, and 70-meter 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. 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 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 meters to 120 meters.

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

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 meters. These data have been 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 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.

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 (U.S. EPA, Region 10, 1984) noted an apparent biphasic behavior in their more homogenous data set.

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

Case #	Water Depth (m)	Rate (bbl/hr)	Current (cm/sec)	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.

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 (m)	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/see 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.

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 meters for a water depth of 15 meters was 562 dilutions; for water depths of 40 meters and 70 meters, the respective means were 787 dilutions and 1,721 dilutions.

4.3 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 PAHs 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.

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) recently 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; Stremgren 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

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]	1,000	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 Fields [5]	2,800	2-3	Dredged Canal, Bayou	100	100
Bayou Sale Fields [5]	2,500	2-3	Dredged Canal	500	100
Buccaneer Fields [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.

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 and 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 μg/l, representing a nearly 150,000-fold dilution compared to the concentration of benzene in the produced water effluent (9,500 μg/l). Concentrations of total gaseous and volatile hydrocarbons, including BTEX aromatics (75 percent of the total) decreased from 22,000 μg/l in the effluent, to 65 μg/l at the air:water interface below the outfall, to less than 2 μg/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 to 0.332 μg/l (Sauer, 1980) compared to background concentrations of 0.009 to 0.10 μg/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, depending on 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 μg/l) in the ambient sea water 20 m from the outfall. The inverse relationship between molecular weight 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 μg/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.

4.3.1 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 to 50 μm) and excrete large fecal pellets (30 μm to 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 organisms. In a central Gulf of Mexico 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 mean alkane 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 reflects the 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 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 and Jirka, 1990).

4.4.1 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 and Jirka, 1993). CORMIX (Version 3.20) 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 FORTRAN. CORMIX uses 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 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 an adjustment was needed to make the projections more accurate.

The 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 km/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 meter 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.

4.4.2 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 1,070 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 meter depth in 30 meters of water.

Operational data for the three existing produced water outfalls were supplied by the operators at the request of 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 feet (15.25 m) of water. The outfall is shunted to 40 feet (12.2 m) below the water surface and the average produced water discharge rate is 1,500 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. Chevron is operating in Mobile Block 990 located in 54 feet (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 feet (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 CORMIX dilution at 100 m 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 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	450	2
Current Speed (m/sec)	0.05	0.05	0.05
Ambient Surface Density (kg/m^3)	1,023	1,020.15	1,019.56
Ambient Bottom Density (kg/m^3)	1025.49	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 100 m	170	599	31,360

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

Factors 1 and 6 of the 10 factors for determining unreasonable degradation address concerns about the toxic and human health effects from discharges. This chapter provides a summary of the information available concerning the toxicity and potential for bioaccumulation of discharges of drilling fluids and produced water.

5.1 Overview

The release of drilling fluids and cuttings and produced water from oil and gas platforms is of interest because of the magnitude and potential toxicity of the discharges. Also, studies have shown a limited bioaccumulation of components in drilling fluid discharges. Many data are available on the toxicity of drilling fluids and produced water to marine species. The following is a brief summary of information on these subjects. In reviewing the data contained in this section, it is important to note that the permit limits the toxicity of drilling fluids (30,000 ppm of the suspended particulate phase), prohibits the discharge of mud containing diesel, and limits the cadmium and mercury content of drilling mud so that only the less contaminated sources of barite may be used to formulate muds discharged from these operations. In addition, produced water discharges must be analyzed to determine their toxicity and to assess compliance with water quality-based permitting strategies.

5.2 Toxicity of Drilling Fluids

Toxicity testing data are often used to assess the toxicologic 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 μm filter and the resulting solution is the filtered mud aqueous fraction.

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 on 70 species and found 1 to 2 percent had 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 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 percent MAF is the supernatant from a 10 percent drilling fluid mixture and is therefore expressed as 100,000 ppm (10 percent 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

	Number of species tested	Number of fluids tested	Number of tests	Not determinable	Number of 96-hr LC50 values (ppm)[a]				
					< 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)[b]	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	407	31[c]	0	4-9	25	179	171

[a] 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.

[b] 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.

[c] 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.

Source: Adapted from Petrazzuolo, 1983.

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 animals 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 breeding 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 to 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 percent 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 used drilling mud study (Duke and Parrish, 1984) were found to contain some No. 2 fuel (diesel) oil. Surrogate "diesel" oil content ranged from 0.10 to 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.

	Correlation Coefficient		
Test Material	Aromatic	Aliphatic	"Diesel
Whole Mud	-0.79	-0.77	-0.81
Suspended Particulate Phase	-0.77	-0.89	-0.96

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

Mud	Type	96-hr LC50 (95% CI)	
MIB	Seawater Lignosulfonate	2,875 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 Lignosulfonate	3,570 ppm	(3,272-3,854)
P6	Low Solids Nondispersed	10,0000 ppm	—
P7	Lightly Treated Lignosulfonate	35,420 ppm	(32,564-38,877)
P8	Seawater/Potassium/Polymer	2,577 ppm	(2,231-2,794)
NBS 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)[a]		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

[a] EC50 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.

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 rolled)	18.20	18.20	116 (89-133)
NBS mud + mineral oil	18.20	18.20	778 (713-845)
NBS mud + mineral oil (hot rolled)	18.20	18.20	715 (638-788)
P1 drilling mud	None	18.20	142 (133-153)

[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.

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 to 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 variegates)* 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.

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 and 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 percent mortality at the 1,000 ppm level (Thompson and Bright, 1980). Stress reactions 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- to 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 percent. Eggs were more sensitive; exposure to 1,000 mg/ml (262-fold dilution of the whole fluid) reduced fertilization from 88-90 percent to

46 percent. 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 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-lignosulfonate mud (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 percent 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 percent 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 percent for control shrimp and 60 percent for exposed shrimp (no concentrations of barite given). In 40 percent 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 percent 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 Gulf of Mexico laboratory examined the effects of drilling muds or drilling mud components on community recruitment and development of benthic macrofauna (Tagatz et al., 1980; Tagatz and Tobia, 1978) and meiofauna (Cantelmo et al., 1979). Test substances were mixed at various ratios with sediment, or were applied as a 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 and Tobia, 1978). Annelid abundance was also reduced by exposure to barite covering (Tagatz and 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 impact. 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, silver, vanadium, 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 downcurrent 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 114-day deputation 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 Cr. Cu. Cd, Ag, Zn) do not increase with trophic level either in open water or in contaminated regions such as coastal sewage outfalls.

5.3 Toxicity of Produced Water

In addition to mud and cuttings, produced water constitutes a major discharge from offshore production operations. Water brought up from the hydrocarbon-bearing strata with the produced oil and gas includes brines trapped with the oil and gas in the formation and possibly water injected into the reservoir to increase productivity. (Water injected to increase hydrocarbon recovery is normally injected into wells other than the producing wells.) The actual amount of produced water derived from each site is a function of the geological formation encountered and the method of recovery. The proportion of water in the produced fluids may vary from 0% to over 90% and can increase, decrease, or remain constant over the lifetime of an individual well (Menzie, 1982). Produced fluids generally increase in water content as most fields mature. The generation of produced water is a relatively continuous feature of producing platforms, unlike the intermittent discharge of drilling mud and cuttings from exploration, development, and production operations.

Brines are the major form of produced water, and the major inorganic constituents are chlorides. Menzie (1982) reports typical dissolved solids concentrations of 80,000-100,000 mg/1 in produced water, although a range from a few mg/l to approximately 300,000 mg/1 has been observed. An analysis of coastal Louisiana produced water by *Avanti* Corporation (1992) reports chlorides levels ranging from 218 ppm to 180,000 ppm with a mean of 68,218 ppm for 235 outfalls reporting. In comparison, seawater of 30 ppt salinity has a dissolved solids concentration of 30,000 mg/1.

In most oil fields, treatment of the total fluid to separate oils from produced water ranges from simple gravity separation at offshore facilities to multi-step processes at centralized onshore facilities. Any gas coproduced with the oil is separated out. Use of the multi-step processes can lead to reduction of oil content, volatile aliphate hydrocarbons, and volatile aromatic hydrocarbons. The gas is either flared at the platforms, used for energy, or sold and is not part of the final discharge. Chemical analyses of produced water are described in Chapter 3 of this document.

Potential biological effects occurring as a result of produced water discharges include osmotic stress if salinity varies significantly from ambient sea water, respiratory stress if dissolved oxygen (DO) levels are low, bioaccumulation of various components, and toxic effects from hydrocarbon and heavy metal constituents. The probability of these effects occurring on the OCS is a function of total volume discharged within a water mass and the dilution/dispersion of the effluent plume. The latter may be affected by salinity of the discharge. Low saline produced water (relative to ambient seawater) will tend to rise to the surface, whereas briny produced water will tend to sink to the bottom layer. The mixing rates of these types of discharges depend on current/wave conditions and the density difference between the effluent and the receiving water.

If the salinity of the produced water is similar to ambient sea water, osmotic stress is improbable and respiratory stress is likely to be restricted to localized, nearfield areas. Minimal impact of this type is likely unless the quantity (volume) of discharge is such that DO is measurably depressed within the water mass.

This is most likely to occur only in shallow, poorly flushed embayments, not in the open water found in the coverage area of the OCS permit.

5.3.1 Acute Toxicity

Until the past few years, few studies had examined the toxicity of produced water. In 1981, Rose and Ward carried out a bioassay program on produced water from the Buccaneer Field in the Gulf of Mexico off Tacas. Results were presented for four series of test conditions. Test series Nos. 1-3 were performed at a shore-based laboratory, while test series No. 4 was conducted on the production platform. The results indicate a range in toxicity of LC50 (concentration lethal to 50% of test organisms) values from 8,000 to 154,000 ppm for invertebrates and 7,000 to 408,000 ppm for the vertebrate tested (Table 5-6). More recent studies have conducted toxicity evaluations and tests using produced water and a variety of test species. These acute toxicity test results are summarized in Table 5-7.

A more recent and extensive database of produced water toxicity has resulted from produced water toxicity tests data submitted under Louisiana state-issued permit requirements. A summary of these data is presented in Table 5-8. LC50s reported by operators discharging produced water to the state waters of Louisiana range from 0.05% to >100% effluent, with a mean 96-hr LC50 of 12.1% for mysids and from 1.17% to >100% effluent, with a mean of 27.4% for sheepshead minnows.

Several studies have examined the causes of toxicity in produced water. Sauer et al. (1992) used produced waters with low total dissolved solids to conduct toxicity identification evaluations. The authors concluded that toxicity in produced water is due to volatile compounds, neutral semivolatile organic compounds, particulate matter (precipitated at neutral pH), and suspended solids. The particular toxicants identified are hydrogen sulfide and hydrocarbons. Brendenhaug et al. (1992) found a 10-fold reduction in toxicity during biodegradation of produced water resulting in a 95% removal of dissolved organic carbon.

5.3.2 Chronic and Sublethal Toxicity

Although the acute toxic effects of produced water appear to be low (when biocides are absent), chronic lethal and sublethal effects must be considered. Such effects are expected to occur at concentrations below those that are acutely toxic. Chronic exposures to organisms in the water column could occur in areas where the hydrocarbons discharged to the water column are not rapidly removed from the system and where there is a continuous input. The potential for build-up of hydrocarbons in the water column would be greater in shallow, semi-enclosed coastal embayments with limited flushing than in offshore regions.

In areas where a hypersaline produced water plume contacts the bottom, mortality can be expected to occur as a result of anoxic and hypersaline conditions. The extent of these effects will depend on the duration, volume, and dispersion of the plume. It is likely that the benthic community, especially infauna and less mobile epifauna, would be severely disrupted in the immediate vicinity of the discharge.

Table 5-6. Median Lethal Concentration and Associated 95% Confidence Intervals for Organisms Acutely Exposed to Formation Water under Various Experimental Conditions

Organism	Season of Test	Formation Water Used	Testing Temperature	LC50[a, b]	95% Confidence Interval[a, b]
Test Series No. 1[c]					
Brown Shrimp	Spring 1979	D	28	10,000	7,000-15,000
Larva		E	28	12,000	9,000-18,000
		F	28	8,000	6,000-12,000
		G	28	8,000	5,000-11,000
Subadult	Summer 1978	A	25±1	94,000	63,000-172,000
	Fall 1978	B	22±1	60,000	0-100,000
	Winter 1979	C	18±2	183,000	130,000-279,000
	Spring 1979	D	24±1	61,000	47,000-76,000
Adult	Summer 1978	A	25±1	94,000	63,000-172,000
	Fall 1978	B	22±1	78,000	38,000-183,000
	Winter 1979	C	18±2	178,000	132,000-240,000
	Spring 1979	D	24±1	90,000	61,000-156,000
White Shrimp					
Subadult	Summer 1978	A	25±1	56,000	51,000-62,000
	Fall 1978	B	22±1	61,000	48,000-76,000
	Winter 1979	D	18±1	133,000	67,000-366,000
Adult	Summer 1978	A	25±1	81,000	48,000-153,000
	Fall 1978	B	22±1	62,000	27,000-110,000
	Winter 1979	C	18±1	92,000	58,000-150,000
	Spring 1979	D	22±1	37,000	24,000-52,000
Barnacle	Summer 1978	A	25±1	33,000	25,000-38,000
	Fall 1978	B	22±1	84,000	68,000-104,000
	Winter 1979	C	18±2	154,000	111,000-222,000
	Spring 1979	D	24±1	60,000	79,000-71,000
Crested blenny	Summer 1978	A	25±1	158,000	100,000-320,000
	Fall 1978	B	22±1	408,000	320,000-560,000
	Spring 1979	D	24±1	178,000	135,000-235,000
Test Series No. 2[d]					
Barnacle	Winter 1979	C	18±2	8,000	5,000-13,000
Crested blenny	Spring 1979	D	24±1	7,000	5,000-12,000
Test Series No. 3[e]					
White shrimp					
Subadult	Fall 1978	B	22±1	62,000	48,000-76,000
Test Series No. 4[f]					
Brown shrimp					
Subadult	Spring 1979	H	25-29	44,000	25,000-60,000
Barnacle	Spring 1979	H	25-29	51,000	34,000-68,000

Source: Rose and Ward; 1981; footnotes on following page.

Table 5-6. Median Lethal Concentrations and Associated 95% Confidence Intervals for Organisms Acutely Exposed to Formation Water under Various Experimental Conditions (continued)

[a] All LC50s and associated 95% confidence intervals are 96-hr values except in the case of larval brown shrimp, for which 48-hr values are reported. Units are ppm formation water.

[b] In most cases, LC50s and related confidence intervals were calculated by the moving average method. However, the binomial method was employed in Test Series No. 1 for subadult brown shrimp tested in the fall as well as for crested blennies tested in the summer and fall. The probit method was used for Test Series No. 4.

[c] Static laboratory tests; oxygen demand of formation water not evaluated. Except in the case of tests with larval brown shrimp, test and control media were aerated to maintain dissolved oxygen concentration (DO) above 4 mg/l. Aeration was not required to maintain a DO above 4 mg/l in tests with larval shrimp.

[d] Static laboratory tests; oxygen demand of formation water evaluated. Test and control media were not aerated. Although DO of control media remained above 4 mg/l during the tests, DO of test media decreased to 0.5-3.2 mg/l (barnacle) and 1.2-4.0 mg/l (crested blenny) by the end of the 96-hr testing period.

[e] Flow-through laboratory tests; oxygen demand of formation water not evaluated. Test and control media were aerated to maintain DO above 4 mg/l.

[f] Flow-through platform tests; oxygen demand of formation water not evaluated. Test and control media were aerated to maintain DO above 4 mg/l.

Table 5-7. Acute Lethal Toxicity of Produced Waters to Marine Organisms

Species	Life Stage	LC50/EC50 (ppm)[a]	Reference
Balanus tintinnabulum (Barnacle)	Adult	83,000	NMFS, 1980
Penaeus setiferus (White shrimp)	Adult Adult Subadult Larvae Larvae	116,000 78,000-178,000 60,000-183,000 9,500 (48-hr LC50) 8,000-12,000 (48-hr LC50)	NMFS, 1980 Rose & Ward, 1981 Rose & Ward, 1981 NMFS, 1980 Rose & Ward, 1981
Penaeus aztecus (Brown shrimp)	Adult	70,000	NMFS, 1980
Hypleurochilus geminatus (Crested blenny)	Adult Adult	269,000 158,000-408,000	NMFS, 1980 Rose & Ward, 1981
Cyprinodon variegatus (Sheepshead minnow)	Adult Adult Adult	550,000-600,000 11,700->1,000,000 54,400->280,000	Andreason & Spears, 1983 *Avanti* Corp., 1992 Moffit et al., 1992
Mytilus californianus (California mussels)	Embryo	21,200 (48-hr EC50)	Higashi et al., 1992
Mysidopsis bahia (Mysid)	Adult	23,000-160,000 19,000-93,000 500->1,000,000	Moffitt et al., 1987 Montgomery, 1987 Avanti Corp., 1992
Pimephales promelas (Fathead minnow)	Adult	170,000-220,000 (24-hr LC50)	Sauer et al., 1992
Ceriodaphnia dubia (Daphnid)	Adult	80,000 (24-hr LC50)	Sauer et al., 1992
Skeletonema costatum	—	45,000-676,000 (48-hr EC50)	Brandenhaug et al., 1992
Microtox	—	40,000-192,000 (4-hr)	Brandenhaug et al., 1992

[a] 96-hour LC50/EC50 unless otherwise noted.

Armstrong et al. (1979) noted severe disruption of benthos within 150 m (490 ft) of the discharge point in Trinity Bay, Texas (a shallow, coastal embayment).

In another study of impacts from produced water outfalls in shallow coastal waters of Texas (Roach et al., 1992), significantly reduced benthic community abundance, richness, and diversity (using the Shannon-Weaver function) occurred. Sediment and pore-water toxicity tests conducted for one of two discharge sites found significant impact to within 370 meters of the outfall.

All of the above study results of produced water impacts have been located in shallow coastal waters where flushing is low, dilution is limited, and sediment:plume interactions are high. These factors are

Table 5-8. Summary of Louisiana Department of Environmental Quality Produced Water Toxicity Data

	Mysidopsis bahia				*Cyprinodon variegatus*		
	96-hr LC50	Survival	Growth	Fecundity	96-hr LC50	Survival	Growth
No. of Outfalls	241	226	221	150	239	221	218
Mean	12.1	4.51	5.92	6.44	27.4	8.04	8.23
Lower 95th Confidence of the Mean	10.0	3.29	4.05	4.19	23.9	6.33	6.48
Minimum	0.05	0.04	0.06	0.13	1.17	0.14	0.15
Maximum	100	100	100	100	100	100	100
Median	5.20	2.16	2.08	3.00	17.9	2.50	4.90
95th Percentile	1.31	0.19	0.34	0.29	2.69	0.50	0.56
99th Percentile	0.26	0.09	0.09	0.13	1.67	0.16	0.29

Source: *Avanti* Corporation, 1992. All toxicity values are expressed as percent effluent.

permit. However, a series of reports have suggested chronic, sublethal effects may occur from a produced water outfall offshore southern California. In a study conducted in Santa Barbara, California, Krause et al. (1992) tested effects of produced water on purple sea urchins both in the laboratory and in the field. The effect of 1% produced water on gametes (particularly sperm) in the laboratory is reported as virtually instantaneous. In the field, detectable developmental effects were observed to 100-500 m from the outfall. The authors note that this distance is projected to represent the area at which the effluent would be diluted to 1% given the outfall configuration.

5.4 Bioaccumulation Potential of Produced Water Constituents

The environmental accumulation potential of selected trace metal and organic constituents of produced waters has been previously estimated from predetermined bioconcentration factors (BCF; Table 5-9). Estimated BCFs for pollutants found in produced water suggest that benzo(a)pyrene, naphthalene, zinc, copper, xylenes, and radium would exhibit the highest bioaccumulation potential.

In three studies of produced water discharges to shallow estuarine and near shore coastal waters of the Gulf of Mexico, very little evidence was found of accumulation of metals in bottom sediments near produced water discharges (Boesch and Rabalais, 1989; Neff et al., 1989; 1992; Rabalais et al., 1991; 1992). There was some evidence of accumulation of small amounts of zinc in sediments near two produced water discharge sites. Concentrations of barium in sediments were elevated above expected background at nearly all distances from some shallow-water produced water discharges.

Table 5-9. Estimated Accumulation Factors of Pollutants Found in Produced Waters

Component	Bioconcentration Factor
Aluminum	NA
Anthracene	30
Arsenic	44
Benzene	5.21
Benzo(a)pyrene	55,000
Boron	NA
2-Butanone	1
Cadmium	64
Chlorobenzene	10.3
Copper	290
2,4-Dimethylphenol	94
Di-n-butylphthalate	89
Ethylbenzene	37.5
Iron	NA
Lead	49
Manganese	NA
n-Alkanes	NA
Naphthalene	426
Nickel	47
p-chloro-m-cresol	79
Phenol	1.4
Radium	140
Steranes	NA
Titanium	NA
Toluene	10.7
Triterpanes	NA
Xylene (total)	208
Zinc	432

Source: Versar, 1992.

Radium concentrations were slightly elevated in near-bottom water near shallow water discharges at Pass Fourchon, but not in bottom sediments (Rabalais et al., 1991). In a recent DOE study of bioaccumulation of metals and petroleum hydrocarbons by marine animals near offshore produced water discharges in the Gulf of Mexico, there was no evidence of bioaccumulation of any produced water discharges (DOE, 1997). Small amounts of produced water-derived low molecular weight polycyclic aromatic hydrocarbons (PAHs) were accumulated by bivalves on submerged platform structures near a produced water discharge. Only low molecular weight PAHs similar to those in produced water were bioaccumulated. Fish near the discharges did not bioaccumulate any PAHs. PAHs, but not metals, were present at slightly elevated levels in sediments near some of the produced water outfalls.

6. BIOLOGICAL OVERVIEW

Factors 3 and 4 of the 10 factors used to determine unreasonable degradation under the Ocean Discharge Criteria regulations call for the assessment of the biological communities 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. This chapter describes the biological community of the eastern Gulf of Mexico. The species identified as threatened or endangered by the USFWS and NMFS (Stevens, 1993; Carmody, 1993) are characterized in the last section of this chapter and also are evaluated in a separate document prepared for consultation under Section 7 of the Endangered Species Act (*Avanti* Corporation, 1993).

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 Gulf of Mexico 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 and Kamykowski, 1984);
- 103 g C/m^2/yr (Flint and 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 and 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 to 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 Gulf of Mexico is difficult to measure. Shipboard or station measurements cannot provide information about large areas at one moment in time, and satellite imagery 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 by patchy 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 Gulf of Mexico, phytoplankton are also often closely associated with 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 to 77.8 km from shore in the Gulf of Mexico between St. Petersburg and Ft. Myers, Florida. Diatoms averaged 1.4 x 10^7 μ^2/l surface area offshore, 13.6 x 10^7 μ^2/l at intermediate locations and 13.0 x 10^8 μ^2/l inshore. The ten most 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.)

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 and Williams, 1970.

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 Gulf of Mexico.

- 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.

- 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, where as larvae were more abundant in depth zones greater than 50 meters (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.

Of the more than 3 million hectares (1 ha = 2.471 acres) of submerged seagrass beds in the shallow coastal waters of the northern Gulf of Mexico, 98.5% is found off the Florida coast and 1% is found off the Mississippi and Alabama coasts. The most predominant species is *Thalassia testudinum*, commonly known as turtle grass -- average biomass values for turtle grass are 500-3,100 g/m^2. Other common seagrass species include: *Syringodium filiforme* (manatee grass), average biomass production of 100-300 g/m^2; *Halodule wrightii* (shoal grass) average biomass value of 50-250 g/m^2; and three Halophila species that tend to be less productive than aforementioned species (MMS, 1990).

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, ascideians 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.

Mississippi/Alabama

The northeastern portion of the central Gulf has a "pinnacle trend" area found at the outer edge of the Mississippi/Alabama shelf. The pinnacles rise 20 m from the seafloor and are found at depths of 50-100 m. Suspension-feeding invertebrates dominate the biological assemblages. Large features have rich assemblages distinguished by a high relative abundance of sponges, gorgonian corals, crinoids, bryozoans, and coralline algae. Non-pinnacle trend regions of the east-central Gulf have mud and mixed sand/mud substrate and are not considered live-bottoms.

Florida

Within southwest Florida shelf waters (depths of 10-200 m), the distribution of biological assemblages is associated with substrate type and correlates strongly with three depth zones: the inner shelf zone between 10 and 60 m, a transitional zone between 60 and 90 m, and an outer-shelf zone from 90-200 m (Woodward-Clyde Consultants and CSA, 1984; CSA, 1986). The following describes southwest Florida shelf assemblages; however, similar community types may be expected throughout the eastern Gulf:

- *Inner and Middle Shelf Sand Bottom Assemblage* (not considered a live bottom): algae, asteroids, bryozoans, corals, echinoids, sea fans, and sponges;

- *Outer Shelf Sand Bottom Assemblage* (not considered a live bottom): lacks macroalgae, assemblage includes asteroids, crinoids, echinoids, ophiuroids, sea fans, anemones, crustaceans, and sponges;

- *Inner Shelf Seagrass/Algal Bed Live-bottom Assemblage:* located in soft bottom areas, typified by seagrass, Halophila, and various algae;

- *Inner Shelf Live-bottom Assemblages 1 and 2:* consist of patches of algae, ascidians, hard corals, gorgonians, hydrozoans, and sponges; the two assemblages are distinguished by large gorgonians, or lack thereof, and also may vary in specific genera;

- *Outer Shelf Low-relief Live-bottom Assemblage:* located on low-relief rock surfaces with a sand veneer; organisms include octocorals, antipatharians, crinoids, and sponges;

- *Outer Shelf Prominence Live-bottom Assemblage:* attached to prominences, most likely dead coral arising from the sea floor; organisms include octocoral species, antipatharian corals, a hard coral species, bryozoans, crinoids, and sponges;

- *Middle Shelf Algal Nodule Assemblage:* consists of coraline algal nodules, formed by two genera of algae, Lithophyllum and Lithothamnium; other algae are abundant, hard corals and sponges are present;

- *Agaricia Coral Plate Assemblage:* consists of hard coral-coralline algae substrate covered with living algae, hard corals, gorgonians and sponges;

- *Outer Shelf Crinoid Assemblage:* consists of numerous crinoids and some small sponges.

6.5 Fishes

The following section describes some of the species of fish and shrimp that occupy the waters of Alabama, Florida, and Mississippi. These species were chosen because of their commercial, recreational, and/or ecological significance and their occurrence in offshore waters of the eastern Gulf. The commercial and recreational fisheries associated with these species are described in Chapter 7 of this document.

6.5.1 Spotted Seatrout

Spotted seatrout *(Cynoscion nebulosus)* are restricted mainly to estuaries and emigrate only during periods of environmental extremes or in association with spawning, feeding, and protection from predators (Lorio and Perret, 1980). The importance of estuaries to this species was emphasized by Etzold and Christmas (1979) who pointed out that spotted seatrout not only spawn in estuaries but also depend on estuaries for food throughout their life span. Spotted seatrout spawn from spring through early fall in deep channels and depressions in estuaries (Lorio and Perret, 1980). Larvae move into grassbeds and marshes where growth occurs rapidly. As they develop, they move into deeper portions of the estuary. During spring and summer, adults concentrate in inlets and passes to feed on migrating shrimp and small fish.

6.5.2 Sand Seatrout

A demersal species, the sand seatrout *(Cynoscion arenarius) is* one of the most abundant fish in the estuaries and continental shelf waters of the Gulf of Mexico (Moffett et al., 1979; Shlossman, 1980; NOAA, 1985). Juveniles and prespawners are found in estuarine and coastal waters, and adults are generally found to the edge of the continental shelf. Spawning occurs from March to September in grounds located in Gulf waters between 15 and 50 meters deep. From spring through fall, juveniles occupy nursery areas located further inshore and in estuaries. Salt marshes also may be used during the early stages of growth. In the late fall, juveniles leave estuarine nursery areas to winter in the open Gulf waters. Adults migrate to spawning grounds in the spring.

6.5.3 Red Drum

The red drum *(Sciaenops ocellatus)* inhabits estuaries and coastal waters out to distances of 25 km at depths up to 50 m (NOAA, 1985; 1986). Certain adult populations may live exclusively in open waters while others live in bay systems (Simmons and Breuer, 1962). After first spawning, adults tend to spend more time in Gulf waters and less time in estuaries (NOAA, 1986). Spawning occurs in the fall and winter throughout coastal waters outside of estuaries and in and near barrier island passes to estuaries (Christmas and Waller, 1973; Johnson, 1978; NOAA, 1985). The young fish are carried into the shallow estuaries and tend to associate with seagrasses and marshes (Yokel, 1966; Jannke, 1971; Loman, 1978). Although found in coastal areas throughout the year, the red drum resides in estuaries in the summer and offshore in the winter.

6.5.4 Tarpon

Tarpon *(Megalops altanticus)* are pelagic fish found throughout the nearshore zone of the Gulf of Mexico in waters mostly to depths of 20 m and rarely to 100 m (Wade and Robins, 1972; McClane, 1974; Smith, 1980; USFWS, 1978; NOAA, 1985). Tarpon usually inhabit nearshore areas, estuaries, inlets, passes, and occasionally freshwater rivers. Spawning occurs from May to August in offshore waters. The larvae move inshore, and juveniles are found in nearshore, estuarine, and freshwater areas. As size increases, movement toward ocean waters occurs. Tarpon may also move in and out of estuaries, depending on temperature.

6.5.5 Red Snapper

Red snapper *(Lutjanus campechanus)*, a demersal fish, is usually found seaward of the 18-m bottom contour (occasionally up to 1,200 m) over a variety of surfaces, congregating in depressions or near coral and rock outcrops (U.S. FWS, 1978; Collins et al., 1980; GMFMC, 1980; Benson, 1982; NOAA, 1985). Individuals generally move inshore in the summer and offshore in the winter. Spawning occurs offshore in water depths from 15 to 40 m over hard sand and reefs from June to October. Larvae remain in offshore waters near the bottom; juveniles inhabit estuaries and shallow inshore areas, beaches, and channels. As juveniles mature, they move into deeper waters.

6.5.6 Spanish and King Mackerel

The Spanish and king mackerel *(Scomberomorus maculatus* and *S. cavalla)* are migratory pelagic species found in estuaries and coastal waters to depths of 100 to 200 m (NOAA, 1985). Large schools are known to pass near the beach during seasonal migrations (GMSAFMC, 1985) and may enter tidal estuaries, bays, and lagoons (Berrien and Finan, 1977). Mackerel spawn from spring to fall in shallow waters, usually less than 20 m deep (McEachran et al., 1980; NOAA, 1985; Godcharles and Murphy, 1986). Mackerel seldom enter brackish waters (NOAA, 1985). Some juveniles use estuaries as nursery grounds, but most stay nearshore in open beach waters (Kelly, 1965).

6.5.7 Atlantic Croaker

Atlantic croaker *(Micropogonias undulatus)* are demersal bony fish found in estuarine and coastal waters seaward to approximately 120 m depths. The species is estuarine-dependent; all life stages are abundant in estuarine waters (Lassuy, 1983a). When inshore temperatures are high in late spring to early fall, heavy concentrations of croakers are found inside the 20-m depth, and when inshore temperatures drop, populations move offshore (GMFMC, 1980). Croakers appear to spawn during fall and winter from open waters near passes and channel entrances to estuaries in water depths up to 20 m (Juhl et al., 1975;

White and Chittenden, 1977; Warren et al., 1978; NOAA, 1985). Larvae are first pelagic and soon become demersal, moving into estuarine nursery grounds where transition to the juvenile stage occurs (Fruge and Truesdale, 1978; Diaz and Onuf, 1985). Young croakers remain in estuaries at least through spring or early summer before migrating to open waters (Lassuy, 1983a).

6.5.8 Groupers

Groupers are demersal reef fish that are found at depths of 30-120 m, favoring vertical relief areas such as natural and artificial reefs or rock outcroppings. Juveniles are found in grass beds, rock formations, and shallow reef areas. Spawning occurs over the continental shelf from January to July depending on the species. Common species in the Gulf of Mexico include the red grouper *(Epinephelus morio)* and the black grouper *(Myoteroperca bonaci).*

6.5.9 Southern Flounder

The southern flounder *(Paralichthys lethostigma)* occurs in the western Atlantic from North Carolina to the Loxahatchee River, Florida and in the Gulf of Mexico from the Calooshatchee River, Florida to Laguna de Tamiahua, Mexico. Adults are found to 60 meters depths during winter spawning. Nursery areas are in estuaries. Prey include other demersal fish, crabs, and shrimp.

6.5.10 Pinfish

Pinfish inhabit rocky or vegetated marine bottoms, reefs, jetties, and mangrove swamps and are believed to have a significant impact on epifaunal seagrass communities. They prey on crustaceans such as amphipods and shrimp. Their predators include ladyfish, porpoise, spotted seatrout, alligator gar, and gulf flounder (Muncy, 1984b).

6.5.11 Saltwater Catfish

Saltwater catfish in the Gulf of Mexico include sea catfish and gafftopsail catfish. They are opportunistic feeders that prefer sandy and organic substrate. Their diet includes seagrass, corals, sea cucumbers, gastropods, polychaetes, and crustaceans (Muncy and Wingo, 1983).

6.6 Crustaceans

6.6.1 Spiny Lobster

Spiny lobsters *(Panulirus argus)* are benthic invertebrates that inhabit reefs, rubble, and crevices at depths of 10-80 m or more. They are opportunistic omnivores that forage at night. Adults reach sexual maturity at 3 or more years of age and spawn offshore in deeper reef fringes from April to October. Larvae develop offshore for 8 to 9 months, and as they mature they migrate inshore to seagrass or mangrove habitats (MMS, 1990).

6.6.2 Blue Crabs and Stone Crabs

Blue crabs *(Callinectes sapidus)* are opportunistic omnivores and inhabit nearshore benthos with muddy and sandy bottoms and aquatic vegetation. Blue crabs migrate offshore from March to November to mate and then migrate to lower estuary and nearshore waters to spawn. Spawning occurs year round in south Florida waters. Zoeae are transported great distances by currents and develop offshore. During post larval development, megalopae migrate into estuaries (MMS, 1990).

Stone crabs *(Menippe mercenaria)* inhabit areas from shore to 55 m water depths. They are primarily nocturnal carnivores, but also may eat seagrasses. Stone crabs spawn offshore. Upon hatching, plankton develop for 2 to 4 weeks. Principal nursery areas are Florida Bay and Ten Thousand Islands. The principal fishery is located off Collier County, Florida; however, harvesting occurs from Tampa to the Florida Keys and in Apalachee Bay (MMS, 1990).

6.6.3 Shrimp

Shrimp are omnivores that feed on detritus, algae, other invertebrates, and zooplankton. Adult shrimp live on a variety of benthic substrates. There are three species of shrimp of importance in the eastern Gulf of Mexico: pink, white, and brown. Pink shrimp predominate off the west/southwest coast of Florida; white shrimp off the coasts of Alabama, Mississippi, and northern Florida; and brown shrimp are most common off the coast of Mississippi. As juveniles, all three species are estuarine dependent.

Pink shrimp *(Penaeus duorarum)* are found along the coast of the Gulf of Mexico with highest concentrations occurring off the southwest Florida coast, and where the shelf is broad and shallow, from the shore to 65 meters. Spawning occurs offshore throughout the year in southern Florida and primarily in summer in northern Florida. Larvae develop offshore, followed by postlarval migration to estuarine waters where juveniles remain for 2 to 6 months (MMS, 1986).

The white shrimp (*P. setiferus)* fishery in the eastern Gulf is concentrated in the north. White shrimp prefer mud or clay bottoms and inland brackish waters of depths less than 35 m. Adults spawn offshore in waters greater than 8 m, with peak spawning occurring in June and July (MMS, 1986).

In the eastern Gulf of Mexico, the brown shrimp fishery is concentrated off the coast of Mississippi. Brown shrimp (*P. aztecus)* occupy depths to 110 m, but are most common between 30-55 m on mud or sandy mud substrates (MMS, 1986). Spawning varies with depth, occurring in two peak periods: October through December and March through May (MMS, 1990). Adults migrate offshore during winter, and return inshore during spring.

6.7 Marine Mammals

Twenty-eight species of marine mammals are known to occur in or migrate through the northern Gulf of Mexico based on sightings and/or strandings (Schmidly, 1981). Cetaceans (whales, dolphins, and porpoises) are the most common. During 1978 to 1987, a total of 1,200 cetacean strandings/sightings were reported for Alabama, Florida and Mississippi to the Southeastern U.S. Marine Strandings Network. Ninety percent of these strandings/sightings occurred off Florida coasts (the Florida figure reflects strandings from both the Gulf and the Atlantic waters; NOAA, 1991). The cetaceans found in 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, occurs in small numbers only in the feral condition. All marine mammals are protected under the Marine Mammal Protection Act of 1972.

6.7.1 Minke Whale

Minke wales *(Balaenoptera acutorostrata)* are the smallest baleen whales in the northern hemisphere. In the western North Atlantic they occur from the ice pack south to the West Indies and the Gulf of Mexico (Leatherwood and Platter, 1975). They have a general north-south and onshore-offshore trend between summer and winter. Evidence suggests minkes winter offshore south of Florida and the Lesser Antilles, and summer north of Cape Cod. Minke whales are more solitary than other species of baleen whales. Pairing occurs from October to March; gestation is about 10 months and lactation is estimated to be less than 6 months. Diet consists of euphausiids and small fish (Lowery, 1974).

6.7.2 Pygmy Sperm Whale

Pygmy sperm whales *(Kogia breviceps)* have a worldwide distribution in warmer seas and tend to be relatively rare. These small whales strand frequently throughout the eastern and northern Gulf of Mexico. Mating takes place in late summer and there is a gestation period of nine months. Diet consists of squid, crab, shrimp, and some fishes. Pygmy sperm whales appear to occur in small schools of three to six individuals. The Southeastern U.S. Marine Mammal Strandings Network reports the pygmy sperm whale as the second most common singly-stranded species, with an occurrence of 224 strandings/sightings between 1978-1987 (151 of these occurred off Florida coasts; NOAA, 1991).

6.7.3 Dwarf Sperm Whale

Dwarf sperm whales (*K. simus)* are very similar in appearance to pygmy sperm whales. Their range, habitat requirements, and diet are very similar, but dwarf sperm whales have been reported more frequently on the Atlantic coast than on the Gulf coast.

6.7.4 Antillean Beaked Whale

In the western North Atlantic, the Antillean beaked whale occurs from New York south to Trinidad and the Gulf of Mexico. They are rare in the Gulf, known only from five records, three from Texas and two from Florida. They may inhabit deep waters close to shorelines. Their seasonal movements are unknown. Diet consists primarily of squid (Lowery, 1974).

6.7.5 Short-Finned Pilot Whale

Short-finned pilot whales *(Globicephala macrorhynchus)* occur in the tropical and warm temperate regions of the Atlantic, Indian, and Pacific oceans. Their range in the western North Atlantic extends south from Virginia to northern South America and includes the Gulf of Mexico. These whales normally live in deep waters from the continental shelf seaward. They have an extended breeding and calving season and the gestation period is about one year. Diet consists of squid and fish. Short-finned pilot whales are known to occur in groups of 60 or more, but smaller groups are more common (Leatherwood and Platter, 1975). Four events of mass strandings were reported by the Southeastern U. S. Marine Mammal Network between 1978-1987, with 83 individuals being reported off Florida coasts.

6.7.6 Bottlenose Dolphin

Bottlenose dolphin *(Tursiops truncatus)* are the most common cetacean in the Gulf of Mexico. They occur in bays, inland waterways, ship channels, and nearshore waters. Apparently, there are two groups of bottlenose dolphins–small discrete populations that inhabit coastal areas, and offshore populations that congregate in large groups. Surveys of the Louisiana/Mississippi coastal waters report about 2,000-6,000 bottlenose dolphins (Leatherwood and Platter, 1975). The Southeastern U.S. Marine Strandings Network reported 531 strandings/sightings for Florida (both east and west Coast) from 1978-1987 (NOAA, 1991). Dolphins usually occur in pods of three to seven animals, but large herds of 200-600 dolphins have been observed. Calving and mating occurs from February to May. Gestation lasts approximately 12 months and lactation up to 18 months. The calving interval is two to three years.

Bottlenose dolphins feed on a variety of fishes, mollusks, and arthropods, apparently selectively choosing the most abundant prey. Leatherwood and Platter (1975) recorded seven recurrent feeding patterns in the northern Gulf: (1) foraging behind working shrimp boats and eating organisms disturbed by the nets; (2) feeding on trashfish dumped from the decks of shrimp boats; (3) feeding on fish attracted to nonworking shrimpers; (4) herding schools of fish by encircling and charging the school, or feeding on the stragglers; (5) sweeping schools of small bait fish into shallow water ahead of a line of dolphins, and charging into the school or feeding on stragglers; (6) crowding small fish into shoals or mud banks at the base of grass flats, driving fish completely out of the water and then sliding onto banks to retrieve them; and (7) individual feeding.

6.7.7 Striped Dolphin

The striped dolphin *(Steno ceruleoalba)* is found widely throughout temperate and tropical waters of the world. In the western North Atlantic they prefer warmer, offshore waters and normally are confined to the Gulf Stream or continental slope (Leatherwood and Platter, 1975). With one exception, all records from the Gulf of Mexico are from summer and fall. This may be the result of seasonal movements of the striped dolphin in and out of the Gulf. Diet consists of squid and small fish.

6.8 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 actions do not jeopardize the continued existence of listed species or destroy or adversely modify critical habitat (Carmody, 1993).

The USFWS and NMFS sent lists of species under their respective jurisdictions that could be impacted by the permitting action (Stevens, 1993; Carmody, 1993). These species are listed in Table 6-2. In 1997, the USFWS sent comments regarding the proposed permit issuance and expressed concurrence with EPA's determination that the permit would "not likely...adversely affect" endangered or threatened species (Carmody, 1997).

6.8.1 Endangered Marine Mammals

The Florida manatee and five species of whales (the right, set, fin, humpback, and sperm) are endangered marine mammals in the Gulf of Mexico. The set, fin, and humpback whales are eurythermic, with a broad range of temperature tolerances and are found in most major oceans (Schmidly, 1981). The right whales have a distinct bipolar distribution and are regarded as cold-stenothermal (Schmidly, 1981). The fin, humpback, right, and set whales are baleen whales, whereas the sperm whale belongs to the odontocetes or "toothed' whale group. Few whales commonly occur in the inshore waters.

6.8.1.1 Florida Manatee

The Florida manatee *(Trichechus manatus latirostris)* is a subspecies of the West Indian manatee and is endangered in Florida and Mississippi. It is a massive, fusiform, thick skinned, aquatic mammal with paddle-like forelimbs, no hindlimbs, and a spatulate, horizontally flattened tail. The diet of the manatee consists of submergent, emergent, and floating plants. Adults range in color from gray to brown, while calves are darker at birth and change to a grayish color by about one month. The average length of a manatee is about 3 meters (9.8 ft.) and the average weight is 360-540 kilograms (793-1190 pounds; Van Meter, 1989). Females may be bigger and heavier than males. The Florida manatee is found only in the southeastern United States ranging only as far north as Charlotte Harbor on the west coast of Florida in the winter.

The exact number of Florida manatees is unknown, but winter aerial surveys at warm-water refuges in 1985 counted a minimum of 800-1,200 animals (USFWS, 1989), of which 9 to 13 percent were calves (Van Meter, 1989). These figures may reflect a tendency for females with calves to seek out warm-water refuges more than other adults. It is unknown if the birthrate is high enough to offset the 120 or so dead manatees recovered annually in Florida in recent years (Van Meter, 1989).

Table 6-2. Federally Listed and Candidate Species in Impact Areas of the Eastern Gulf of Mexico

Species	Scientific Name	Federal Listing in Each State[a]		
		Florida	Mississippi	Alabama
Brown pelican	*Pelicanus occidentalis*	—	—	—
Bald eagle	*Haliaeetus leucocephalus*	E	E	E
Piping plover	*Charadrius melodus*	T	T	T
Arctic peregrine falcon[b,c]	*Falco peregrinus tundrius*	T	T	T
American peregrine falcon	*F. peregrinus anatum*	—	—	E
Wood stork	*Mycteria americana*	E	—	E
Roseate tern	*Sterna dougalli dougalli*	T	—	—
Cape Sable sparrow	*Ammodramus maritima*	E, CH	—	—
American crocodile	*Crocodylus acutus*	E, CH	—	—
Loggerhead sea turtle	*Caretta caretta*	T	T	T
Kemp's ridley sea turtle	*Lepidochelys kempii*	E	E	E
Green sea turtle	*Chelonia mydas*	E	T	T
Hawksbill sea turtle	*Eretmochelys imbricata*	E	E	E
Leatherback sea turtle	*Dermochelys coriacea*	E		E
Key deer	*Odocolieus virginianus clavium*	E	—	—
Florida manatee	*Trichechus manatus latirostris*	E, CH	—	E
Finback whale	*Balaenoptera physalus*	E	E	E
Humpback whale	*Megaptera novaeangliae*	E	E	E
Right whale	*Eubaleana glacialis*	E	E	E
Blue whale	*B. musculus*	E	E	E
Sei whale	*B. borealis*	E	E	E
Sperm whale	*Physeter macrocephalus*	E	E	E
Choctawhatchee beach mouse	*Peromyscus polionotus allophrys*	E, CH	—	—
Alabama beach mouse	*P. polionotus ammobates*	—	—	E, CH
Perdido Key beach mouse	*P. polionotus trissyllepsis*	E, CH	—	E, CH
Key Largo cotton mouse	*P. gossypinus allapaticola*	E	—	—
Florida panther[c]	*Felis concolor coryi*	E	E	E
Key Largo woodrat[c]	*Neotoma floridana smalli*	E	—	—
Loweer Keys rabbit[c]	*Sylvilagus palustris hefneri*	E	—	—
Gulf sturgeon	*Acipenser oxyrhinchus desotoi*	T	T	T
Stock Island tree snail	*Orthalicus reses reses*	T	—	—
Schaus swallowtail butterfly	*Papilio aristodemus ponceanus*	E	—	—
Key tree cactus	*Cereus robinii*	E	—	—
Garber's spurge	*Euphorbia garberi*	T	—	—
Southeastern snowy plover[c]	*Charadrius alexandrinus tenuirostris*	C	C	C
St. Andrew beach mouse	*P. polionotus peninsularis*	C	—	—
Santa Rosa beach mouse	*P. polionotus leucocephalus*	C	—	—

[a] E=endangered; T=threatened; CH=critical habitat; — = not listed for that state; C=candidate
[b] The arctic peregrine falcon was delisted from the endangered species list October 5, 1994 (50 FR 50796-805).
[c] These species are not likely to be impacted and are not discussed in detail in Chapter 6.
Source: Carmody, 1993; Stevens, 1993.

The following areas are designated as critical habitat for the manatee on the Gulf coast of Florida (USFWS, 1990).

- Crystal River and its head waters
- Kings Bay in Citrus County
- Little Manatee River in Hillsborough County
- Myakka River in Sarasota and Charlotte Counties
- Charlotte Harbor in Charlotte County
- Caloosahatchee River in Lee County
- U.S. territorial waters adjoining coasts and islands in Lee County
- U.S. territorial waters adjoining coasts and island and all connecting bays, estuaries, and rivers from Gordon's Pass in Collier County to Whitewater Bay, Monroe County
- All waters of Card, Barnes, Blackwater, Little Blackwater, Manatee, and Buttonwood Sounds between Key Largo in Monroe County

Decline of the manatee is attributed to overfishing of the species for its meat, oil, and leather. Currently, cold stress, calf mortality, and human disturbance also are threats to the manatee.

6.8.1.2 Right Whale

The right whale *(Eubaleana glacialis)* is listed as endangered by USFWS. The range of the western North Atlantic population is from Iceland to Florida and the Gulf of Mexico. This population estimated to be 250 to 350 individuals; the Gulf of Mexico population is unknown. The most recent observation of right whales in the eastern Gulf was in 1963 off Manatee County, Florida (MMS, 1990). The only other recent record of the right whale in the Gulf is a stranding in Texas (Mullin et al., 1991). The whales migrate northward along the eastern Florida coast between January and March and have been observed in the Gulf of Mexico during this time. The southward migration occurs in fall farther offshore. Mating takes place in the North Atlantic in late summer. Gestation is assumed to be one year, with calves suckling for approximately one year. Right whales feed by "skimming" at or below the surface for copepods and euphasids.

6.8.1.3 Sei Whale

Sei whales *(Balaenoptera borealis)* occur in all oceans and are listed as endangered. Sei whales are widely distributed in the nearshore and offshore waters of the western North Atlantic but are rare in tropical and polar areas. A set whale was reported in 1973 off Gulfport, Mississippi (MMS, 1990). Little information is available on their seasonal movements. In thc North Atlantic, their diet consists primarily of copepods, although they take euphasids and small schooling fish. Sei whales usually travel in groups of two to five individuals but may concentrate in larger numbers in their feeding grounds (Leatherwood et al., 1976). During an eleven month aerial survey from July 1989 until June 1990, Mullin et al. (1991) may have sighted a set whale in De Soto Canyon off the coast of Mississippi, although it is unclear whether it was a set whale or a Bryde's whale.

6.8.1.4 Fin Whale

Fin whales *(Balaenoptera physalus)* are listed as endangered by NMFS. They occur from Greenland in the western North Atlantic, to the Gulf of Mexico and the Caribbean (Leatherwood et al., 1976) and their diet consists mainly of krill, squid, and small fish (Lowery, 1974). Fin whales have been stranded in all regions of the Gulf. Sightings have been recorded in the Gulf throughout the year and suggest a somewhat isolated population (Caldwell and Caldwell, 1973). During an eleven month aerial survey, one fin whale was sighted in the De Soto Canyon area in November 1989 (Mullin et. al., 1991).

6.8.1.5 Humpback Whale

Humpback whales *(Megaptera novaeangliae)* have been listed as endangered since 1970 after a great reduction in number from commercial whaling (Marine Mammal Commission, 1988). Historically, the species has been threatened by commercial vessel traffic, commercial fisheries, coastal development, and more recently, whale-watching tour boats. They inhabit most of the world's oceans with only rare sightings in the eastern and central Gulf of Mexico. North Atlantic populations breed and calve during the winter months.

In 1962 and 1983, humpback whales were sighted near the mouth of Tampa Bay and in 1983 near Seashore Key, Florida (MMS, 1990). Historically, they were sighted in the central Gulf in 1952 and 1957 (MMS, 1990).

6.8.1.6 Sperm Whale

Sperm whales *(Physeter catodon)* also are endangered. They occur in all of the world's oceans, limited to deeper waters along the edge of the continental shelf, and are rarely found on the shelf itself. In the past, they were numerous enough in the Gulf of Mexico to justify full-scale whaling operations. This fact, and relatively common sightings, suggest there may be a separate population in the Gulf (Fritts et al., 1983). In 1989, a sperm whale was stranded on Ft. Myers Beach, Florida (MMS, 1990). During an aerial survey in 1989, sperm whales were the second most commonly sighted whale, while herd densities were close to the median of other whale herd densities (Mullin et al., 1991). In 1989, a sperm whale was stranded on Ft. Myers Beach, Florida (MMS, 1990).

In spring, bull sperm whales join female nursery schools and form "harems." Mating occurs in spring during the migration north. Gestation lasts 14 to 16 months with a 1- to 2-year lactation period. The sperm whale diet consists primarily of squid but includes many other deep water species and bottom dwellers.

6.8.2 Endangered Birds

6.8.2.1 Brown Pelican

The brown pelican *(Pelecanus occidentalis)* is endangered in Mississippi. It was taken off the endangered species list in Alabama in 1985 and is not listed as endangered in Florida. The brown pelican is a species of colonial bird that nests on small coastal islands in salt and brackish waters. They are rarely found more than 20 miles from land. Their diet consists primarily of fish, including menhaden, mullet, sardines, and pinfish. The decline of the brown pelican is attributed to their ingestion of pesticides (USFWS, 1991). They are also highly susceptible to abandoning their nests once disturbed (USFWS, 1991). As of 1990, there were no known nesting colonies in Mississippi (USFWS, 1991).

6.8.2.2 American Peregrine Falcon

The American peregine *(Falco peregrinus anatum)* is listed as endangered in Alabama. The original eastern United States population of the peregrine, which was extirpated, was considered by most ornithologists to be non-migratory. However, in order to find better feeding conditions, there was apparently some fall/winter movement from the mountains to the coast. The birds returned to their natural breeding area in the spring (FWS, Region 4, 1991).

A cliff or series of cliffs that tend to dominate the surrounding landscape constituted typical nesting habitat in the eastern United States. However, other forms of nesting habitat have also been utilized, such as river cutbanks, trees, and manmade structures including tall towers and the ledges of tall buildings (FWS, Region 4, 1991).

The principal cause of the peregrine's decline was due to the presence of chlorinated pesticides, especially DDT and its metabolite DDE, which accumulated in peregrines as a result of feeding on contaminated prey. Other less significant factors in the decline include shooting, natural collecting, disease, falconers, human disturbance of nesting sites, and loss of habitat to human encroachment (FWS, Region 4, 1991).

A comprehensive recovery plan was completed in 1979, and revised in 1987. The primary objective of the plan is to restore a self-sustaining population of peregrine falcons in the eastern United States. A captive breeding program was initiated by the Peregrine Fund at Cornell University beginning with the 1971 breeding season. As of 1990, approximately 1,178 falcons had been released in 11 northeastern states (FWS, Region 4, 1991).

6.8.2.3 Bald Eagle

Bald eagles *(Haliaeetus leucocephalus)* are listed as endangered or threatened in all 48 contiguous states. They are listed as endangered in Mississippi, Alabama, and Florida. Before becoming endangered, their nests were a common occurrence along major lakes and rivers and throughout the southeastern coastal plain, from the Chesapeake Bay to the Florida Keys, and north along the west coast of Florida to the panhandle, through Louisiana and into Texas. Bald eagles mate for life; pairs begin nest building in early fall and lay eggs in October. Nesting populations are gradually increasing in most areas of the country (USFWS, 1987a). The endangered bald eagles feed primarily on fish, but, as opportunistic feeders, also feed on waterfowl and shorebirds, particularly sick or injured individuals and carrion (USFWS, 1991).

As of 1989, an active nest was located north of the junction of Biloxi River and Biloxi Bay, in Harrison County, Mississippi (USFWS, 1991). In 1988, a nest was reported near the town of Logtown in Hancock County, Mississippi; its status is currently unknown (USFWS, 1991). Although bald eagles are sighted on Bon Secour National Wildlife Refuge, there are no known active nests (USFWS, 1991). There are plans to introduce bald eagles to the northern part of Alabama.

A survey from 1973 to 1988 in Florida showed reproduction to be successful. The highest reproductive year was 1988 when 448 young were born from 399 occupied breeding areas (USFWS, 1990). Most of the breeding occurs in the west coast counties. Each county on the Gulf, except Dixie and Jefferson Counties, fosters active bald eagle nests (USFWS, 1990).

An area of concentrated nesting or "essential habit" is viewed as a nuclear population and is considered important for long-term survival of the species. In Florida, population centers are found in Charlotte County along portions of the western Charlotte Harbor coast east of State Road 771 and adjacent to Gasparilla Sound; and in Lee County in areas adjacent to San Carlos Bay, Matlacha Pass south of State Road 78, Matanzas Pass, and Estero Bay (USFWS, 1990). Destruction or alteration of this habitat would be detrimental to the species.

6.8.2.4 Piping Plover

The piping plover *(Charadrius melodus)* is listed as threatened in Florida, Mississippi, and Alabama. The estimated world population is 4,000 birds. The piping plover frequents unvegetated open sand areas where it feeds mainly on surface and infaunal invertebrates. The extensive sand flats of Laguna Madre and other barrier islands are important habitats. This bird has three primary breeding areas: the Great Lakes, the midwest prairies, and the North Atlantic coast. During winter, piping plovers inhabit the beaches, sandflats, and dunes of the Atlantic and Gulf Coast, from North Carolina to Mexico. Intercoastal spoil islands also are used.

A survey from 1987 to 1989 indicates that approximately 403 birds were located on the Florida and Alabama beaches (USFWS, 1990). The sites with the two highest densities in these two states include Little Dauphin Island in Bon Secour Wildlife Refuge, Alabama, and Honeymoon Island State Park and Mullet Key in Pinellas County, Florida (USFWS, 1990). Other important sites in Florida include the following (USFWS, 1990):

Marco-Island, Collier County
Estero Island, Lee County

Sandbar Island, Pinellas County
Phipps Reserve, Wakulla County
Cape San Blas, Gulf County
St. Joseph Peninsular, Gulf County
Crooked Island East, Bay County
Shell Island, Bay County

In Mississippi important sites include the following (USFWS, 1991):

Buccaneer State Park, Gulf Islands National Seashore
Horn Island, Gulf Islands National Seashore
Ship Island, Gulf Islands National Seashore
East Ship Island, Gulf Islands National Seashore
Hewes Avenue, Gulfport
Moses Pier, Gulfport
Pass Christian
American Legion Pier

Loss of appropriate beaches and other littoral habitats for the piping plover is due to recreation, coastal development, and dune stabilization. The species' preferred breeding habitat is often disturbed by humans (USFWS, 1990).

6.8.2.5 Wood Stork

The wood stork *(Mycteria americana)* is endangered in Florida and Mississippi. Breeding in the United States takes place only in Florida, Georgia, and minimally in South Carolina (USFWS, 1990). After breeding the storks move northward, as far as Arkansas in the Mississippi River Valley, and into North Carolina, along the Atlantic Coast. The population is estimated to be approximately 10,000 adults (USFWS, 1990).

In Florida, wood storks are known to nest from Leon to Duval Counties, south to Everglades National Park (USFWS, 1990). Storks have been sighted in Alabama in Bon Secour, St. Vincent Island, St. Marks, and Lower Suwannee refuges (USFWS, 1990).

Man's alteration of wetlands is the cause of the decline of the wood stork. The storks' feeding habits require a high concentration of prey. Optimal feeding ground for the stork is that which alternates periods of flooding with periods of dry. During the flooding periods the fish swim into the storks' habitat and are then trapped and concentrated by nature during the dry periods. The dry period coincides with the stork's breeding season. This would provide the stork with an ample food supply for the offspring. However, loss of cypress swamps in Florida, which are appropriate feeding grounds, is a factor in the decline of the wood stork (USFWS, 1990).

6.8.2.6 Roseate Tern

The roseate tern *(Sterna dougalli dougalli)* is listed as threatened in Florida. The roseate tern nests from Nova Scotia to Virginia and in the Florida Keys, Bahamas, eastern West Indies, and along the coast of South America from the Guianas to Brazil. These buds are ocean feeders that pluck fish from waters adjacent to their breeding grounds. As the young mature, they travel farther from shore to look for food (USFWS, 1990).

In the Florida Keys there are two colonies of roseate terns. There is one colony of 225 terns on a low lying island near the reef line off Key West (USFWS, 1990). In 1988, this colony was located on Tank Island (USFWS, 1990). The eggs from this colony were examined after two nesting failures. This examination revealed the presence of *Escherichia coli* and *Pseudomonas* species. This is believed to be caused by the sewage outfall from Key West. The second colony is located on the roof of a condominium complex in the middle of the Keys. These colonies can be disturbed by humans, pollution, and tropical storms. It is believed that these colonies have not declined significantly in the past ten years (USFWS, 1990).

6.8.2.7 Cape Sable Sparrow

The Cape Sable sparrow *(Ammodramus maritima)* has been listed as endangered since March 11, 1967 (USFWS, 1990). It has an olive-gray body with an olive-brown tail and wings, light grey with dark olive grey streaks on the breast and the sides, and gray legs, ear patch, and bill. It has brown eyes and a white throat (Werner, 1979). The Cape Sable sparrow inhabits interior, fresh to brackish marshes in extreme southern and southwestern Florida. At one time, their range extended east of the mangrove zone from Carnstown to Shark Valley Slough (Werner, 1979). Currently, they are only occasionally sighted in this area. The sparrow prefers cordgrass broken by patches of spike rush, salt grass, and small ponds. It is highly adapted to a fire environment (Werner, 1979).

The Cape Sable seaside sparrow is listed as endangered due to its restricted distribution and specific habitat requirements. A 1985 survey indicated that the population has not decreased since 1981 (O'Meara and Marion, 1985).

Cape Sable sparrows are territorial, and except during breeding season, they are secretive (Werner, 1979). The nest is suspended and hidden in a tuft of grass, and is woven out of fine grasses in the shape of a dome or cup. They nest between February and August, laying 3 to 4 eggs in a clutch. Some lay as many as 3 clutches a season and eggs are incubated at least 11 days. The breeding season seems to correspond with the hydroperiods of the marsh, with nesting decreasing during the flood periods. The young stay in the nest for 9 to 11 days and are capable of short flights after 2½ weeks (Werner, 1979). They feed on insects and flowers (Werner, 1979).

6.8.3 Endangered Reptiles

Endangered reptiles within the permit coverage area include five marine turtles and the American Crocodile. The marine turtles are strongly adapted to aquatic life, mating at sea and only visiting dry land to lay their eggs. Most of the sea turtles of the United States nest in Florida, from Sarasota to Boca Grande and in the Cape Sable Region (Van Meter, 1990). The eggs are buried in the duneline above mean high tide, where they are preyed upon by man, raccoons, dogs, cats, rats, feral pigs, foxes, crabs, lizards, and insects; they incubate 50 to 70 days before hatching. Hatchlings immediately enter the water; they are preyed upon by gulls, crows, raccoons, dogs, cats, etc. Predators of adult sea turtles include man, crocodiles, large fish (groupers), killer whales, and sharks (Mager, 1985).

6.8.3.1 Green Sea Turtle

The green sea turtle *(Chelonia mydas)* is listed by the USFWS as endangered in Florida and threatened in Mississippi and Alabama. It is found throughout the world in tropical and semi-tropical waters. Green turtles are believed to be long-lived (20 years or longer), but longevity rates in the wild are uncertain (Hirth, 1971). Ehrenfeld (1974) estimated that the total world population of sexually mature green turtles was no more than 100,000 to 400,000, while Caribbean stocks alone may have amounted to 50 million in the 17th century.

Primary breeding grounds in North America are on the southern Florida beaches. It is estimated that 375 green turtles nest in Florida, with 400 to 800 nests being reported each year. Nesting is primarily reported between May and August and occurs only on Florida beaches and along the Yucatan Peninsula (Rabalais, 1987) . In the eastern Gulf, six nests were reported in Monroe County, Florida, on East, Marquesas, Woman, and Boca Grande Keys. Recently, nests have been recorded on the northwest coast of Florida--in 1987 on Eglin Air Force Base, and in 1989 on Navarre Beach and on Santa Rosa Island (USFWS, 1990).

Females deposit between 3 and 7 clutches per season at intervals of 10 to 18 days. Average clutch size varies between 80 and 150 eggs that hatch within 48 to 72 days. Hatchlings emerge, usually nocturnally, and travel quickly to water to spend a year in a so-called "swimming frenzy" before they graduate to adult diving behavior farther out to sea (Mager, 1985).

Juvenile green turtles are common in the lagoons and bays along the Florida and Texas coasts. The upper west coast of Florida is a principal feeding ground. Observations indicate that they enter inlets during the summer months and feed on the copious supplies of turtle grass *(Thalassia testudinum),* shoal grass *(Halodule wrighti),* widgeon grass *(Ruppia maritima),* and other plant life, algae, and small invertebrates that exist in these locations (Raymond, 1985). These juvenile greens frequently spend daylight hours in inshore waters, venturing out to the open sea at night.

Since breeding and nesting grounds tend to be far from forage areas, the green turtle frequently migrates very long distances, and tagged females rarely appear in the same nesting area twice. Along the east coast of the U.S., adult green turtles are found from Massachusetts to the Gulf of Mexico. Adult green turtles are rarely sighted in the Gulf of Mexico or along the shores of the southeastern United States.

The turtle's survival in Florida is threatened by beach lighting, habitat alterations, and drowning in fishing gear (Van Meter, 1990). Many of Florida's green turtles have tumorous warts on their bodies called fibropapillomas thought to be viral in origin. Some die, while others recover from this disease. They were first reported in 1982 on a green turtle in the Indian River where large numbers of immature green turtles in the lagoon system were discovered to be afflicted by the disease (Mager, 1985).

6.8.3.2 Hawksbill Sea Turtle

The hawksbill sea turtle *(Eretmochelys imbricata)* is endangered in Mississippi, Florida, and Alabama. No reliable estimates are available on hawksbill populations. However, it is generally agreed that their numbers are decreasing due to habitat encroachment and destruction due to man and natural disasters (Mager, 1985).

Females nest alone and do so very quickly. Nesting sites within the U.S. are limited to southern Florida. Preferred nesting sites are on clean, gravelly-textured beaches with significant oceanic exposure and little activity that would disturb nesting. Hawksbill sea turtles rarely nest in the eastern Gulf. The species is more agile than other sea turtles and can climb over rocks, vegetation, and other obstructions to find its preferred nesting area among the thick vegetation at the rear of the beach platform (Mager, 1985). Females typically nest in two to three-year cycles and deposit one to four clutches at 15 to 19 day intervals. Hatchlings emerge at night and head directly to the sea where they are pelagic for some time.

Hildebrand (1987) studied the movements of hawksbill hatchlings based on the pattern of the IXTOC oil spill, which occurred offshore from their nesting site. He concluded that they were propelled northward in warm months by their neonatal "swimming frenzy." During the colder months they return south; Hildebrand surmised that the pelagic young use sargassum or *Trichodesmium* for cover, at this time.

At a later age, the hawksbill becomes a benthic feeder. It inhabits reefs, shallow coastal areas, rocky areas, and passes and is generally found in waters less than 20 meters deep. The hawksbill is omnivorous. Although it prefers sponge, its diet consists of algae, seagrasses, soft corals, crustaceans, mollusks, sponges, jellyfish, and sea urchins.

6.8.3.3 Leatherback Sea Turtle

The leatherback sea turtle *(Dermochelys coriacea)* is endangered in Florida and Mississippi. It is the largest of the sea turtles. Belonging to the family dermochelyidae, it is distinct from the other sea turtles in the Gulf. The main anatomical difference is, as its name suggests, the lack of a real shell, and instead it is covered by a thick, leather-like skin. The leatherback is the most oceanic of all sea turtles and ranges in the Pacific, Atlantic, and Indian Oceans. It ranges farther north than other turtles, as far as Labrador and Alaska, probably because of its ability to maintain warmer body temperatures over longer periods of time.

Although it was once thought that males, juveniles, and hatchlings stay mainly in deep waters, they have been sighted in the shallow waters of the Gulfs of Maine and Mexico, including both the east and west coasts of Florida. The leatherback's diet consists of tunicates and jellyfish. In the Gulf of Mexico, its primary prey is the jellyfish, *Stomalophus melagris* (Rabalais, 1987).

The number of nesting females is estimated to be as high as 120,000 (Pritchard, 1983) and as low as 70,000 (Mrosovsky, 1983) worldwide. In the Gulf of Mexico, nesting most often occurs along the coast of Mexico. The interval between nestings in one season is 7 to 13 days with clutch sizes varying between 50 and 160 eggs that hatch in 60 to 70 days. Most of the females tagged while nesting are never seen again (Hughes, 1982). Sightings of leatherbacks are common on the Gulf coast of Florida in March and April, although only one nest has been attempted between 1979 and 1988, this was on Sanibel Island in Lee County (USFWS, 1990).

6.8.3.4 Loggerhead Sea Turtle

Loggerhead turtles *(Caretta caretta)* are threatened in Mississippi, Florida, and Alabama. They are the most abundant of the marine turtles found in the Gulf, concentrated primarily toward the Florida coast. Survival in Florida is threatened by habitat loss and drowning in shrimp trawls.

Loggerhead turtles frequent the temperate waters of the continental shelf along the Atlantic and Gulf of Mexico, foraging around rocky places, offshore oil platforms, coral reefs, and shellfish beds (Raymond, 1985). They have been observed as far as 500 miles out in open sea and in the bays and estuaries of Texas. Rabalais (1987) postulated that they migrate north each year with the shrimp fleet from the Rio Grande. Hildebrand (1987) confirmed that loggerheads and shrimp apparently have similar seasonal migration patterns. USFWS (1990) reports the numbers of loggerheads found along west coast Florida counties.

County	Number of Turtles
Escambia, Santa Rosa, Okaloosa, and Walton	104
Bay, Gulf, and Franklin	84
Pasco through Collier	1,449
(Sarasota)	(804)
(Lee)	(281)
Monroe	129

In the southeastern U.S., an estimated 14,000 females nest each year. In Florida, they nest from late April to September (Van Meter, 1990). Loggerheads nest on various barrier islands and beaches from the Florida Keys up the coast of Florida, north to Georgia and South Carolina, and west to the Chandeleur Islands off Louisiana (where most of the nesting occurs). In Florida, the majority of the nests on the west coast are from Collier to Pinellas Counties (Van Meter, 1990). On Bon Secour Refuge in Baldwin County, Alabama, one nest is usually found every mile. Other nesting locations in Alabama include Gulf Shores and Fort Morgan (13 nests/year), and the western end of Dauphin Island (1-12 nests/year; USFWS, 1991). Petit Bois, Horn, and East Ship Islands, and Biloxi are nesting areas in Mississippi (USFWS, 1991).

Females nest generally at night, depositing an average of 120 eggs which hatch in approximately 60 days. Females typically nest four to five times per season. Loggerheads will disperse to feeding grounds after nesting; these feeding grounds range as far north as New Jersey (in warmer months) to the Florida Keys, and throughout the Gulf of Mexico, the Bahamas, and the Dominican Republic (Van Meter, 1990). Hatchlings enter the sea immediately and may spend the early part of their lives associated with mats of sargassum weed and other flotsam (Pritchard, 1979). Loggerheads are omnivorous, feeding on shellfish, crabs, hermit crabs, barnacles, oysters, conchs, sponges, jellyfish, squid, sea urchins and sometimes fish, algae, and seaweed (NMFS, 1987).

6.8.3.5 Kemp's Ridley Sea Turtle

The Kemp's ridley sea turtle *(Lepidochelys kempi)* is endangered in Florida, Mississippi, and Alabama. It is among the smallest of the sea turtles. It is not known how many years are required to reach sexual maturity. The previously assumed onset of maturity at 6 to 8 years has been reassessed to perhaps 15 years (Woody, 1986). Population size estimates vary, but the Kemp's ridley adult population is believed to be less than 2,000 (USFWS, 1987b). It is threatened by shrimp trawl drowning, habitat alterations, and pollution (Van Meter, 1990).

The Kemp's ridley has the most restricted range of the five species found in the Gulf, with the greatest concentrations of mature Kemp's ridleys being in the shallow coastal areas of Louisiana and the Tabasco-Campeche area of Mexico (Raymond, 1985). Young Kemp's ridleys are known to occur in U.S. coastal waters from Florida to the Gulf of Maine, leading to the speculation that they migrate north passively along the course of the Gulf Stream. By the time they reach the New England shoreline, they are large enough for active swimming. At this point, they head south to the Gulf of Mexico (NMFS, 1987).

There is only one key nesting area, an isolated stretch of beach no more than 15 miles long, in the Mexican state of Tamaulipas near the village of Rancho Nuevo. Only 300 to 350 females nest each year between April and June (Van Meter, 1990). Isolated females have nested on Padre Island National Seashore and other locations in the western Gulf. The Kemp's ridley is the only sea turtle to routinely nest during daylight hours. Nesting occurs during periods of strong wind, possibly because the wind will cover the tracks and nest sites. The only documentation of a Kemp's ridley sea turtle nesting in the eastern Gulf was in May, 1989, at Madeira Beach in Pinellas County, Florida. The result of 116 eggs was 24 hatchlings (USFWS, 1990).

The diet of the Kemp's ridley sea turtle consists mostly of various species of crabs (e.g., *Ovalipes, Callinectes)* but includes crustaceans, jellyfish, mollusks, fish, gastropods, and echinoderms. Hatchlings are omnivorous, becoming more carnivorous as they become larger and more mobile.

Because of the alarming decline in the Kemp's ridley population, the Mexican Fisheries Department, USFWS, the NMFS, and the National Park Service reached an agreement in 1978 to cooperate in a 10-year program designed to establish nesting sites in the United States. Eggs are collected in Mexico and transported to artificial nests at Padre Island National Seashore (USFWS, 1990).

6.8.3.6 American Crocodile

The American crocodile *(Crocodylus acutus)* is endangered in Florida. It is a scavenger that feeds on dead or injured small fish and invertebrates as juveniles, or dead and injured fish, crabs, birds, and snakes as adults. It inhabits coastal areas, mostly salt and brackish bays and brackish creeks. There is evidence that the young cannot withstand full seawater salinity, although adults can, and may often wander into coastal areas. The crocodile is not a very mobile animal, although radiotelemetry studies have followed the crocodiles up to 100 hectares. One crocodile in Florida that was moved 100 km from Pine Island, Lee County, to Seminole Park, Collier County, returned to its home. Nesting occurs from April or May with the eggs hatching in July or August (USFWS, 1990).

Biscayne Bay along the Atlantic Ocean, around the upper keys, across Florida Bay, and to the Everglades has been designated as critical habitat. A population of 300 individuals lives in southern Florida. The only places the crocodile breeds are along Florida Bay, Turkey Point, and Crocodile Lake Refuge in the Everglades National Park. Due to sightings north and south of the area, it is believe that there may be a population located in Estero Bay, Lee County (USFWS, 1990).

Loss of habitat due to urbanization and human disturbances, killings by humans, and accidental deaths in commercial fishing nets and on highways are all factors leading to the decline of the species. Because the hatchlings may not be able to tolerate higher salinities, a decreased flow of fresh water in the Florida Keys may be another contributing factor (USFWS, 1990).

6.8.4 Endangered Mammals

6.8.4.1 Key Deer

The key deer is endangered in Florida. It ranges from Big Pine Key to Sugarloaf Key. The current population is estimated at 250 to 300 individuals (USFWS, 1990). In 1978, the population was estimated at 400 deer. The key deer inhabit only those islands with a permanent freshwater supply. Most of the population are found on Big Pine Key and No Name Key. Key deer move between the larger keys and the outlying smaller keys. This movement is believed to depend on the availability of a freshwater supply (USFWS, 1990). Habitat destruction and human disturbances are mostly responsible for the decline of this species; other causes include road kills, falling into drainage ditches, feral dogs and pigs, and illegal feeding.

6.8.4.2 Florida Saltmarsh Vole

The Florida saltmarsh vole *(Microtus pennsylvanicus dukocampbelli)* is endangered in Florida. The population is located in a tidal salt marsh on Waccasassa Bay on the Gulf coast of Florida (Woods et al., 1982). The subspecies was discovered in 1979 (Smith, 1990). The vole's diet is believed to consist of seeds and parts of succulent plants, although it also may include insects, snails and crabs, and possibly sparrow and wren eggs (Smith, 1990).

Predators include other salt marsh rodents (e.g., voles, marsh rats, cotton rats, and cotton mice), marsh hawks, short-eared owls, and raccoons (Smith, 1990). The vole species *M. pennsylvanicus* demonstrates extraordinary swimming, diving, and climbing abilities (Smith, 1990). Their nests are found above the high water line. These factors contribute this species' survival in the harsh environment of the salt marsh.

Natural forces, especially tropical storms, are the biggest threat to such a small population. Hurricane Elena of 1983 "inspired" Smith's trapping survey which yielded only one trapped male Florida salt marsh vole. It is believed that other populations may exist; however, they may be so small that they are hard to detect (Smith, 1990).

6.8.4.3 Choctawatchee Beach Mouse
Perdido Key Beach Mouse
Alabama Beach Mouse

The Choctawatchee beach mouse *(Peromyscus polionotus ammobates)* and Perdido Key beach mouse *(Peromyscus polionotus trisyllepsis)* are endangered in Florida. The Alabama Beach Mouse *(Peromyscus polionotus allophrys)* is endangered in Florida and Alabama. The mice are nocturnal herbivores that inhabit primary and secondary dunes and scrub dunes along the Gulf. They eat the seeds of beach grass *(Paicum amarum* and *P. repens)* and sea oats *(Uniola paniculata)*. They dig burrows into the lee side of sand dunes and are known to utilize ghost crab *(Ocypeda quadratus)* burrows. Loss of habitat due to tropical storms is the most important cause for the decline of these beach mice (USFWS, 1990).

The Choctawatchee beach mouse is located in three Florida areas: 7.9 km of beach around Morrison Lake to Stalworth Lake, Walton County; Shell Island at St. Andrew Bay in Bay County; and Grayton Beach State Park. The Grayton Beach population was relocated from Shell Island and bred at Auburn University. All of these areas plus part of St. Andrews State Recreation Area in Bay County have been designated as critical habitat (USFWS, 1990).

In 1986, the only known population of the Perdido Key beach mouse was located at Gulf State Park, Alabama. Through a cooperative effort between the state and Federal government, the species has been reintroduced to Gulf National Seashore on Perdido Key by translocating individuals from Gulf State Park. Critical habitat has been designated in Gulf State Park, Baldwin County, Alabama, and Perdido Key State

Recreation Area and Perdido Key Unit of Gulf Islands National Seashore, Escambia County, Florida (USFWS, 1990; 1991).

The Alabama beach mouse ranges from Fort Morgan State Park to the Romar Beach Area, but has disappeared from most of this range (USFWS, 1990). Fort Morgan and Bon Secour State Park National Wildlife Refuge, and part of the Gulf State Park in Baldwin County, Alabama, have been designated as critical habitat (USFWS, 1990; 1991).

6.8.4.4 St. Andrew Beach Mouse
Santa Rosa Beach Mouse

The St. Andrew beach mouse *(Peromyscus polionotus peninsularis)* and Santa Rosa beach mouse *(Peromyscus polionotus leucocephalus)* are listed as Category 2 candidate species in Florida. Not enough information is currently available to propose them as being threatened or endangered (Carmody, 1991). These beach mice hold similar niches as the Choctawatchee, Perdido Key, and St. Alabama beach mice.

Two unstable populations of the St. Andrews beach mouse occur on the mainland portion of Tyndall Air Force Base, Bay County, and on Cape San Blas on St. Joseph State Park, Gulf County. A stable population of the Santa Rosa beach mouse occurs on the undeveloped portion of Santa Rosa Island and on the Gulf Islands National Seashore (USFWS, 1990).

6.8.5 Endangered Fishes

6.8.5.1 Gulf of Mexico Sturgeon

The Gulf of Mexico sturgeon *(Acipenser oxyrhynchus desotoi)* is a threatened species in Florida, Mississippi, and Alabama. The sturgeon occurs in the marine waters of the central and eastern Gulf of Mexico south to Florida Bay, and in most major rivers, from the Mississippi River to the Suwannee River. Table 6-3 presents the reported occurrences of the Gulf of Mexico sturgeon in major river systems in Mississippi, Alabama, and Florida. According to an analysis by Wirgin and Waldman, there are significant differences in the DNA of six geographically disjunct populations in the Gulf of Mexico (Patrick, 1993).

Overfishing, water pollution, and damming of rivers are attributed with the near disappearance of sturgeon at the turn of the century (USFWS, 1991). The most abundant population of the Gulf of Mexico sturgeon is in the Suwannee River, where population estimates ranged from 60 to 282 fish, between 1983 and 1988 (USFWS, 1991). A limited commercial fishery existed in Escambia county (Florida) prior to 1984.

Gulf of Mexico sturgeon are anadromous fish, migrating between fresh water and saltwater. The sturgeon begin their upriver migrations when river temperatures increase to 16°-23°C (60.8°-75°F), the migration continues until early May. They begin their downriver migration in late September and October

Table 6-3. Recent Occurrences of Gulf of Mexico Sturgeon in Mississippi, Alabama, and Florida

River System	Year	No. Observed	Locality
Pearl	1992 1991 1990 1988 1985 1984	13 1 5 1 63 1	Middle Pearl River Middle Pearl River West Pearl River Lower Pearl River south of Jackson, MS
Pascagoula	1992 1987 1985 Late 1980's/early 1990's	1 1 1 UNK-commercially caught	Mikes River (trib) Chickasawhay River (trib) Mouth of Pascagoula River
Mobile	1991 1986 1987 1998 1985 1989-1991	1 1 1 1 1 UNK-commercial gill netters	Tensaw River Tensaw River Tombigbee River head of Mobile Bay N. end of Mobile Bay Blakely River
Pensacola	1978 1988	1 1	Pensacola Bay Santa Rosa Sound
Escambia	1980	incidental catches reported	
Blackwater	1991	3	
Yellow	1988	spotted	
Choctawatchee	1992 1988, 1990, 1991 1991 1991	3 27 1 3	confluence w/Pea River Btwn Howell Bluff & Rocky Landing Below Caryville, FL Below confluence with Pea River
Apalachicola	1983-1990 1970	96-131 1	Below J. Woodruff Lock Dam
Ochlockonee	1991	4	mouth of Womack Cr.
Suwannee	1986-present 1988-1992	1,670 1,500	River mouth Throughout River
Tampa Bay	1987	1	Near Pinellas Pt.
Charlotte Harbor	1992	1	Near mouth

Source: Patrick, 1993.

when the river temperature decreases to about 19°C (66.2°F). They return to the estuaries of the Gulf of Mexico by mid-November and early December (Patrick, 1993). Young sturgeon remain at the river mouths and do not travel far into the Gulf of Mexico. There have been no reported catches of Gulf of Mexico sturgeon in Federal waters (USFWS, 1991). This information is a result of ultrasonic and radiotelemetry tagging studies in the Apalachicola and Suwannee Rivers; these rivers are still being monitored. The tagging studies also found high probability of recapturing fish in the same river in which they were originally tagged, suggesting that sturgeon return to the same area each summer (Patrick, 1993).

Litt!e is known about the Gulf of Mexico sturgeon reproduction in the wild. Sexual maturity is believed to occur between the ages of 7 to 21 years for females and 8 to 17 years for males. Optimal spawning habitat probably includes river springs and rocky substrate (Patrick, 1993).

There is little information about the predators and competitors of sturgeon. Sturgeon seem to be protected from predators due to their protective plates and secretive nature, although other species may prey on sturgeon eggs. Other benthic organisms, especially fish may also compete with the sturgeon for space and food (Patrick, 1993).

Stomach content analyses indicate that sturgeon may prefer hard bottom, sandy bottom, and sea grass community habitats (USFWS, 1991). No studies have been performed to delineate their exact marine habitat preference, but this stomach content analysis may explain why their range does not include the western Gulf, where the substrate is muddy (USFWS, 1991). Stomach content analyses also indicate that the most important food organism for the Gulf of Mexico sturgeon are amphipods. Other prey include isopods, midge larvae, polychaetes, oligochaetes, lancelets, brachiopods and some unidentifiable vegetable or animal matter (Patrick, 1993). Sturgeon feed while in marine waters for three or four months, but do not feed while in the river for eight or nine months (Patrick, 1993). This trend coincides with growth studies that indicate that weight is only gained during the three or four winter and spring months spent in the estuary and is lost in the eight or nine months spent in the river (Patrick, 1993).

6.8.6 Endangered Invertebrates

6.8.6.1 Schaus' Swallowtail Butterfly

Schaus' swallowtail butterfly *(Heraclides aristodemus ponceanus)* is endangered in Florida. It is a large butterfly that is dark brown with yellow markings (USFWS, Undated). The range of Schaus' swallowtail butterfly is now limited to localized colonies on Key Largo and Elliot Key, although it once inhabited areas from Miami to Lower Matecumbe Key (USFWS, Undated). A survey in 1986 estimated the population on Elliot Key as 750 to 1000 individuals (USFWS, Undated). Two reasons for the decline of the Schaus' swallowtail butterfly are the use of pesticides and loss of habitat due to urbanization and droughts (Baggett, 1982; USFWS, Undated).

The preferred habitat is tropical hardwood hammock forests (USFWS, Undated). Eggs are laid on the under side of fresh, new growth leaves of younger shrub-sized torchwoods, which is the most important host to the caterpillar. There have been reports of eggs being deposited on wild lime and prickly ash (Baggett, 1982). The caterpillar feeds on the new growth for about 20 days. It forms a thick chrysalis attached to a branch (USFWS, Undated). It remains in the pupal stage one or two years, until emergence in May or June which is induced by favorable conditions, probably rainfall (USFWS, Undated).

The butterfly feeds on the nectar of guava, cheese shrub, and wild coffee blossoms. Courtship is performed by the male hovering above the female to fertilize the eggs. The female is positioned on the ground with her wings flattened and vibrating and her abdomen raised. The eggs are deposited after fertilization (USFWS, Undated). Adult butterflies live for approximately two weeks (USFWS, Undated).

6.8.6.2 Stock Island Tree Snail

The Stock Island tree snail *(Orthalicus reses reses)* is threatened in Florida. It is a large cone shaped snail with a thin shell. The coloration is white with three spiral bands and narrow, flamelike, purple-brown axial stripes (USFWS, 1982). The Stock Island tree snail can be distinguished from the other subspecies of tree snail (*O. r. nesodryas)* by its coloration. Their anatomical differences and the fact that interbreeding does not take place suggest that these two tree snails are actually different species.

The Stock Island tree snail is restricted to 4.8 acres of land on the municipal golf course and botanical gardens of Stock Island, Monroe County, Florida. Its original range may have included Key West, but the most recent Key West specimen is from 1938 (USFWS, 1982). The population is estimated at 200 to 800 tree snails. The basis of this estimation is the number of individuals observed in some trees multiplied by the number of suitable trees in its range (USFWS, 1982). For the past 40 years, the population has appeared to be stable. The limited range of the Stock Island tree snail is the reason for its status as threatened. A single natural or man-made disaster could cause this species' extinction (USFWS, 1982). Predation may include birds, domestic cats, rodents, and raccoons. Current threats to the population are recreational use and development of habitat areas and possibly overcollecting.

The preferred habitat of the Stock Island tree snail is a wide variety of hammock trees native to the Stock Island, although it has adapted well to some decorative exotic trees (USFWS, 1982). It feeds on lichens, fungi, and algae that grow on tree limbs and leaves. They are nocturnal foragers that are most active during the rainy season in August and September. They have been reported foraging during damp times throughout June to December, while aestivating during the dry times. They aestivate (or remain dormant) by fastening the opening of the shell on a flat surface or within a hollow of the tree with a mucous seal. It stays more hidden during prolonged dry seasons (USFWS, 1982).

Very little is known about the reproduction of the Stock Island tree snail. Although theoretically it takes a minimum of two Stock Island tree snails to reproduce, they are functional hermaphrodites. Each snail can be a reproducing individual, but crossbreeding is necessary (USFWS, 1982). Sexual maturity occurs around the ages of 2 or 3 years (USFWS, 1982). They lay their eggs in burrows at the base of a host tree.

6.8.7 Endangered Plants

6.8.7.1 Garber's Spurge

Garber's spurge *(Euphorbia [Chamaesyce] garberi)* is threatened in Florida. Garber's spurge is described as a "prostrate herb with hairy stems, ovate leaves 4-9 mm long, and inconspicuous flowers." It is a species of plant that occurs in hardwood hammocks, pine rocklands, and on beach ridges in saline, coastal, transitional areas (USFWS, 1988). The range of this plant is now limited to four sites in the Everglades National Park and one site in the Florida Keys. Historically, it occurred throughout Dade and Monroe Counties, including the Keys (USFWS, 1988).

Garber's spurge is one of five endangered or threatened plant species endemic to a unique habitat in south Florida called the pine rocklands. The pine rocklands are described as a "plant community occurring on limestone ridges formed of calcareous marine deposits which accumulated during the previous geologic times when the Florida plateau was more deeply submerged." The Garber's spurge is the only one of these five species that is not restricted to the pine rocklands (USFWS, 1988).

Garber's spurge has declined with the pine rockland conversion into agricultural, commercial, residential, and recreational lands, intrusions of exotic plants, and trash dumping. The destruction of habitat in the Florida Keys has probably also led to the decline of this species. Conservation measures for pine rocklands include state acquisition projects of pine rockland areas and controlled burns to eliminate the intrusion of exotics and hardwoods (USFWS, 1988).

6.8.7.2 Key Tree-cactus

The key tree-cactus *(Cereus robinii)* is endangered in Florida. It a large branchless or limitedly branched cactus native to Florida. It grows in erect columns up to 10 meters tall. It has a distinct trunk and the branches are 8 to 10 cm thick (USFWS, 1986). The flowers that are produced on the upper part of the branches have petals that are green to purplish with white in the center and they smell of garlic. The fruit is the shape of flattened spheres and are reddish in color (USFWS, 1986). There may be several varieties of this species, but the taxonomy is still not verified so they are discussed as one group. Their range, which once included the Florida Keys and Cuba, is now restricted to five sites in the keys: one on Upper Matecumbe Key, two on Long Key, and two on Big Pine Key (USFWS, 1986). The habitat most suitable for the key tree cactus is a rocky tropical hammock. The decline of this cactus is due to the destruction of its habitat due to construction of roads, housing, military installations, rock mines, commercial and industrial sites, airports, and collection of the species (USFWS, 1986). A critical habitat has not been designated for the key tree cactus because it is feared that if the location is published it will lead to further collection of the species (USFWS, 1986).

7. COMMERCIAL AND RECREATIONAL FISHERIES

This chapter addresses Factor 7 of the 10 factors used to determine unreasonable degradation. This factor requires the assessment of any impacts to existing or potential recreational or commercial fisheries, including finfishing and shellfishing. This chapter characterizes the important commercial and recreational fisheries of the eastern Gulf of Mexico by measure of value and volume.

7.1 Overview

In 1995 and 1996 the Gulf of Mexico region was second only to the Pacific coast and Alaska region for pounds of commercial fish landed (15% of total U.S. landings in 1995 and 16% in 1996), and also was second to the Pacific and Alaska region for the value of the commercial catch landed (19% of the U.S. catch in 1995 and 20% in 1996; NMFS, 1997). The weight and value of commercial fish landings for the states of the eastern Gulf are presented in Table 7-1.

Table 7-1. Weight and Value for Commercial Fish Landings of the Eastern Gulf of Mexico

State	Weight (millions lbs.)		Dollar Value ($ Million)	
	1995	1996	1995	1996
Alabama	28.74	26.58	49.66	38.34
Florida (West Coast)	92.32	94.02	157.1	163.8
Mississippi	145.5	162.4	41.74	32.78

Source: NMFS, 1997.

In Alabama, shellfish such as shrimp, crabs, and oysters dominate commercial catches. Brown, white, pink, and northern shrimp are the most valuable catch, bringing in a total of $31 million in revenue in 1996 (NMFS, 1998). Blue crab and eastern oyster were the second and third most valuable fisheries. Important commercial finfish caught in Alabama in 1996 include mullet, Atlantic menhaden, sheepshead, and snapper (NMFS, 1998).

In Florida, invertebrates such as shrimp, lobster and crab were the dominant commercial species in 1996, with a combined total value of over $107 million. Shrimp are the singly most valuable species caught on the Gulf coast of Florida. Important commercial finfish on the Gulf coast of Florida include grouper, snapper, swordfish, shark, ladyfish, and tuna (NMFS, 1998).

In 1996, the most valuable commercial fisheries in Mississippi were brown, white, and pink shrimp with a combined value of $20.4 million. The most valuable commercial finfish was menhaden. Other commercial finfish include mullet, snapper, flounder, and seatrout (NMFS, 1998).

Recreational fishing is very popular in the Gulf of Mexico. In 1996, in the Gulf (excluding Texas) a total of 16.3 million trips were made by 1.8 million participants. Table 7-2 presents a summary of the marine recreational fishing trips and participants in Alabama, Florida, and Mississippi for the past five years. The following are numbers (as opposed to weight or values) of fish recreationally caught in the eastern Gulf of Mexico for 1996 (NMFS, 1998).

In Alabama, the largest recreational fishery in 1996 was sand seatrout with 863,295 fish caught. The rest of the top five marine recreational fisheries in 1996 were red snapper, saltwater catfish, kingfish, and pinfish. In Florida, spotted seatrout was the largest recreational fishery in 1996 with 2.98 million fish caught. The remainder of the top five recreational fisheries in Florida were pinfish, gray snapper, saltwater catfish, and red drum. In Mississippi, the largest recreational fishery in 1996 was sand seatrout, with 227,829 landed. The rest of the top five recreational fisheries in Mississippi were red snapper, spotted seatrout, red drum, and Spanish mackerel.

7.2 Shellfisheries

7.2.1 Brown, White, and Pink Shrimp

Brown, white, and pink shrimp make up the most valuable commercial fishery of the U.S. (Muncy, 1984a). These shrimp are estuarine-dependent, demersal species found throughout the Gulf.

Brown shrimp have a maximum density along the Texas-Louisiana coast. They are found from the shore to depths of 110 meters, but are most common on mud or sandy-mud substrates between 30 and 55 meters deep (NOAA, 1985). They are omnivorous, with anything from detritus to small invertebrates and fish being found in the stomach (Larson et al., 1989). Brown shrimp represented 34% of the eastern Gulf of Mexico shrimp fishery in 1996 (NMFS, 1998). Brown shrimp fishery activities are concentrated inside the 55-meter contour, but extend to at least the 90-meter contour (NOAA, 1985). Brown shrimp accounted for the largest weight and value of shrimp caught in 1996 in Alabama and Mississippi, valued at $19 million in Alabama and $14 million in Mississippi.

White shrimp inhabit the Gulf of Mexico coast from Apalachee Bay, Florida to Ciudad, Mexico, with a center of abundance in Louisiana waters. They are plentiful in waters where the continental shelf is broad and shallow, generally from the shore to 65-meter water depths, and rarely occur at greater depths (NOAA, 1985). White shrimp also are omnivorous. Although pink shrimp constitute the largest portion of the eastern Gulf shrimp fishery, white shrimp are highly valued for human food. Historically, in Mississippi the market value of shrimp as bait has been three times more than its value as human food (Muncy, 1984a). The white shrimp fishery was the second most valuable of the shrimp fisheries in 1996 in Mississippi, valued at approximately $6.1 million. In Florida and Alabama, the white shrimp fishery was valued at $1.7 million and $4.2 million, respectively (NMFS, 1998).

Pink shrimp are most abundant on the southwest coast of Florida. In 1996, the Florida pink shrimp fishery was valued at $47 million, representing 46% of the eastern Gulf shrimp fishery (NMFS, 1998).

Table 7-2. Number of Recreational Fishing Participants and Trips on the Eastern Gulf

Year	West Florida		Alabama		Mississippi		Total Eastern Gulf	
	Participants (,000)	Trips (,000)	Participants (,000)	Trips (,000)	Participants (,000)	Trips (,000)	Participants (,000)	Trips (,000)
1992	2,379	13,764	215	763	264	1,001	2,858	15,528
1993	2,402	12,928	284	933	251	866	2,937	14,727
1994	2,665	13,167	275	887	240	964	3,180	15,018
1995	2,231	12,159	283	977	280	1,033	2,794	14,169
1996	2,251	11,766	258	870	230	903	2,739	13,539

Source: NMFS, 1997.

The shrimp are omnivorous and inhabit broad shallow areas on the continental shelf from the shore to 65-meter water depths. Adults prefer firm substrate such as sand, shell sand, or coral; juveniles prefer shallow estuarine areas and seagrass beds. Pink shrimp also contribute to the commercial shrimp fishery in Alabama ($7.6 million) and Mississippi ($0.29 million; NMFS, 1998).

7.2.2 American Oyster

The American oyster is a bivalve mollusk found throughout the Gulf of Mexico in estuaries, shallow nearshore waters, and on reefs located near river mouths (NOAA, 1985). Most concentrations are found in depths of 10 meters or less. The American oyster supports an important commercial fishery in the Gulf of Mexico ($45 million). However, the eastern Gulf represents only 12% of the Gulf total in 1996 (NMFS, 1998). The species also is harvested recreationally.

7.2.3 Blue Crab

The blue crab is a demersal decapod crustacean found throughout the Gulf of Mexico, from Florida to the Yucatan Peninsula. It inhabits estuaries and nearshore waters to depths of about 90 meters, but is most common in water depths of 35 meters or less. The species generally favors muddy and sandy bottoms in shallow waters with some vegetation (NOAA, 1985). The commercial blue crab fishery has become increasingly important and is one of the largest in volume in the Gulf of Mexico, with 63 million pounds harvested in 1996 (NMFS, 1998). Louisiana is the largest commercial producer of blue crabs in the Gulf of Mexico, although there are major fishing grounds on the coasts of Mississippi, Alabama, and Florida (NOAA, 1985). In 1996, commercial blue crab landings were valued at $1.8 million in Alabama, $8.4 million in Florida, and $0.27 million in Mississippi (NMFS, 1998). Historically, Florida along with Louisiana has contributed most of the commercial blue crab fishery of the Gulf (Perry and McIlwain, 1986). There also is a substantial recreational fishery for blue crab in the Gulf. The sport fishery is thought to contribute significantly to the total catch of blue crabs of the U.S., although estimates of recreational fishing vary widely.

7.2.4 Stone Crab

The stone crab is a carnivorous decapod crustacean. Juveniles live in estuaries on shell and rocky substrates, while mature stone crabs live in deep water (approximately 54 m), often burrowing in soft substrate or living among vegetation, rock crevices, or wrecks. Stone crabs are found throughout the Gulf of Mexico, but are abundant in southwest Florida where they are a major commercial shellfishery; they also are recreationally fished (NOAA, 1985). The fishery is unique in that crabs are trapped, one claw is removed, and the crabs are released. As a commercial fishery in western Florida, stone crabs were third in value to only pink shrimp and Caribbean spiny lobsters in 1996 (NMFS, 1998).

7.2.5 Spiny Lobster

The spiny lobster is a omnivorous decapod crustacean found throughout the Gulf of Mexico. They live in crevices and dens in water as deep as 80 meters. They are an important commercial trap fishery in southwest Florida and are caught recreationally throughout the Gulf (NOAA, 1985). The commercial spiny lobster fishery in Florida was valued at $27 million in 1996 (NMFS, 1998) making it the second most valuable shellfishery in western Florida.

7.3 Finfisheries

7.3.1 Red Grouper

The red grouper is a demersal fish, favoring sublittoral habitats with rock outcroppings, reefs, and wrecks. It occurs at depths from 3 meters to about 200 meters, preferring 30 to 120 meter depths (NOAA, 1985). Juveniles favor grass beds, rock formations, and shallow reef areas as nursery areas. The major commercial fisheries in the Gulf are off Louisiana, throughout the eastern Gulf, and off the Yucatan peninsula. The red grouper fishery in Florida was valued at $11.4 million in 1996 (NMFS, 1998).

7.3.2 Red Snapper

The red snapper is a demersal fish found throughout the Gulf of Mexico, with centers of abundance in U.S. waters in the southern Gulf and west Florida, where the principal fishing grounds are located (Moran, 1988). The species is found over sandy and rocky bottoms, around reefs and underwater objects at shallow depths from the shoreline to 100 meters (Moran, 1988). Juveniles inhabit shallow nearshore and estuarine waters and are most abundant over sand or mud bottoms (NOAA, 1985). The species is a popular sport fish, primarily in the northern Gulf and Florida. They are called snappers because they will snap at a bare hook (Moran, 1988). In 1996, the red snapper was the fifth most common sport fish in the eastern Gulf (NMFS, 1998). Commercially, the red snapper fishery was valued at $0.085 million in Alabama, $0.48 million in Florida, and $0.43 million in Mississippi in 1996 (NMFS, 1998).

7.3.3 Atlantic Croaker

The Atlantic croaker is an estuarine-dependent, demersal fish that is common throughout the Gulf of Mexico. It is usually found over mud and sandy/mud bottoms in coastal waters to depths of 120 meters (NOAA, 1985). The Atlantic croaker is subject to significant commercial and sport fisheries in the Gulf of Mexico. Major commercial harvesting areas are located between Mobile Bay, Alabama and Lake Calcasieu, Louisiana.

7.3.4 Spotted Seatrout

The spotted seatrout is a demersal, estuarine species that inhabits Gulf of Mexico waters up to 20 meters in depth and is often associated with sand flats, seagrass beds, salt marshes, and tidal pools of higher salinity (NOAA, 1985). They are carnivores at the top of the food chain in estuaries. The spotted seatrout supports valuable commercial and sport fisheries throughout the coastal Gulf of Mexico. In 1996, it was the first most common sport fish caught in Florida with nearly 3 million fish landed (NMFS, 1998). The commercial catch is sold to restaurants, fish markets, and wholesalers.

7.3.5 Sand Seatrout

The sand seatrout is a demersal fish found in the coastal and shelf waters of the Gulf of Mexico. It is one of the most abundant fish in estuaries and in the shelf waters of the Gulf, usually inhabiting sandy and muddy bottoms out to the edge of the continental shelf (NOAA, 1985). Commercial fishing for sand seatrout is concentrated along the coasts of Florida, Mississippi, and Louisiana. The sand seatrout is also fished recreationally throughout its range (NOAA, 1985). In 1996, the sand seatrout was the most common sport fish caught in Alabama and Mississippi and the fourth most common in Florida (NMFS, 1998).

7.3.6 Saltwater Catfish

Saltwater catfish in the Gulf of Mexico include sea catfish and gafftopsail catfish. They are opportunistic feeders that prefer sandy and organic substrate. Their diet includes seagrass, corals, sea cucumbers, gastropods, polychaetes, crustaceans, and human garbage (Muncy and Wingo, 1983). Commercially, the saltwater catfish are considered a nuisance, and even dangerous. Areas of abundance are purposefully avoided. They are a significant bycatch of menhaden purse seines. Saltwater catfish were the sixth most common sport fish caught in the eastern Gulf in 1996 (NMFS, 1998).

7.3.7 Pinfish

Pinfish are abundant throughout the coastal waters of the Gulf of Mexico. They inhabit rocky or vegetated marine bottoms, reefs, jetties, and mangrove swamps. Pinfish prey on crustaceans such as amphipods and shrimp. They are believed to have a significant impacts on epifaunal seagrass communities. Their predators include ladyfish, porpoise, spotted seatrout, alligator gar, and gulf flounder (Muncy, 1984b). Although pinfish have little value as food, there exists a significant baitfish market (Muncy, 1984b). In 1996 pinfish were the second most popular recreational fishery in Florida and the fifth most popular in Alabama (NMFS, 1998).

8. COASTAL ZONE MANAGEMENT AND SPECIAL AQUATIC SITES

Factor 8 requires that any activity that affects state waters must be subject to review for determination of consistency with approved Coastal Zone Management Plans. The general permit for the eastern Gulf of Mexico covers areas in Federal waters only. However, this chapter reviews the plans for Alabama, Florida, and Mississippi state waters due to the proximity of the coverage area to waters covered by the state Coastal Zone Management Plans.

8.1 Requirements of the Coastal Zone Management Act

The Coastal Zone Management Act requires that any Federally-licensed or permitted activity affecting the coastal zone of a state that has an approved coastal zone management program (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 affected states 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.

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 provide an understanding of the requirements of each state's management plan for consistency determination.

8.2 Alabama Coastal Area Management Program

8.2.1 Understanding of Program Requirements

Alabama Coastal Area Board (CAB) was given authority in 1976 to develop and implement the Alabama Coastal Area Management Program (ACAMP). In 1982, the CAB was abolished and the responsibilities of carrying out the ACAMP was divided between the Alabama Department of Environmental Management (ADEM), which is responsible for all coastal area permit, regulation, and enforcement functions and the Alabama Department of Economic and Community Affairs (ADECA), Office of State Planning and Federal Programs, which is responsible for all other functions.

The program, approved in September, 1979, is a "tool for the protection and enhancement of Alabama's Coastal Area land and water resources." The document entitled *Alabama Coastal Area Management Program - Amendment II* was used to prepare the following understanding of the requirements of the program. (A revised plan has been drafted, but is not yet approved.)

The goals and policies of ACAMP are designed to meet the following seven objectives:

- Improve management capabilities in the coastal area
- Add specificity and predictability to the review for compliance with the management program
- Increase the States' ability to develop methods to solve problems within the coastal area
- Continue to clarify the permitting process by interaction with the public and improving the awareness of ADEM's permit procedures and by improving interagency coordination
- Provide the necessary scientific data to determine "present levels" which is the basis for a number of ACAMP's regulations
- Provide for adequate consideration of the national interest
- Assure continued consistency with the Program of all Federal and State actions in the coastal zone through a review of Federal and State actions that affect the coastal areas

Uses determined by the Department to have a degrading affect on the coastal area shall not be permitted unless there is a compelling public interest. In this case these uses shall, to the maximum extent practicable, minimize degradation of the coastal area. The following factors will be considered when determining if the importance of the public interest is on balance with the ability to meet ADEM's rules:

- Significant national interest such as energy facilities or uses to improve water quality, air quality, or wetlands
- Enhancement or protection of geographic areas of particular concern and areas for preservation and restoration, such as construction or improvement of facilities in Port of Mobile
- Significant economic benefit for the coastal area
- Water dependency
- Other similar factors.

If ADEM finds that an imminent peril to the public health and safety or welfare requires immediate action, ADEM may approve proposed emergency actions without prior notice or hearing. The procedure may be effective no longer than 120 days.

Major projects that may have direct and significant impacts shall show, to the satisfaction of the ADEM, the potential impacts of the proposed activities on the following coastal and natural resources. The relevant resource protection policies, operational rules and regulations, and action items identified for coastal and natural resources are presented below.

8.2.2 Coastal Resource Protection Policies

Mineral Resource Exploration and Extraction

It is the policy of the Management Program to encourage the extraction of mineral resources in coastal Alabama consistent with the water quality policies and natural resource policies of the Plan.

Commercial Fishing

To encourage and promote the commercial fishing industry in coastal Alabama, it is the policy of the Plan to maintain conditions that support present populations, and where feasible, to enhance marine species and to encourage conservation practices favoring increases of marine and estuarine species which will increase the potential yield of Alabama's coastal fisheries.

8.2.3 Coastal Resource Protection Operational Rules and Regulations

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 the following Federal and state statutes and any regulations adopted pursuant to these statutes to the extent applicable under the terms of those statutes or regulations. Only those statutes and regulations deemed relevant to the general permit are listed here.

- Rivers and Harbors Act of 1899, as amended
- Federal Water Pollution Control Act, as amended
- Clean Air Act
- Marine Mammals Protection Act of 1972, as amended
- Endangered Species Act of 1972 1973, as amended
- National Historic Preservation Act of 1966, as amended
- National Environmental Policy Act of 1969, as amended
- Outer Continental Shelf Lands Act, as amended
- Solid Wastes Disposal Act, Code of Alabama 1975, §§ 22-27-2 to 22-27-7, as amended
- Alabama Water Pollution Control Act, Code of Alabama 1975, §§ 22-22-1 to 22-22-14, as amended
- Alabama Air Pollution Control Act of 1971, Code of Alabama 1975, §§ 22-28- 1 to 22-28-23, as amended
- Code of Alabama 1975, §§ 9- 11- 1 to 9- 11-398, as amended (fish, game and wildlife)
- Code of Alabama 1975, §§ 9-12-1 to 9-12-184, as amended (marine resources)

8.2.4 Natural Resource Protection Policies

Water Quality

Alabama's policy is to maintain coastal waters at a quality which will support present levels of estuarine organisms, plants and animals, and, where feasible, to enhance and restore water quality to support optimum levels of estuarine organisms, plants, and animals.

Air Quality

Air quality shall be maintained at a level which supports the health and well-being of Alabama's citizens and, where feasible, to enhance air quality.

Wetlands and Submersed Grassbeds

The quality and quantity of coastal wetlands and submersed grassbeds shall be maintained at the level necessary to provide for present levels of habitat for both terrestrial and aquatic life to play their pivotal role in the aquatic food web and to provide natural control for shoreline erosion and, where practicable, to enhance the quality and quantity of these wetlands and submersed grassbeds.

Beach and Dune Protection

Recognizing the natural value of beaches and dunes for erosion control, wildlife habitat, and recreational opportunities, it is Alabama's policy to maintain the natural integrity of the beach and dune systems and to restore and enhance these resources where feasible.

Wildlife Habitat Protection

It is the policy of Alabama to maintain areas of wildlife habitat sufficient to support present levels of terrestrial and aquatic life, including fish and shellfish, and to preserve endangered species of plants and animals and, where feasible, to provide for optimum levels of terrestrial and aquatic life.

Biological Resources

It is Alabama's biological productivity policy to maintain present levels of plants and animals within coastal Alabama; to enhance, where feasible, biological productivity; and to monitor directly these levels through regular sampling.

Cultural Resource Protection

Because of the unique and representative archaeological and historic sites in coastal Alabama and their educational and cultural values, it is the policy of Alabama to support preservation and protection of Alabama's cultural resources.

Endangered Species

It is the policy of the Program to promote and encourage the preservation of the critical habitat of recognized endangered species.

8.2.5 Natural Resource Protection Operational Rules and Regulations

The specific rules and regulations for natural resources are in the same statutes and regulations as described for the coastal resource protection operational rules and regulations in Section 8.2.3, above.

8.2.6 Assessment of Consistency

Chapter 11 of this document addresses many of the concerns of Alabama's policies, rules, and regulations for protection of coastal and natural resources, commercial and recreational fisheries, endangered species, and the potential impacts on these resources given the permitted discharges. Many of the statutes and regulations listed under the Program as necessary for consistency are also required by the NPDES program for permit issuance. The Federal Water Pollution Control Act, as amended, gives EPA the authority to implement the NPDES program. The Endangered Species Act requires consultation with the U.S. Fish and Wildlife Service and National Marine Fisheries Service to certify that the permit will comply with the goals of the Act. The National Environmental Policy Act requires that EPA prepare an environmental impact statement for the permit coverage area. This requirement has been satisfied by a separate Environmental Impact Statement prepared by EPA Region 4. This document also addresses the Clean Air Act requirements for offshore activities. The Outer Continental Shelf Lands Act governs the leasing of mineral rights and the exploration and production activities undertaken in U.S. waters. That Act gives states authority to enact regulations that protect their coast and water resources and those requirements are met during the leasing process and during approval of plans of exploration or production. The Rivers and Harbors Act is concerned with navigation of the nation's waters and the Marine Mammals Protection Act concerns takings of marine mammals. They are not pertinent to this permit.

Although the permit covers waters that are under Federal jurisdiction, the Region has taken state statutes into consideration. The Alabama Water Pollution Control Act also is addressed in Chapter 9 of this document. The pollutant levels in the permitted discharges are compared to state water quality standards to determine compliance. The Solid Waste Disposal Act is not within the jurisdiction of this NPDES permit. However, wastes hauled to shore will be governed by state regulations implementing that Act.

8.3 Florida Coastal Management Program

8.3.1 Understanding of Program Requirements

The Florida Coastal Management Program (FCMP) was formally submitted and approved in 1981. Actions of ten state agencies and five water management districts are coordinated under the plan. The Department of Community Affairs is the lead agency. Their document *1997 Revision, Florida Coastal Plan Guide* (Florida DCA, 1997) was used to prepare the following understanding.

Table 8-1 provides a listing and brief description of the Florida statutes that are potentially relevant for a consistency determination for the general permit. The statutes that are applicable are summarized below.

8.3.2 Summary of Potentially Applicable Statutes

State and Regional Planning

The Conceptual State Lands Management Plan establishes policies governing all lands under the ownership and control of the Board of Trustees of the Internal Improvement Trust Fund. This Board consists of the Governor and Cabinet acting for the general public good to acquire, manage, conserve, protect, and dispose of all state lands to assure maximum benefit and use. State lands include lands under navigable (fresh and salt) waters, which Florida gained title to upon statehood. The Conceptual State Lands Management Plan also governs the management of sovereignty submerged lands. The Division of State Lands will review the consistency statement with regard to the following elements of the Plan that are relevant to activities covered under the general permit.

1) Location, evaluation, and protection of archaeological and historical resources

2) Water resources:
   a) maximum protection for the waters of the state, especially those used for public drinking water supplies, shellfish harvesting, public recreation, fish and wildlife propagation and management
   b) compliance with state water quality standards and their intent

3) Fish and wildlife resources:
   a) maintenance of natural diversity of habitats and balanced fish and wildlife populations
   b) protection of threatened and endangered species habitats

4) Submerged grass beds and other benthic communities:
   a) encourage the identification of and an evaluation of submerged grass beds and other benthic communities in state ownership
   b) control the use of submerged lands to maintain essentially natural conditions and protect the values and functions of submerged grass beds and other benthic communities

Table 8-1. Florida Statutes to be Addressed Under CZM Review

Statute	Applicability and Requirements
Beach and Shore Preservation	Not Applicable (N/A) - Coastal construction projects.
State and Regional Planning	Statewide resource planning; must address potential for conflict with State Comprehensive Plan (including water resources, coastal and marine resources, air quality, and hazardous and nonhazardous materials and waste.
State Lands	N/A - Covers all state-owned lands including uses, leasing, dredging, etc.
State Parks and Preserves	Protects state parks and submerged lands with exceptional biological, aesthetic and scientific value.
Saltwater Fisheries	Covers fisheries management; must address potential impacts on areas of importance to fisheries, endangered species or critical habitats; currents and larval transport; eggs and larvae; and bottom habitat characteristics.
Wildlife	N/A - Management of freshwater and upland wildlife and aquatic life.
Water Resources	N/A - Withdrawal, diversion, and consumption of water.
Outdoor Recreation and Conservation	N/A - Purchase and management of recreational lands.
Pollution Discharge Prevention and Removal	N/A - Storage, transportation, and clean ups of pollutants.
Energy Resources	Covers all phases of oil and gas exploration, drilling, and production.
Land and Water Management	N/A - Covers land and water management policies which guide development decisions.
Environmental Control	Regulates pollution releases and implements standards for pollution.
Soil and Water Conservation	N/A - Erosion control.

Additional enforceable policies of the FCMP that were deemed not applicable to this permitting activity are County and Municipal Planning and Land Development Regulation; Emergency Management; Land Acquisitions for Conservation or Recreation; Recreational Trails System; Archives, History, and Records Management; Commercial Development and Capital Improvements; Transportation Administration and Finance; Public Health, General Provisions; and Mosquito Control.

c) prohibit development activities that adversely effect significant beds of submerged grasses and other benthic communities, unless the development is to be of overriding public importance with no reasonable alternatives, and adequate mitigation measures are included

5) Mineral resources:
   a) encourage detailed inventories and evaluation of state-owned mineral resources
   b) control management activities on state-owned land that would preclude or seriously impair the ability to extract significant mineral resources
   c) allow extraction of state-owned mineral resources in environmentally sensitive areas only upon demonstration that the extraction is of overriding public importance, that all reasonable steps will be taken to minimize adverse environmental impacts, and that there are no reasonable alternatives

6) Unique natural features (such as coral reefs and exceptional vegetation and habitat areas)

7) Submerged lands:
   a) all submerged lands shall be considered single-use lands and shall be managed primarily for the maintenance of essentially natural conditions, the propagation of fish and wildlife and public recreation, including hunting and fishing where deemed appropriate by the managing agency
   b) issue oil, gas, and other petroleum drilling leases only when the proposed lease area is at least one mile seaward of the outer coastline of Florida, upon adequate demonstration that the proposed activity is in the public interest, that the effect upon aquatic resources has been thoroughly considered, and that every effort has been made to minimize potential adverse effects on sport and commercial fishing, navigation, and national security.

State Parks and Aquatic Preserves

The Florida Aquatic Preserves Act limits or conditions certain activities within aquatic preserves. Regulated activities include the drilling for gas and oil. The Division of State Lands will review the consistency statement with regard to the following directives that are relevant to activities covered under the proposed general permit:

1) Discourage all activities that adversely impact significant benthic communities
2) Limit use of and protect aquatic preserves.

Saltwater Fisheries

The Florida Department of Environmental Protection and Marine Fisheries Commission are charged with the following goals under Chapter 370, F.S.:

1) To preserve, manage, and protect marine, crustacean, shell, and anadromous fishery resources in state waters

2) To protect and enhance the marine and estuarine environment
3) To protect marine and estuarine water quality
4) To protect threatened and endangered species.

For the review of the consistency statement, the following issues will be assessed by the DEP.

1) Potential impact upon areas of unique importance to Florida's recreational or commercial fisheries or concentrations of endangered or threatened species; proximity to major areas of critical habitat which would affect other protected species, or plants and animals of economic importance
2) Potential impact upon currents and larval transport and the related impact on recruitment to nearshore nursery areas
3) Potential impact on the survival of eggs and larvae in the area for important species which are subject to minimum catch sizes
4) Enforceability of any law, rule, or regulation impacting Florida's marine resources
5) Cumulative impacts of the proposed activities.

Energy Resources

The Division of Resource Management within the DEP regulates all phases of exploration, drilling, and production of oil, gas, and other petroleum products within the state of Florida. The Division issues permits for all activities associated with oil and gas exploration, development, and production based on consideration of compliance with statutory provisions; protection of submerged lands and wildlife preserves; and potential impacts as weighed against risks for each phase of drilling or production activities.

Environmental Control

The DEP controls pollution of the air and waters of the state and protects their quality for beneficial uses. All discharges into surface waters of the state are covered by the Department's permitting processes and standards. In evaluating the consistency statement, the Department will consider the following.

1) Conservation and protection of environmentally sensitive living resource systems
2) Conservation and protection of lands and waters specially designated under state and Federal law
3) Protection of surface water quality and quantity
4) Protection of recreational benefits
5) Minimization of adverse hydrographic and hydrogeologic impacts
6) Induced or secondary impacts on area natural resources
7) Solid, sanitary, and hazardous waste disposal.

8.3.3 Assessment of Consistency

This document addresses concerns related to water and wetland resources, fish and wildlife resources, commercial and recreational fisheries, socioeconomic impacts, water quality standards, and nonwaterquality impacts. Conclusions concerning potential impacts from activities under the general permit are presented in Chapter 11 of this document. Specific concerns of FCMP that are not discussed in that chapter are addressed below.

There are no state parks or aquatic preserves within the coverage area of the proposed permit. Protection of any such areas, for example areas under moratoria, would occur at the time of leasing the mineral rights. The general permit does not decide where drilling or production can occur; that is the responsibility of MMS and the State of Florida. If areas in or near parks or preserves were to be leased for activity, EPA can require that the operator apply for an individual permit so that more stringent conditions may be explored (see Part I.A.2 of the permit). This permit provision also hold true for any area that the Region feels warrants extra protection or reconsideration of the permit conditions.

Facilities in compliance with the NPDES general permit will meet requirements of demonstration of the ability to prevent, control, and abate pollution discharges. Further, a spill prevention plan is not under the jurisdiction of the EPA and discharges in compliance with NPDES permits are not subject to the Oil Spill requirements of Section 311 of the Clean Water Act. However, because of the potential effects from a large spill, Region 4 has included a reference to compliance with the Oil Spill Requirements of the Clean Water Act in the permit.

In conclusion, compliance with the conditions and limitations of the permit will ensure consistency with the Coastal Management Plan of Florida. The permit limitations, conditions, and monitoring will provide sufficient protection for Florida's natural resources.

8.4 Mississippi Coastal Program

8.4.1 Understanding of Program Requirements

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. The MCWC carries out its responsibilities through the Bureau of Marine Resources of the Mississippi Department of Wildlife Conservation. The Coastal Program Advisory Committee also was established to participate in implementation of the Coastal Program. The committee participates in permit reconsiderations and acts as an advisor to the Governor.

The ten goals of the Mississippi Coastal Program designed to promote decisions that balance development with the environment are the following.

- To provide for reasonable industrial expansion in the coastal area and to insure the efficient utilization of waterfront industrial sites so that suitable sites are conserved for water dependent industry.
- To favor the preservation of the coastal wetlands and ecosystems, except where a specific alteration of a specific coastal wetlands would serve a higher public interest in compliance with the public purposes of the public trust in which the coastal wetlands are held.
- To protect, propagate, and conserve the state's seafood and revitalization of the seafood industry of the State of Mississippi.
- To conserve the air and waters of the state, and to protect, maintain, and improve the water quality thereof for public use, for the propagation of wildlife, fish and aquatic life, and for domestic, agricultural, industrial, recreational, and other legitimate beneficial uses.
- To put to the beneficial use, to the fullest extent of which they are capable, the water resources of the state, and to prevent the waste, unreasonable use, or unreasonable method of use of water.
- To preserve the state's historical and archaeological resources, to prevent their destruction, and to enhance these resources wherever possible.
- To encourage the preservation of natural scenic qualities in the coastal area.
- To consider the national interest involved in planning for and in the sighting of facilities and services in a manner consistent with the coastal program.
- To assist local governments in the provision of the public facilities and services in a manner consistent with the coastal program.
- To insure the effective, coordinated implementation of public policy in the coastal area of Mississippi comprised of Hancock, Harrison, and Jackson counties.

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. Oil and gas exploration and production activities are subject to the decision-making criteria of the wetlands management guidelines and section 402 permits are subject to review under policy coordination guidelines.

8.4.2 Summary of Applicable Management Guidelines

Wetlands Management Guidelines

The following guidelines under the wetlands management plan shall be met for oil and gas exploration activities that may cause displacement of coastal waters, artificially alter water levels or currents, or kill or materially damage the flora and fauna of coastal wetlands. The permit covers only offshore leases; therefore, only those guidelines deemed applicable to offshore activities are included here.

The wetlands management guidelines require that the Bureau of Marine resources review the proposed action for consistency with respect to the following aspects of the Coastal Program.

- Existing navigable waters shall be used for access to oil and gas extraction sites in preference to new dredging.
- Environmentally sensitive areas including oyster reefs, submerged grass beds, and other productive shallow water areas shall be avoided when siting extraction facilities. Also, directional drilling should be employed when the shorelines of barrier islands or beaches, small fishing banks, hard banks or reefs would otherwise be disturbed.
- No discharge into coastal waters of cuttings, drilling fluids, produced waters, sanitary wastes, contaminated deck drainage, or any other materials that are associated with oil and gas operations, in the coastal waters of Mississippi, except for noncontact cooling waters when permitted for discharge under the NPDES program shall be allowed.
- To maintain the integrity of small fishing banks (generally 500 acres or less) and their accessibility to sport and commercial fishermen, no structures shall be placed either temporarily or permanently on the top of these banks.
- For exploration and production activities in close proximity to oyster reefs, seagrass beds, fishing areas or hard banks containing reef building organisms the following shall be observed:
  - Uncontaminated drill cuttings shall be shunted away from sensitive areas and discharged at or near the bottom, or shall be transported to shore or to less sensitive offshore locations. Usually shunting is only effective when the point of shunted discharging can be replaced deeper than the area of the bank being protected.
  - Drilling and production structures, and oil pipelines shall not be placed within one mile of the bases of live reefs.
- All facilities, obstructions, or debris, which could impair recreational or commercial fishing shall be removed or terminated beneath the water bottom. Whenever this is not practicable, they shall be marked by a lighted buoy to prevent fouling of fishing gear.
- All pipelines placed in coastal wetlands shall be buried.

Policy Coordination Guidelines

The policy coordination guidelines require that the Bureau of Marine Resources coordinate the consistency review by Coastal Program agencies with respect to the following aspects of the Coastal Program.

- Wetlands protection (Mississippi Code Section 49-27-3)
- Effective utilization of waterfront sites (Mississippi Code Section 57-15-6(1)(a))
- Seafood conservation (Mississippi Code Section 49-15-1)
- Preservation of natural scenic qualities (Mississippi Code Section 57-15-6(1)(d))
- Natural interest

The State's A-95 notification system will be used for policy coordination between state officials under the Coastal Program. The Bureau of Pollution Control is responsible for reviewing the proposed action with respect to preserving air and water quality (Mississippi Code Section 49-17-3). The Department of

Archives and History reviews and comments on the proposed actions for their potential impact on historical or archaeological resources (Mississippi Code 51-3-1).

8.4.3 Assessment of Consistency

The Wetlands Management Guidelines are mainly concerned with the placing of structures and pipelines. These concerns are addressed by MMS 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, as presented in Chapter 11 of this document, demonstrate that the permit is consistent with the policy guidelines of Mississippi.

9. FEDERAL WATER QUALITY CRITERIA AND STATE WATER QUALITY STANDARDS

Factor 10 of the 10 factors 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, although the coverage area of the general permit does not include state waters, compliance with the water quality standards of each of the eastern Gulf of Mexico states 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 Criteria (μg/l)	Marine Chronic Criteria (μg/l)	Human Health Criteria[a] (μg/l)
Anthracene			110,000
Antimony			4,300
Arsenic	69	36	0.14
Benzene			71
Benzo(a)pyrene			0.031
Cadmium	42	9.3	
Chlorobenzene			21,000
Chromium (VI)	1,100	50	
Copper	2.4	2.4	
Di-n-butylphthalate			12,000
Ethylbenzene			29,000
Lead	210	8.1	
Mercury	1.8	0.025	0.15
Nickel	74	8.2	4,600
Phenol			4,600,000
Selenium	290	71	
Silver	1.9		
Thallium			6.3
Toluene			200,000
Zinc	90	81	

Human health criteria for consumption of organisms only; risk factor of 10^{-6} for carcinogens.
Source: Tabulation of water quality criteria, U.S. EPA Health and Ecological Criteria Division, February 1997.

9.2 Alabama Water Quality Standards

The Alabama Water Quality Criteria Standards are set forth by the Alabama Environmental Management Commission as Title 22, adopted May 5, 1967 and last amended May 30, 1997 (Chapter 335-6-10).

The antidegradation policy of the standards requires that all existing water uses shall be maintained and protected and "new and existing point source discharges shall be subject to the highest statutory and regulatory requirements...." New or increased discharges of pollutants may be allowed after inter-governmental coordination and public participation (through the permitting process) when the discharge is necessary for important economic or social development.

The following minimum conditions are applicable to state waters "at all places and at all times regardless of their uses."

- State waters shall be free from substances that will settle to form bottom deposits that are unsightly, putrescent, or interfere directly or indirectly with any classified water use.
- State waters shall be free from floating debris, oil, scum, and other floatable materials in amounts sufficient to be unsightly or interfere directly or indirectly with any classified water use.
- State waters shall be free from substances in concentrations or combinations that are toxic or harmful to human, animal, or aquatic life to the extent commensurate with the designated usage of such waters.

Toxic pollutant standards applicable to state waters are presented in Table 9-2. Alabama water quality standards provide instruction for calculating human health criteria based on pollutant-specific reference doses, bioconcentration factors, and cancer potentency factors. The values used for these calculations are presented in Table 9-3.

Secondary treatment, at a minimum, must be applied to biologically degradable waste. Secondary treatment is interpreted as the capability of removing substantially all floating and settleable solids and to achieve a minimum removal of 85% of both the 5-day BOD and suspended solids. In addition, industrial waste treatment requirements include those established under the provisions of Sections 301, 304, 306, and 307 of the Federal Water Pollution Control Act.

For coastal waters of the Gulf of Mexico, contiguous to the state of Alabama, water use classifications for swimming and other whole body water-contact sports, shellfish harvesting, and fish and wildlife must be maintained. The following conditions apply to these use classifications.

pH	Shall not cause the pH to deviate more than one unit from the normal or natural pH, nor be less than 6.0, nor greater than 8.5

Table 9-2. Alabama Toxic Pollutant Standards

Pollutant	Marine Acute Criteria (µg/l)	Marine Chronic Criteria (µg/l)	Human Health Criteria (µg/l)
Antimony			933 [a]
Arsenic	69	36	
Benzene			
Benzo(a)pyrene			155 [b]
Cadmium	43	9.3	0.0675 [b]
Chromium (VI)	1,100	50	
Copper	2.9	2.9	
2,4-			498 [a]
Dimethylphenol			2,622 [a]
Di-n-			6,222 [a]
butylphthalate	220	8.5	
Ethylbenzene	2.1	0.025	0.121 [a]
Lead	75	8.3	933 [a]
Mercury			1,000,000 [a]
Nickel	300	71	
Phenol	2.3		
Selenium			133 [a]
Silver			43,614 [a]
Thallium	95	86	
Toluene			
Zinc			

[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 9-3)
BCF = Bioconcentration Factor (Values presented in Table 9-3)

[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 9-3)

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

DO	Shall not be less than 5 mg/1, except where natural phenomena cause the value to be depressed between 5 mg/l and 4 mg/l; DO shall be measured at a depth of 5 feet in waters 10 feet or greater in depth
Radioactivity	Concentrations of radioactive materials present shall not exceed the requirements of the State Department of Public Health
Turbidity	Shall be no turbidity of other than natural origin that will cause substantial visible contrast or interfere with beneficial uses and in no case exceed 50 NTU above background

Table 9-3. Reference Dose and BCF Values 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	11.53
Beryllium		19	4.3
Chromium (III)	1	16	
Chromium (VI)	0.005	16	
2,4 Dimethylphenol	0.02	93.8	
Di-n-butylphthalate	0.1	89	
Ethylbenzene	0.1	37.5	
Mercury	0.0003	5,500	
Nickel	0.02	47	
Phenol	0.6	1.4	
Thallium	0.0373	119	
Toluene	0.2	10.7	

Source: Alabama Department of Environmental Management Water Division, Water Quality Program, May 30, 1997.

Toxic substances — Shall not exhibit acute or chronic effluent toxicity as demonstrated by effluent toxicity testing or by application of specific numeric criteria; impair the marketability or palatability of seafood; or affect the aesthetic value of waters for any use

Temperature — The normal daily and seasonal temperature variations shall be maintained and there shall be no thermal block to the migration of aquatic organisms.

9.3 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 62-301 - Surface Waters of the State, and Chapter 62-302 - Surface Water Quality Standards (Adopted May 29, 1990 and last amended December 26, 1996).

The antidegradation policy of the standards requires that new and existing point sources are subject to the highest statutory and regulatory requirements under Sections 301(b) and 306 of the Act. 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.

General criteria of surface water quality 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 surface 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 concentrations in the receiving water. The following surface water quality criteria shall not be exceeded.

Arsenic	0.05 mg/l
BOD	Shall not be increased to exceed values which would cause DO to be depressed below the limit established for each class (minimum of 5 mg/l)
Chlorides	Not more than 10% above normal background chloride content
Chromium	0.05 mg/l (hexavalent)
Chronic toxicity	Shall not be chronically toxic to, or produce adverse physiological or behavioral response in humans, animals, or plants. (Defined as 1/20 of the 96-hour LC50)
Copper	0.5 mg/l
Detergents	0.5 mg/l
DO	Shall not average less than 5.0 mg/l in a 24-hr period and shall never be less than 4.0 mg/l
Fluorides	10.0 mg/l
Lead	0.05 mg/l
Oil and grease	Dissolved or emulsified oils and greases shall not exceed 5.0 mg/l. No undissolved oil, or visible oil defined as iridescence, shall be present so as to cause taste or odor, or otherwise interfere with the beneficial use of waters
pH	Not more than 1 unit above or below background; between 6 - 8.5
Phenolic compounds	(2,4-dinitrophenol; 2,4-dichlorophenol and pentachlorophenol; 2-chlorophenol; phenol) - 1.0 μg/l, unless higher values are shown to be chronically toxic
Radioactive Substances	Combined Ra226 and Ra228 - 5 pCi/l; gross alpha particle activity (including Ra 226) - 15 pCi/l

Turbidity	Shall not exceed 29 NTU above natural background
Zinc	1.0 mg/l

The water classifications that apply to the open waters of the Gulf of Mexico are recreation, fish, and wildlife (marine); and shellfish propagation or harvesting. A summary of the numeric water quality standards for these classifications is presented in Table 9-4.

9.4 Mississippi Water Quality Standards

The Mississippi Water Quality Criteria for Intrastate, Interstate, and Coastal Waters are set forth by the Mississippi Air & Water Pollution Control Commission as adopted March 22, 1990. The Mississippi water quality criteria general conditions require that the following be met in all waters of the state:

- In open ocean waters there shall be no oxygen demanding substances added which will depress the dissolved oxygen content below 5.0 mg/l.
- 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.
- The location of the mixing zone shall not significantly alter 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. Under no circumstances shall mixing zones overlap or cover tributaries, nursery locations, or other ecologically sensitive areas.

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

- Waters shall be free from substances that will settle to form putrescent or otherwise objectionable sludge deposits.
- Waters shall be free from floating debris, oil, scum, and other floating materials in amounts sufficient to be unsightly or deleterious.
- Waters shall be free from substances producing color, odor, taste, total suspended solids, or other conditions in such a 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 uses. Specifically, the turbidity outside a 750-foot mixing zone shall not exceed the background turbidity at the time of the discharge by more than 50 NTU.
- Waters shall be free from substances in concentrations or combinations which are toxic or harmful to humans, animals, or aquatic life.
- Wastes shall receive effective treatment or control in accordance with Section 301, 306, and 307 of the Federal Clean Water Act or to a greater degree of treatment if needed to protect water uses.

Table 9-4. Florida Water Quality Standards

Parameter	Shellfish Propagation of Harvesting Class II[a] (μg/l)	Recreation, Fish and Wildlife Class III-Marine[a] (μg/l)
Aluminum	1,500	1500
Antimony	4,300	4300
Arsenic	50	50
Benzene	71.28	71.28
Biological Integrity[b]	not reduced <75% NB[c]	not reduced <75% NB[c]
BOD	shall not cause DO to drop below depressed limit for each class	shall not cause DO to drop below depressed limit for each class
Cadmium	9.3	9.3
Chlorides	not more than 10% above NB[c]	not more than 10% above NB[c]
Chlorine (total residual)	10	10
Chromium (VI)	50	50
Copper	2.9	2.9
Detergents	500	500
Dissolved Oxygen	5,000	5,000
Fluorides	1,500	1,500
Iron	300	300
Lead	5.6	5.6
Manganese	100	---
Mercury	0.025	0.025
Nickel	8.3	8.3
Oil and Grease	none visible	none visible
dissolved or emulsified	5,000	5,000
pH	NB ± 1 unit; 6.5 min. - 8.5 max.	NB ± 1 unit; 6.5 min. - 8.5 max.
Phenol	300	300
Phenol Compounds[d]	1.0	1.0
Radioactive Substances - radium	5 pCi/l	5 pCi/l
- gross alpha	15 pCi/l	15 pCi/l
Selenium	71	71
Silver	0.05	0.05
Thallium	6.3	6.3
Turbidity	≤29 NTU above NB[c]	≤29 NTU above NB[c]
Zinc	86	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] NB = natural background

- Dissolved oxygen concentrations shall be maintained at a daily average of not less than 5.0 mg/l with an instantaneous minimum of not less than 4.0 mg/l in estuaries.
- The normal pH of waters shall be 6.5 to 9.0 and shall not vary more than 1.0 unit.
- In coastal or estuarine waters, the maximum temperature rise above natural temperatures shall not exceed 4°F during the period October through May nor more than 1.5°F above natural for the months June through September.

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	43	9.3	168
Chromium			673,077
(III)	1,100	50	3,365
Chromium	2.9	2.9	1,000
(VI)	140	5.6	
Copper			0.153
Lead	75	8.3	4,584
Mercury	300	58	300
Nickel	300	71	
Phenol	2.3		
Selenium	95	86	5,000
Silver			
Zinc			

Source: State of Mississippi Water Quality Criteria for Intrastate, Interstate, and Coastal Waters,

9.5 Compliance with Water Quality Criteria and Standards

Modeled discharges of produced water result in only one exceedance of Federal water quality criteria (Table 9-6). The arsenic concentration of produced water effluent at 100 m from the Shell facility exceeds federal criteria by a factor of 3.1. Drilling fluids discharges were modeled at the maximum discharge rate allowed under the permit and using mean dilutions of 562, 787, and 1,721 for the respective water depths modeled at 15m, 40m, and 70m. In addition, leach extraction factors were used to modify the concentration of metals in the effluent by taking into account that the majority of the metal concentration in drilling fluid is bound to solids. The leach extraction factors are a measure of the fraction of the concentration of a given metal that is potentially solubilized into the water column (Avanti Corp., 1993). For example, only 2% of the effluent lead concentration is estimated to be solubilized and hence, potentially bioavailable. However, the amount of effluent metals solubilized is dependent on ambient conditions. In 1993, EPA studied leaching effects under various ambient conditions and determined the corresponding leach factors (Avanti Corp., 1993). The most appropriate leach factor for the Eastern Gulf of Mexico conditions and used in the current analysis is the mean seawater leach factor. No exceedances of Federal water quality criteria occurred from the modeled drilling fluid discharges (Table 9-7).

Projected produced water concentrations do not exceed any of the Alabama water quality standards (Table 9-8). For drilling fluid discharges, the Alabama standards are also not exceeded (Table 9-9).

Table 9-6. Comparison of Federal Water Quality Criteria to Projected Produced Water Pollutant Concentrations at 100 meters (in μg/l)

Pollutant	Effluent Conc.[a]	Federal Criteria[b]			Effluent Concentration at 100m			Factor of Exceed.[f]
		Marine Acute	Marine Chronic	Human Health	Shell[c]	Chevron[d]	Callon[e]	
Anthracene	7.4	--	--	110,000	0.044	0.012	2.36e-04	
Arsenic	73.08	69	36	0.14	0.430	0.122	0.002	3.1
Benzene	1225.91	--	--	71	7.21	2.05	0.039	
Benzo(a)pyrene	4.65	--	--	0.031	0.027	0.008	1.48e-04	
Cadmium	14.47	42	9.3	–	0.085	0.024	4.61e-04	
Chlorobenzene	7.79	--	--	21,000	0.046	0.013	2.48e-04	
Copper	284.58	2.4	2.4	--	1.67	0.475	0.009	
Di-n-butylphthalate	6.43	--	--	12,000	0.038	0.011	2.05e-04	
Ethylbenzene	62.18	--	--	29,000	0.366	0.104	0.002	
Lead	124.86	210	8.1	--	0.734	0.208	0.004	
Nickel	1091.49	74	8.2	4,600	6.42	1.82	0.035	
Phenol	536	--	--	4,600,000	3.15	0.895	0.017	
Toluene	827.8	--	--	200,000	4.87	1.38	0.026	
Zinc	133.85	90	81		0.787	0.223	0.004	

a See Table 3-5.
b See Table 9-1.
c Based on a 170:1 dilution projected by CORMIX Expert System.
d Based on a 599:1 dilution projected by CORMIX Expert System.
e Based on a 31,360:1 dilution projected by CORMIX Expert System.
f The exceedance factor is calculated as (effluent concentration at 100 m – the federal criteria). Shell effluent

In Florida, the projected produced water discharges do not exceed any of the state water quality standards (Table 9- 10). The maximum drilling fluid discharge rate would cause exceedances of one

Table 9-7. Comparison of Federal Water Quality Criteria to Projected Drilling Fluid Pollutant Concentrations at 100 meters (in μg/l)

Pollutant	Effluent Concentration[a]	Effluent Extraction Factors[b]	Concentration at 100 meters			Federal Criteria		
			15 m water depth[c]	40 m water depth[c]	70 m water depth[c]	Marine Acute	Marine Chronic	Human Health
Antimony	2,592	100 %	4.612	3.293	1.506			4,300
Arsenic	3,228	0.51 %	0.029	0.021	0.010	69	36	0.14
Cadmium	500	11 %	0.098	0.070	0.032	42	9.3	
Chromium VI	109,116	3.4%	6.60	4.714	2.156	1,100	50	
Copper	8,502	0.63 %	0.095	0.068	0.031	2.4	2.4	
Lead	15,958	2.0%	0.568	0.406	0.185	210	8.1	
Mercury	45	1.8 %	0.001	0.001	0.0005	1.8	0.025	0.15
Nickel	6,138	4.3 %	0.470	0.335	0.153	74	8.2	4,600
Selenium	500	100%	0.890	0.635	0.290	290	71	
Silver	318	100%	0.566	0.404	0.185	1.9		
Thallium	546	100 %	0.971	0.693	0.317			6.3
Zinc	91,1587	0.41%	0.665	0.475	0.217	90	81	

[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.

Source: Avanti Corp., 1993.

Table 9-8. Comparison of Alabama Water Quality Standards to Projected Produced Water Pollutant Concentrations at 100 meters (in μg/l)

Pollutant	Effluent Concentration [a]	State Standard [b]			Effluent Concentration at 100m		
		Marine Acute	Marine Chronic	Human Health	Shell [c]	Chevron [d]	Callon [e]
Arsenic	73.08	69	36	--	0.430	0.122	0.002
Benzene	1,225.91	--	--	155	7.21	2.05	0.039
Benzo(a)pyrene	4.65	--	--	0.0675	0.027	0.008	1.48e-04
Cadmium	14.47	42	9.3	--	0.085	0.024	4.61e-04
Copper	284.58	2.9	2.9	--	1.67	0.475	0.009
2,4-Dimethylphenol	250	--	--	498	1.47	0.417	0.008
Di-n-butylphthalate	6.43	--	--	2,622	0.038	0.011	2.05e-04
Ethylbenzene	62.18	--	--	6,222	0.366	0.104	0.002
Lead	124.86	220	8.5	--	0.734	0.208	0.004
Nickel	1,091.49	75	8.3	993	6.42	1.82	0.035
Phenol	536	--	--	1,000,000	3.15	0.895	0.017
Toluene	827.8	--	--	43,614	4.87	1.38	0.026
Zinc	133.85	95	86	--	0.787	0.223	0.004

[a] See Table 3-5.
[b] See Table 9-2.
[c] Based on a 170:1 dilution projected by CORMIX Expert System.
[d] Based on a 599:1 dilution projected by CORMIX Expert System.
[e] Based on a 31,360:1 dilution projected by CORMIX Expert System.

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

Pollutant	Effluent Concentration[a]	Extraction Factors[b]	Concentration at 100 meters			State Standard[e]		
			15 m water depth[c]	40 m water depth[c]	70 m water depth[c]	Marine Acute	Marine Chronic	Human Health
Antimony	2,592	100%	4.612	3.293	1.506			933
Arsenic	3,228	0.51%	0.029	0.021	0.010	69	36	
Cadmium	500	11%	0.098	0.070	0.032	43	9.3	
Chromium VI	109,116	3.4%	6.60	4.714	2.156	1,100	50	
Copper	8,502	0.63%	0.095	0.068	0.031	2.9	2.9	
Lead	15,958	2.0%	0.568	0.406	0.185	220	8.5	
Mercury	45	1.8%	0.001	0.001	0.0005	2.1	0.025	0.121
Nickel	6,138	4.3%	0.470	0.335	0.153	75	8.3	993
Selenium	500	100%	0.890	0.635	0.290	300	71	
Silver	318	100%	0.566	0.404	0.185	2.3		
Thallium	546	100%	0.971	0.693	0.137			1.33
Zinc	91,157	0.41%	0.665	0.475	0.217	95	86	

[a] See Table 3-3.
[b] The extraction factors represent the trace metal leach percentages from barite and drilling fluids.
[c] The average OOC Modd run dilution results were used for each of the water depths (See Table ~7). For 15m, dilution = 562, 40m = 787, and 70m as 1,721.
[e] See Table 9-2.

Source: Avanti, 1993.

Table 9-10. Comparison of Florida Water Quality Standards to Projected Produced Water Pollutant Concentrations at 100 meters (in μg/l)

Pollutant	Effluent Concentration [a]	State Surface Water Standard [b]	Effluent Concentration at 100m		
			Shell [c]	Chevron [d]	Callon [e]
Arsenic	73.08	50	0.430	0.122	0.002
Benzene	1,225.91	71.28	7.21	2.05	0.039
Cadmium	14.47	9.3	0.085	0.024	4.61e-04
Copper	284.58	2.9	1.67	0.475	0.009
Iron	3,146.5	300	18.51	5.25	0.100
Lead	124.86	5.6	0.734	0.208	0.004
Nickel	1,091.49	8.3	6.42	1.82	0.035
Phenol	536	300	3.15	0.895	0.017
Zinc	133.85	86	0.787	0.223	0.004

[a] See Table 3-5.
[b] See Table 9-4.
[c] Based on a 170:1 dilution projected by CORMIX Expert System.
[d] Based on a 599:1 dilution projected by CORMIX Expert System.
[e] Based on a 31,360:1 dilution projected by CORMIX Expert System.

standard (Table 9-11). The projected iron concentration exceeds the marine standard by a factor of 5.4, 3.8, and 1.8 for 15 m, 40 m, and 70 m water depths, respectively.

In Mississippi, the projected produced water discharges exceed the state water quality standards for one pollutant (Table 9-12). The modeled discharges from the Shell facility result in the exceedance of the arsenic concentration at 100 m by a factor of 3.1. The maximum drilling fluid discharge rate would not cause any exceedances of the state water quality standards (Table 9- 13).

Table 9-11. Comparison of Florida Water Quality Standards to Projected Drilling Fluid Pollutant Concentrations at 100 meters (in μg/l) at 100 meters (in μg/l)

Pollutant	Effluent Concentration [a]	Extraction Factors [b]	Concentration at 100 meters			State Marine Standard [d]	Exceedance Factor [e]
			15 m water depth [c]	40 m water depth [c]	70 m water depth [c]		
Antimony	2,592	100%	4.612	3.293	1.506	4,300	
Arsenic	3,228	0.51%	0.029	0.021	0.010	50	
Cadmium	500	11%	0.098	0.070	0.032	9.3	
Chromium VI	109,116	3.4%	6.60	4.714	2.156	50	
Copper	8,502	0.63%	0.095	0.068	0.031	2.9	
Iron	6,976,260	13%	1,613.7	1,152.4	527.0	300	5.4/3.8/1.8
Lead	15,958	2.0%	0.568	0.406	0.185	5.6	
Mercury	45	1.8%	0.001	0.001	0.0005	0.025	
Nickel	6,138	4.3%	0.470	0.335	0.153	8.3	
Selenium	500	100%	0.890	0.635	0.290	71	
Silver	318	100%	0.566	0.404	0.185	0.05	
Thallium	546	100%	0.971	0.693	0.137	6.3	
Zinc	91,157	0.41%	0.665	0.475	0.217	86	

[a] See Table 3-3.
[b] The extraction factors represent the trace metal leach percentages from barite and drilling fluids.
[c] The average OOC Modd run dilution results were used for each of the water depths (See Table 4-7). For 15m, dilution = 562, 40m = 787, and 70m as 1,721.
[d] See Table 9-4.
[e] The exceedance factor is calculated as: (pollutant concentration at 100 m ÷ the state standard). For iron, the exceedances are given for 15m, 40m, and 70m, respectively.

Source: Avanti, 1993.

Table 9-12. Comparison of Mississippi Water Quality Standards to Projected Produced Water Pollutant Concentrations at 100 meters (in μg/l)

Pollutant	Effluent Concentration [a]	State Standard [b]			Effluent Concentration at 100m			Exceedance Factor [f]
		Marine Acute	Marine Chronic	Human Health	Shell[c]	Chevron [d]	Callon[e]	
Arsenic	73.08	69	36	0.14	0.430	0.122	0.002	3.1
Cadmium	14.47	43	9.3	168	0.085	0.024	4.61e-04	
Copper	284.58	2.9	2.9	1,000	1.67	0.475	0.009	
Lead	124.86	140	5.6		0.734	0.208	0.004	
Nickel	1091.49	75	8.3	4,584	6.42	1.82	0.035	
Phenol	536	300	58	300	3.15	0.895	0.017	
Zinc	133.85	95	86	5,000	0.787	0.223	0.004	

a See Table 3-5.
b See Table 9-5.
c Based on a 170:1 dilution projected by CORMIX Expert System.
d Based on a 599:1 dilution projected by CORMIX Expert System.
e Based on a 31,360:1 dilution projected by CORMS Expert System.
f The exceedance factor is calculated as: (effluent concentration at 100m – the state standard). Shell effluent

Table 9-13. 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. POTENTIAL IMPACTS

This chapter summarizes the potential effects that may occur as a result of the activities permitted under the general permit for the Eastern Gulf of Mexico. This chapter summarizes and evaluates the information presented in the previous chapters.

10.1 Overview

Discharges from exploration, development, and production of oil and gas resources, particularly drilling fluids, cuttings, and produced water, have the demonstrated potential to adversely affect the marine environment. These effects include both toxic effects and physical effects (smothering and sediment texture alterations). Based on available data, however, these demonstrated effects have been shown to be relatively localized, i.e. within 1,000 m of the discharge for drilling fluids and cuttings and within several hundred meters for produced waters. Permit conditions and limitations have been imposed that mitigate against known sources of potential impact and specifically address final offshore BAT, BCT, and NSPS effluent limitations guidelines as well as third round permitting requirements (whole effluent toxicity).

Analyses of potential impacts are based on single species toxicity tests and field observations discussed in Chapter 5 of this report. If an adverse impact occurs, the severity of the impact depends upon several factors including: toxicity of the discharge to endemic biota, the exposure concentration over time, the capacity of the biota to accumulate components of the discharge (bioaccumulation) and chemical/ physical properties of the discharge and receiving waters. Those factors and others form the basis for a risk assessment whereby toxicity and exposure concentrations are used to estimate potential impacts. A brief discussion of potential impacts based on current information follows. Special emphasis is placed on benthic communities because they appear to be most susceptible to these discharges and to fisheries because of their commercial importance.

In this chapter on potential impacts, the types of adverse effects that have been documented in laboratory or field studies are presented. However, the vast majority of these data are derived from pre-BAT discharges that were much less stringently regulated than the discharges that will be covered by this general permit. The general permit imposes an extensive set of conditions and limitations that have, in large part, been developed either in response to the potential impacts discussed below or to improvements in pollution control technologies and practice. Thus, the general permit is expected to reduce or eliminate the expression of potential impacts, such as are described below, to any substantial degree.

10.2 Toxicity

10.2.1 Potential Impacts from Toxicity of Drilling Fluids and Cuttings

Of the major ingredients of water-based drilling fluids, only chrome or ferrochrome lignosulfonate and sodium hydroxide are considered even moderately toxic to marine organisms (NRC, 1983; Neff, 1985). Most of the metals found in used drilling fluids appear in forms which have low toxicities or limited bioavailability to marine organisms (Neff et al., 1978; Hunt and Smith, 1983; Luoma, 1983). Although most major ingredients of drilling fluids apparently have low toxicities to marine organisms, some of the specialty additives that are frequently used to solve specific problems are toxic. The most toxic of these additives have been shown to be diesel fuel, chromate salts, surfactants, paraformaldehyde, and other biocides (NRC, 1983; Conklin et al., 1983).

Numerous (i.e., many hundreds) acute lethal toxicity tests have been reported for drilling fluids. In acute toxicity tests for drilling fluids, the most sensitive of the species tested include rock shrimp, lobster larvae, juvenile ocean scallops, and pink salmon fry (NRC, 1983; Neff, 1985). In most cases, the larvae and/or juvenile life stages are more sensitive than adult stages. Larval, juvenile, and molting crustaceans appear to be more sensitive to drilling fluids than are other life stages and species. The toxicity of drilling fluids seems to be due to a combination of the chemical toxicity of the water-accommodated mud ingredients, the physical irritations caused by chemicals associated with the particulate phase, and damage to delicate gill and other body structures from the mud particles (Neff, 1985). Heavily treated drilling fluids and KCI muds appear to be the most toxic.

Numerous sublethal responses of finfish and shellfish species to drilling fluids have been observed in laboratory studies (Table 10-1). In finfish, sublethal responses include decreased development rate, depressed embryonic heart beat, development abnormalities, gill histopathology, feeding and avoidance behavior, and effects on growth (Houghton et al., 1980; Crawford and Gates, 1981; Olla et al., 1982; Sharp et al., 1984). In crustaceans, sublethal responses included reduced chemosensory responses, inhibition of feeding, altered behavior in larvae and juveniles, cessation of swimming in larvae, extended duration of larvae and juvenile development, decrease or increase in enzyme activity, gill histopathology, and reduced long-term larval and juvenile survival (Atema et al., 1982; Bookhout et al., 1984; Capuzzo and Derby, 1982; Carls and Rice, 1980; Carr et al., 1980; Conklin et al., 1980; Gerber et al., 1980, 1981; Gilbert, 1981; Houghton et al., 1980; Neff, 1980; Olla et al., 1982). Sublethal responses in bivalve mollusks included depressed filtration, byssus thread formation, NH_3 excretion, shell growth, condition index, increased respiration, altered free amino acid ratios, and altered behavior (Gerber et al., 1980, 1981; Gilbert, 1981, 1982; Houghton et al., 1980; Neff, 1980; Powell et al., 1982; Rubinstein et al., 1980; Olla et al., 1982). In evaluating these above findings, however, it should be noted that several of the drilling fluids tested in these studies contained diesel fuel, which could have contributed significantly to their toxicity.

The components of drilling fluids of major environmental concern have been petroleum hydrocarbons and heavy metals. The concern is whether they can accumulate in tissues to concentrations high enough to be toxic to the animals themselves and/or to higher trophic levels (Neff, 1985). The majority of petroleum hydrocarbons in water-based drilling fluids will be adsorbed to the clay fraction of the drilling fluid and will be dispersed in the water column with the slow-settling fraction (Breteler et al., 1983). Hydrocarbons in solution are generally much more bioavailable to marine organisms than those which are absorbed in bottom sediments (Ross, 1977; Roesijadi et al., 1978; McCain et al., 1978; Lyes, 1979; Neff, 1979, 1982; Augenfield et al., 1982; Anderson, 1982). Most of the hydrocarbons may eventually desorb from the clay and evaporate to the atmosphere, be degraded by bacteria, or be deposited with the clay on the bottom (Neff, 1985). Elevated levels of heavy metals discharged with drilling fluids have been reported in the

Table 10-1. Summary of Chronic and/or Sublethal Responses of Marine Animals to Water-based Chrome or Ferrochrome Lignosulfonate-type Drilling Fluids

Organism	Nature and Length of Exposure[a]	Responses	References
Bivalve Mollusks (6 species)	50-33,000 ppm suspension for 3-100 days	Depressed filtration; byssus thread formation; NH_3 excretion; shell growth; condition index; increased respiration; altered free amino acid ratios, and behavior	Gerber et al., 1980, 1981; Gilbert, 1981, 1982; Houghton et al., 1980; Neff, 1980; Powell et al., 1982; Rubinstein et al., 1980; Olla et al., 1982
Crustaceans (15 species)	7.7-100,000 ppm suspension for 5 min. - 42 days; 1-7 mm layer for up to 4 days	Decreased chemosensory response; inhibition of feeding; altered behavior in larvae and juveniles; cessation of swimming in larvae; increased duration of larval and juvenile development; decreased or increased enzyme activity, gill histopathy; decreased long-term larval and juvenile survival	Atema et al., 1982b; Bookhout et al., 1984; Capuzzo and Derby, Conklin et al., 1980; Gerber et al., 1980, 1981; Gilbert, 1981; Houghton et al., 1980; Neff, 1980; 1980; Carr et al., 1980;
Polychaete Worms (1 species)	10 ppm suspension for 100 days	33% mortality	Rubinstein et al., 1980
Echinoderms (5 species)	10-100,000 ppm suspensions 2 days - duration of larval development	Depressed fertilization; decreased development rate; increased incidence of development anomalies	Chaffee and Spies, 1982; Crawford, 1983; Crawford and Gates, 1981

[a] The lowest exposure concentrations eliciting a statistically significant response among experimentally-exposed organisms are given.

Source: Neff, 1985.

vicinity of offshore exploratory wells (Crippen et al., 1980; Ecomar, 1978; EG&G, 1982; Gettleson and Laird, 1980; Meek and Ray, 1980; Tillery and Thomas, 1980; Wheeler et al., 1980; Trocine et al., 1981). As with petroleum hydrocarbons, the bioavailability of sediment-absorbed metals is generally low (Jenne and Luoma, 1977; Bryan, 1983; Luoma, 1983).

Critical determinants of the impacts of discharged drilling fluids and cuttings on water column biota are the rate and extent of the dispersion and dilution processes. The effects of a material like drilling fluid on water column organisms will depend not only on its inherent toxicity, but also on actual exposure concentrations and durations. Offshore field studies have shown that drilling fluids discharged to open ocean waters generally are diluted to low concentrations at which they are not expected to produce adverse effects in water column organisms (Ayers et al., 1980a, 1980b; Ecomar, 1978, 1983; Houghton et al., 1980; Northern Technical Services, 1983).

Field investigations have shown that, in all but deep or high-energy environments, drilling fluids and cuttings initially will settle very rapidly from the discharge plume to the bottom. The severity of impact of deposition on the benthos is directly related to the amount of material accumulating on the substrate, which in turn is related to the amount and physical characteristics of the material discharged, and to the environmental conditions, such as current speed and water depth, at the time and site of discharge (Neff, 1985). In low energy and depositional environments, more material accumulates, and there may be a reduction in the abundance of some benthic species (Neff, 1985). In high energy environments, less drilling fluids or cuttings accumulate, and the impact on benthos would be minimal and of short duration. In general, however, factors enhancing local dispersion contribute to regional scale, low-level contamination. Such types of pollutant effects, if they occur, have historically been very difficult to identify and ascribe cause and effect relationships.

10.2.2 Potential Impact from Toxicity of Produced Water

The chemical properties of produced water that could cause harmful effects in marine organisms and ecosystems include elevated salinity, altered ion ratios, low dissolved oxygen, heavy metals, petroleum hydrocarbons and other organics (Neff, 1985). In addition, deck drainage may contain a variety of chemicals such as detergents, solvents, and metals. Chemicals such as biocides, coagulants, corrosion inhibitors, cleaners, and dispersants also may appear in the effluent waters (Middleditch, 1984; Neff, 1985). The major constituents of concern in produced water are petroleum hydrocarbons and heavy metals (Neff, 1985). Other produced water constituents or properties have either been shown to be unlikely contributors to significant impacts in the marine environment (elevated salinity and altered ion ratios) or their impacts have not been quantified (e.g., BOD; Neff, 1985).

The majority of toxicity tests that have been conducted with produced water indicate that most are not extremely toxic to finfish and shellfish (Rose and Ward, 1981; Andreasen and Spears, 1983; ZeinEldin and Keney, 1979; Avanti Corp., 1992). The studies performed indicate produced water has a fairly low toxicity (on the order of 1-10% for 96-hour LC50s). The most toxic produced waters tested may have been treated with biocides. The most sensitive organisms evaluated were larval brown shrimp (Rose and Ward, 1981) and pink salmon fry (Thomas and Rice, 1979).

Less information is available concerning the chronic and/or sublethal effects of produced water on marine organisms. Adverse potential effects have been inferred from published information about the chronic and sublethal effects of petroleum hydrocarbons and heavy metals to marine organisms (Menzie, 1982; Middleditch, 1984). In a study conducted in Santa Barbara, California, Krause et al. (1992) tested effects of produced water on purple sea urchins both in the laboratory and in the field. The effect of 1% produced water on gametes (particularly sperm) in the laboratory is reported as virtually instantaneous. In the field, detectable developmental effects were observed to 100-500 m from the outfall.

As in the case with drilling fluids, petroleum hydrocarbons in discharged produced water may evaporate or adsorb to suspended particles and be deposited in bottom sediments. A study conducted in Trinity Bay, Texas, a shallow-water, low-energy environment, indicated that higher molecular weight hydrocarbons accumulated in bottom sediments near the discharge site, while light aliphatic and aromatic hydrocarbons from produced water were not found elevated to the same degree (Armstrong et al., 1979). The study is not particularly applicable to the Federal OCS on a qualitative basis, but suggests that if any hydrocarbons are found in the sediment, they would most likely be the higher molecular weight hydrocarbons.

Although there have been several laboratory investigations of bioaccumulation of metals from drilling fluids, there are few studies of the bioaccumulation of metals from produced water by marine organisms (Neff, 1985). Of particular recent concern are the radionuclides ^{226}Ra and ^{228}Ra, which naturally occur in sea water and which readily bioaccumulate in the calcified exoskeleton of marine invertebrates and bones of fishes (van der Borght, 1963; Holtzman, 1969; Moore et al., 1973). Radium concentrations were slightly elevated in near-bottom water near shallow water produced water discharges at Pass Fourchon, but not in bottom sediments (Rabalais et al., 1991). In a recent DOE study of bioaccumulation of metals and petroleum hydrocarbons by marine animals near offshore produced water discharges in the Gulf of Mexico, there was no evidence of bioaccumulation of any produced water discharges (DOE, 1997). Small amounts of produced water-derived low molecular weight polycyclic aromatic hydrocarbons (PAHs) were accumulated by bivalves on submerged platform structures near a produced water discharge. Only low molecular weight PAHs similar to those in produced water were bioaccumulated. Fish near the discharges did not bioaccumulate any PAHs. PAHs, but not metals, were present at slightly elevated levels in sediments near some of the produced water outfalls.

Several field studies of coastal and nearshore sites have been conducted to assess short- and long-term, near-field and area-wide impacts caused by produced water discharges (Neff, 1985; Boesch and Rabalais, 1989; Armstrong et al., 1979). In shallow, turbid waters of coastal bays (Armstrong et al., 1979), these studies have demonstrated an accumulation of petroleum hydrocarbons from produced water in surficial sediments. In greater water depths and lower suspended sediment concentrations, such as are expected in most areas of the Federal OCS, a much smaller fraction of hydrocarbons in produced water discharges is deposited in bottom sediments (Middleditch, 1981).

In offshore areas, produced water is apparently diluted very rapidly following discharge. Significant elevations in salinity, elevated concentrations of hydrocarbons or metals, or decreased dissolved oxygen are not usually observed at distances greater than several hundred meters from the point of discharge (Neff, 1985). Because of the apparent degree of mixing with sea water, most physical/chemical features of produced water do not appear to pose a hazard to water column biota in open waters. Effects on the benthos in these areas are expected to be localized or of a relatively small magnitude.

10.3 Potential Impact of Discharges on Benthos

The effects of drilling and production discharges on benthos result from that portion of the material that settles to the bottom where it can be incorporated into the sediments, resuspended, transported, and dispersed (NRC, 1983). For drilling fluids, the concentration of solids in bottom sediments depends on the types and quantities of drilling fluids discharged, hydrographic conditions at the time of discharge, and the height above the bottom at which the discharge is made (Gettleson and Laird, 1980). In high energy environments, little drilling fluid and cuttings accumulate and impacts on the benthos are minimal and of short duration. In low energy environments, more material accumulates, and there can be localized impacts on benthic organisms. In the case of produced water, in shallow water environments where suspended sediment concentrations are high, dissolved and colloidal hydrocarbons and metals from produced water tend to become adsorbed to suspended particles and settle to the bottom (Armstrong, 1981). In deeper waters, elevated levels of hydrocarbons are restricted to a much smaller area of the bottom or are not detected at all (Middleditch, 1981).

10.3.1 Drilling Fluids

The major ingredients of water-based drilling fluids, bentonite clay and barite, are practically inert toxicologically, although they may cause physical damage to marine organisms through abrasion or clogging, or alter benthic community structure due to sediment texture changes. Several studies have been conducted investigating the sublethal responses of benthic fauna to drilling fluids. Responses observed include altered burrowing behavior; chemosensory responses; alterations in embryological or larval development; depressed feeding; decreased food assimilation and growth efficiency; altered respiration and nitrogen excretion rates; and others (see Table 10-1).

In OCS areas, the impacts of drilling fluids and cuttings discharges may be very localized or patchy in distribution, and may be difficult to distinguish from the effects of other local changes due to drilling activities. These activities include the rain of organic material from the fouling community on the rig and increased predator pressure due to the reef effect or sea bed scour around drilling structures.

Most offshore field studies have shown a minimal impact of water-based drilling fluid discharges on the benthos except immediately adjacent to platforms where a cuttings pile was formed and persisted. Some changes in the local infaunal community structure will occur due to burial and the altered sediment character. The increased bottom micro-relief afforded by the accumulation of cuttings may also attract fish and other motile animals and alter the character of epibenthic infaunal communities (Neff, 1985).

10.3.2 Produced Water

Benthic impacts are more likely from produced water discharges than water column impacts. This is especially true if the produced water is hypersaline. In areas where a hypersaline produced water plume contacts the bottom, benthic impacts may occur as a result of anoxic and hypersaline conditions. The extent of these effects will depend on the duration, volume, and dispersion of the plume. Given the oceanographic conditions over most of the Federal OCS covered by the general permit and the low volume of discharge anticipated, it is unlikely that the benthic community would be disrupted by any appreciable number of operators to any great degree beyond the immediate vicinity of the discharge or to any measurable degree in an area much farther than a few hundred meters. Neff et al. (1988) report little chemical contamination at offshore study sites that exceeded a 300 m radius. It is extremely difficult to predict the extent to which benthos may be affected for any discharge, given the interactions between facility location, volume of produced water discharged, variations in chemical composition of produced water, and hydrographic plume and sediment characteristics.

10.4 Potential for Bioaccumulation

Exposure to oil will vary widely between species. The species that feed in benthic environments by routing in silt or mud to expose prey may ingest larger amounts of hydrocarbons because a wide variety of petroleum components settle and aggregate in benthic environments (NAS, 1975). Contamination of organisms and sediments may be additive over a long period of time. The presence of hydrocarbons in benthic organisms has been related to the presence of such hydrocarbons in nearby sediments (NAS, 1975).

Because of the low bioavailability of sediment-absorbed hydrocarbons, most benthic animals can tolerate relatively high concentrations of sediment hydrocarbons. Some impacts on the benthos could occur if large amounts of hydrocarbon-laden drilling fluid solids were to accumulate in a particular area (Neff, 1985). Also, if produced water discharges interact with bottom sediments, hydrocarbon accumulation would be expected to occur. However, this interaction is not expected to occur frequently on the Federal OCS, and appears to be relatively localized when it does occur.

Field studies have suggested that low levels of sediment metal accumulation (generally <10-fold) and thus bioaccumulation could occur in the vicinity of development or production operations. Such effects should be localized (within 1,000 m of the platform) based on available data.

10.5 Potential Impact of Discharges on Fisheries

Although several types of discharges will take place during oil and gas exploratory, development, and production activities, only those discharges which would occur in sufficient volume to elicit a potential impact on finfish and shellfish populations, and thus the fisheries, are discussed here. These discharges are drilling fluids, cuttings, and produced water. Other discharges (sanitary waste, deck drainage, completion fluids, etc.) may have associated toxic effects, but the volume of discharges from these sources are relatively small in comparison. Further consideration may need to be given to these discharges in shallow or low energy areas or where there is a high concentration of facilities. However, in the case of a single facility, any potential effects could be so localized as to have no significant impact on entire fish populations.

10.6 Socioeconomic Consequences of Discharges on Fisheries

The importance of the commercial and recreational fisheries to the regional economy of the Gulf of Mexico and to the state economies of Alabama, Florida, and Mississippi was discussed in Chapter 7. This chapter focuses on assessing the socioeconomic consequences of adverse effects on these fisheries from discharges of drilling muds, cuttings, and produced waters.

As previously discussed, the Gulf of Mexico was second to the Pacific and Alaska region in the value of the catch landed, bringing in nearly $235 million. In 1996, Alabama's commercial fisheries brought in $38.3 million, Mississippi fisheries brought in $32.8 million, and Florida fisheries brought in $163.8 million. (NMFS, 1997). Combined, these three states brought in nearly 20% of the value of the entire US commercial fishery.

The following summarizes the sport fishing industry of the eastern Gulf of Mexico in 1988 (MMS, 1990).

	Expenditures ($Million)	Output ($Million)	Person Years of Employment
Alabama	519.1	804.4	16,754
Florida	3,100.0	4,200.0	85,584
Mississippi	428.0	806.7	16,160

Oil and gas structures are a major focus of all forms of offshore recreational fishing and some types of commercial fishing (MMS, 1982b; 1983b; 1984). Studies by Ditton and Graefe (1978) and Dugas et al. (1979) show that the preferred fishing locations for private and charterboat fishermen in portions of the western and central Gulf are oil and gas structures. Although any one structure or structure complex may be a popular fishing destination, the ones located in nearshore areas in close association with major coastal population access points are visited most often.

Many of the fish species that congregate around petroleum structures are prime sport-fishing targets (snapper, mackerels, etc). Concerns regarding sublethal effects of discharges on major sportfishing targets around platforms have been addressed by the National Academy of Sciences (1975), Gallaway (1980), and the Norwegian government (Jensen et al., 1984). They concluded that trace contaminants were noted in some sport fish collected near platforms; however, these contaminants were not significant and there was little evidence of bioaccumulation.

Any impacts on fisheries around offshore platforms on the OCS are expected to be relatively localized and short-term, because discharges would be into a large body of water in which dilution and dispersion are rapid. An exception could occur from the indirect effect on commercial and recreational fishing resulting from a high regional impact affecting biological productivity.

11. EVALUATION OF THE OCEAN DISCHARGE CRITERIA

This chapter discusses the ten factors that the Regional Administrator must consider in the analysis of compliance of this permit with Section 403 of the Clean Water Act, how conditions and limitations included in the final general permit for the eastern Gulf of Mexico ensure compliance with these ocean discharge criteria, and the determination, under Section 403, that this NPDES general permit will not cause unreasonable degradation of the marine environment with all permit limitations, conditions, and monitoring requirements in effect.

11.1 Introduction

The ten factors for determining unreasonable degradation were presented in Chapter 1. The chapters that followed discussed the available information concerning the issues to be evaluated. This chapter presents a summary of these issues, the conditions and limitations that are included by the Region in the final NPDES general permit for the eastern Gulf of Mexico that ensure compliance with Section 403, and a discussion of the determination that no unreasonable degradation of the marine environment will result from discharges authorized by this permit.

11.2 Evaluation of the Ten Ocean Discharge Criteria

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

The quantities and composition of the discharged material was presented in Chapter 3 and the potential for bioaccumulation or persistence was addressed in Chapter 5. For discharges other than produced water and 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. Produced water volumes also are required to be monitored and the volume discharged reported.

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 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.

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

Chapter 4 of this document is based on the literature available concerning the transport of drilling fluids and produced water 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, 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. For produced water, the existing facilities were asked to submit data so that modeling could be conducted based on actual conditions. The proposed permit contains provisions to require the same analyses for any new produced water discharges to be covered under the permit.

Both drilling fluids and produced waters 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 and toxicity limitations for produced water are the result of the predicted transport of the constituents of these effluents.

Biological and chemical transport processes are not as well understood for drilling fluid and produced water 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. The physical transport of these waste streams is considered to be the most significant source for dispersion of the wastes and monitoring and regulation is based on the results of those investigations.

Factor 3 - Composition and Vulnerability of Biological Communities

The third factor used to determine no unreasonable degradation of the marine environment is an assessment of the presence of unique species or communities of species, endangered species, or species critical to the structure or function of the ecosystem. Chapter 6 describes the biological community of the eastern 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. The permit covers areas that generally are deeper waters and the permit restricts the discharge rate to 1,000 bbl/hr for all areas. The potential impacts due to toxic effects from drilling fluids have been reduced 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, the biological community and its health are described according to available literature. The permit coverage area includes sites that are sensitive to the discharges that may occur and special conditions have been implemented through the permit. MMS has designated areas of the Gulf as "no activity areas" and when an operator proposes to commence drilling on a lease, MMS may require a live bottom survey, the results of which are sent to EPA for review. With these two identification procedures in place, sensitive habitats should be identified well before any impacts could occur.

For "no activity" areas or areas of biological concern (identified by the live bottom survey), the permit prohibits discharge within 1,000 m of the area. When the operator applies for coverage, he must report the distance from his facility to a "no activity" area or to an area of biological concern.

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

The importance of the receiving waters to the species and communities of the eastern Gulf is discussed in Chapter 6 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 and produced water ensure that levels of these effluents are below levels that could have impacts on local biological communities. By protecting local biological communities, EPA believes 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.

Factor 5 - Existence of Special Aquatic Sites

Designated areas of biological concern are presented in the permit. The general permit excludes from coverage facilities located in these areas. Operators must apply for individual NPDES coverage in these areas. Appropriate permit conditions would be assessed at that time.

Factor 6 - Potential Impacts on Human Health

Chapter 9 details the Federal and state human health criteria and standards for pollutants in drilling fluids and produced water. These criteria and standards are for marine waters based on based on fish consumption. These analyses compare projected pollutant concentrations at 100 m with these criteria and standards.

The permit prohibits the discharge of free oil, oil-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.

Factor 7 - Recreational or Commercial Fisheries

The commercial and recreational fisheries businesses in Alabama, Florida, and Mississippi are assessed in Chapter 7. The conditions and limitations in the general permit for the eastern Gulf 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 muds, no discharge of diesel oil, no discharge of produced sand, oil and grease limitations on produced water, discharge rate limitations around live-bottom areas, and limitations on the whole effluent toxicity of drilling fluids and produced water.

Factor 8 - Coastal Zone Management Plans

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

Factor 9 - Other Factors Relating to Effects of the Discharge

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.

Factor 10 - Marine Water Quality Criteria

The Federal and state marine water quality criteria and standards for pollutants found in drilling fluids and produced water are assessed in Chapter 9. The potential effects due to organic pollutants in drilling fluids have been eliminated with the prohibition of the use of oil-based muds and diesel oil. The heavy metals that exist in drilling fluids have been reduced in concentration by requiring the use of clean barite measured by the concentration of cadmium and mercury.

11.3 Conclusions

After consideration of the ten factors discussed above and elsewhere in this document, 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, the Region 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, under a no reasonable degradation determination as well as other relevant sections of the Act.

The Region has imposed a number of permit requirements that eliminate or reduce potential impacts from authorized discharges. These include:

- A general discharge rate restriction on drilling fluids and cuttings for the entire permit coverage area, and a prohibition near Areas of Biological Concern
- Requiring the use of barite with low trace metal contaminant levels for drilling fluids
- Prohibition on the discharge of oil-based muds and diesel oil as a mud additive
- Toxicity limitations on the major drilling and production waste streams
- An oil and grease limitation of produced water and TWC fluids
- A "no free oil" limitation on numerous discharges from oil and gas extraction and production activities
- The static sheen test for detection of free oil before discharges occur
- Residual chlorine limitations for sanitary waste discharges
- Limitations on solids for both sanitary and domestic waste discharges.

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APPENDIX A
ACUTE LETHAL TOXICITIES OF USED DRILLING FLUIDS AND COMPONENTS TO MARINE ORGANISMS

Appendix A. Acute Lethal Toxicities of Used Drilling Fluids and Components to Marine Organisms

Test Organism	Fluid Description[a]	Criterion Value (ppm)	Toxicity Rating[b]	Reference[c]
USED DRILLING FLUIDS				
ALGA	Imco LDLS/SW	1,325-4,700 (96-h EC50)	4	1
Skeletonema costatum	Imco Lime/SW	1,375 (96-h EC50)	4	1
	Imco non-dispersed/SW	5,700 (96-h EC50)	4	1
	Lightly treated LS/SW-FW	3,700 (96-h EC50)	4	2
COPEPODS	Imco LDLS/SW	5,300-9,300	4	1
Acartia tonsa	Imco Lime/SW	5,600	4	1
	Imco non-dispersed/SW	66,500	5	1
	Lightly treated LS/SW-FW	10,000	5	2
	FCLS/FW	100-230	3	2
	Saltwater Gel	100	3	2
ISOPODS	FCLS/FW	70,000	5-6	3
Gnorimosphaeroma oregonsis	XC-Polymer/Unical	314,000-500,000	6	4
Saduria entomon	CMC-Resinex Tannathin-Gel	530,000-600,000	6	4
AMPHIPODS	FCLS/FW	10,000-50,000	5	3
Anisogammarus confervicolus	FCLS/FW	10,000-200,000 (48-h	5-6	3
	XC-Polymer/Unical	LC50)	6	4
	Spud mud	200,000-436,000	6	5
Onisimus sp./*Boekisima* sp.	MDLS	100,000	5	5
Gammarus locusta	MDLS (MAF)	74,000-90,000	6	5
	HDLS	100,000	5	5
	HDLS (MAF)	28,000-88,000	6	5
		100,000		
GASTROPODS	CMC-Resinex Tannathin-Gel	600,000-700,000	6	4
Nautica clausa, Neptuna sp.,	LDLS (MAF)	100,000	6	5
& *Buccinum* sp.	LDLS	83,000	5	5
Littorina littorea	LDLS (MAF)	100,000	6	5
Thais lapillis	LDLS (suspended WM)	15,000	5	5
	MDLS	100,000	6	5
	MDLS (MAF)	100,000	6	5
	HDLS	100,000	6	5
	HDLS (MAF)	100,000	6	5

Source: Adapted from Petrazzuolo, 1981; footnotes at end of table.

Appendix A. Acute Lethal Toxicities of Used Drilling Fluids and Components to Marine Organisms (cont.)

Test Organism	Fluid Description[a]	Criterion Value (ppm)	Toxicity Rating[b]	Reference[c]
DECAPODS-SHRIMP	FCLS/FW	100,000 (48-h LC50)	6	3
Artemia salina	FCLS/FW	32,000-150,000	5-6	3
Pandalus hypsinotus		50,000-100,000 (48-h	5	3
	Spud mud (MAF)	LC50)100,000	6	5
Crangon septemspinosa	Seawater LS (MAF)	100,000	6	5
	LDLS	71,000	5	5
	LDLS (suspended WM)	15,000	5	5
	LDLS (MAF)	98,000-100,000	5	5
	MDLS	82,000	5	5
	MDLS (suspended WM)	15,000	5	5
	MDLS (MAF)	17,000	5	5
	MDLS (FMAF)	19,000	5	5
	HDLS	92,000	5	5
	HDLS (suspended WM)	15,000	5	5
	HDLS (MAF)	100,000	6	5
	HDLS (FMAF)	100,000	6	5
	HDLS (MAF)	65,000	5	5
	HDLS (FMAF)	55,000	5	6
Pandalus borealis	Spud Mud (MAF)	100,000	6	6
Stage I larvae	Seawater-chrome LS (MAF)	27,500	5	6
Palaemonetes pugio	MDLS (MAF)	35,000	5	6
Stage I zoeae	HDLS (MAF)	18,000	5	6
Adults	HDLS (SPP)	11,800	5	6
	Spud Mud (MAF)	100,000	6	6
	Seawater-chrome LS (MAF)	92,400	5	6
	MDLS (MAF)	91,000	5	6
	HDLS (MAF)	100,000	6	6
Stage III zoeae	Lightly treated LS	201	3	11
Late premolt stage	HDLS (SPP)	11,700-13,200	5	6
D_2 - D_4	Mobile Bay fluid	318-863	3	7
Palaemonetes pugio	Mobile Bay fluid	360-14,560	3-5	9
larvae	Seawater LS	1,706-28,750	4-5	11
	Lightly treated LS	142	3	11
	Freshwater LS	4,276-4,509	4	11
	Lime	658	3	11
	FW/SW-LS	3,570	4	11
	Non-dispersed	100,000	6	11
	LTLS	35,420	5	11

Appendix A. Acute Lethal Toxicities of Used Drilling Fluids and Components to Marine Organisms (cont.)

Test Organism	Fluid Description[a]	Criterion Value (ppm)	Toxicity Rating[b]	Reference[c]
Penaeus aztecus	Seawater-K-polymer	2,557	4	11
juvenile	Seawater-chrome LS (MAF)	41,500	5	6
Orchestia traskiana	MDLS (MAF)	16,000	5	6
	Seawater-polymer	230,000	6	8
	Pelly gel Chemical XC	80,000	5	8
	KCI-XC-Polymer	14,000	5	8
	Weighted shell polymer	34,000	5	8
	Gel-SX-polymer	420,000-500,000	6	8
	Imnak gel-XC-polymer	560,000	6	8
DECAPODS-CRABS	LDLS	89,100	5	5
Carcinus maenus	LDLS (suspended WM)	15,000	5	5
	LDLS (MAF)	100,000	6	5
	MDLS	68,000-100,000	5-6	5
	MDLS (suspended WM)	15,000	5	5
	MDLS (MAF)	100,000	6	5
	HDLS (MAF)	100,000	6	5
	Seawater-chrome LS (MAF)	28,700	5	6
Clibanarius vittatus	MDLS (MAF)	34,500	5	6
	HDLS (MAF)	65,600	5	6
	Seawater polymer	530,000	6	8
Hemigrapsus nudus	Shell Kipnik-KCL polymer	53,000	5	8
	Pelly gell chemical XC	560,000	6	8
	KCI-XC-polymer	78,000	5	8
	Weighted shell polymer	62,000	5	8
	Pelly weighted gel-XC-polymer	560,000	6	8
	Imnak gel-XC-polymer	560,000	6	8
DECAPODS-LOBSTER				
Homarus americanus	LDLS (MAF)	5,000	5	5
Stage V larvae	MDLS	100,000	6	5
	MDLS (MAF)	29,000	5	5
Adult	LDLS	19,000-25,000	5	5
	LDLS (MAF)	100,000	6	5
Larvae	Mobile Bay/Jay fluids	73.8-500 ppm	2-3	10

Appendix A. Acute Lethal Toxicities of Used Drilling Fluids and Components to Marine Organisms (cont.)

Test Organism	Fluid Description[a]	Criterion Value (ppm)	Toxicity Rating[b]	Reference[c]
BIVALVES	FCLS/FW	30,000	5	3
Modiolus modiolus		30,000 (14 day LC50)	5	3
	Spud mud (MAF)	100,000	6	5
Mytilus edilus	Seawater LS (MAF)	100,000	6	5
	MDLS (MAF)	100,000	6	5
	MDLS (suspended WM)	15,000	5	5
	HDLS (MAF)	100,000	6	5
	HDLS (suspended WM)	15,000	5	5
	LDLS	100,000	6	5
Macama balthica	LDLS (MAF)	100,000	6	5
	LDLS (suspended WM)	15,000	5	5
	HDLS	100,000	6	5
	HDLS (MAF)	100,000	6	5
	HDLS (FMAF)	100,000	6	5
	LDLS	49,000	5	5
	MDLS	3,200	4	5
Placopecten magellanicus	Spud mud (SPP)	100,000	6	6
	MDLS (SPP)	50,000-53,000	5	6
Crassostrea gigas	HDLS (SPP)	73,000-74,000	5	6
	Spud mud (SPP)	100,000	6	6
	Seawater-chrome LS (SPP)	53,700	5	6
Donax variabilis texasiana	MDLS (SPP)	29,000	5	6
	HDLS (SPP)	56,000	5	6
	Seawater polymer	320,000	6	8
	Kipnik-KC1 polymer	42,000	5	8
	Polly gel chemical XC	560,000	6	8
Mya arenaria	KC1-XC-polymer	56,000	5	8
	Weighted shell polymer	10,000	5	8
	Weighted gel XC-polymer	560,000	6	8
	Weighted KC1-XC-polymer	560,000	6	8
	Imnak gel-XC-polymer	560,0008	6	8

Appendix A. Acute Lethal Toxicities of Used Drilling Fluids and Components to Marine Organisms (cont.)

Test Organism	Fluid Description[a]	Criterion Value (ppm)	Toxicity Rating[b]	Reference[c]
Mercenaria mercenaria	Seawater LS (LP)	7-3,000	2-4	11
Larvae	Seawater LS (SPP)	117-3,000	3-4	11
	LTLS (LP)	719-3,000	3-4	11
	LTLS (SPP)	122-2,889	3-4	11
	FWLS (LP)	319-330	3	11
	FWLS (SPP)	158-338	3	11
	FW/SW LS (LP)	380	3	11
	FW/SW LS (SPP)	82	2	11
	Lime (LP)	682	3	11
	Lime (SPP)	64	2	11
	Low solids non-dispersed (LP)	3,000	4	11
	Low-solids non-dispersed (SPP)	3,000	4	11
	Potassium polymer (LP)	269	3	11
	Potassium polymer (SPP)	220	3	11
ECHINODERMS	LDLS	55,000	5	5
Strongylocentrotus	LDLS (MAF)	100,000	6	5
droebachiensis	MDLS	100,000	6	5
	MDLS (MAF)	100,000	6	5
MYSIDS				
Neomysis integer	FCLS/FW	10,000-200,000 (48-h	5-6	3
		LC50)	5-6	3
Mysis sp.	CMC-Gel	10,000-125,000	6	4
	CMC-Gel-Resinex	142,000-349,000	5	4
	XC-polymer (supernatant)	58,000-93,000	6	4
Mysidopsis almyra	XC-polymer	250,000	5-6	4
	Spud mud (MAF)	50,000-170,000	6	6
	Seawater-chrome LS (MAF)	100,000	5	6
	MDLS (MAF)	27,000	5	6
	HDLS (MAF)	12,800-13,000	5	6
	MDLS (SPP)	16,000-32,500	5	12
	MDLS (MAF)	32,000	5	12
	MDLS (MAF) (static test)	26,800-66,300	5-6	12
	Reference mud (MAF) (static test)	72,100-113,000	6	12
		100,000		

Appendix A. Acute Lethal Toxicities of Used Drilling Fluids and Components to Marine Organisms (cont.)

Test Organism	Fluid Description[a]	Criterion Value (ppm)	Toxicity Rating[b]	Reference[c]
Mysidopsis bahia	Seawater LS	429-1,557	3-4	11
	Seawater LS (LP)	150,000	6	11
	Seawater LS (SPP)	15,123-19,825	5	11
	Seawater LS (SP)	50,000	5	11
	LTLS	14-1,958	2-4	11
	LTLS (LP)	150,000	6	11
	LTLS (SPP)	1,641-50,000	3-5	11
	LTLS (SP)	1,246-2,437	3	11
	FWLS	301-1,500	3-4	11
	FWLS (LP)	97,238-121,476	5-6	11
	FWLS (SPP)	14,068-29,265	5	11
	Lime	87-98	2	11
	Lime (SPP)	650-791	3	11
	Lime (SP)	8,213-1,369,393	4-6	11
	FW/SW-LS	115-379	3	11
	FW/SW-LS (LP)	150,000	6	11
	FW/SW-LS (SPP)	11,380-38,362	5	11
	FW/SW-LS (SP)	50,000	5	11
	Low-solids non-dispersed	1,500	4	11
	Low-solids non-dispersed (LP)	150,000	6	11
	Low-solids non-dispersed (SPP)	50,000	5	11
	Low-solids non-dispersed (SP)	50,000	5	11
	Potassium polymer	1,500	4	11
	Potassium polymer (LP)	150,000	6	11
	Potassium polymer (SPP)	26,025-28,070	5	11
POLYCHAETES	CMC-Resinex-Tannathin	600,000	6	4
Melaenis loveni	CMC-Resinex-Tannathin-Gel	700,000	6	4
	Spud mud (MAF)	100,000	6	5
Nereis virens	Seawater-LS (MAF)	100,000	6	5
	LDLS	100,000	6	5
	LDLS (MAF)	100,000	6	5
	MDLS	100,000	6	5
	MDLS (MAF)	100,000	6	5
	HDLS	100,000	6	5
	HDLS (MAF)	100,000	6	5
	Spud mud (MAF)	100,000	6	6

Appendix A. Acute Lethal Toxicities of Used Drilling Fluids and Components to Marine Organisms (cont.)

Test Organism	Fluid Description[a]	Criterion Value (ppm)	Toxicity Rating[b]	Reference[c]
Ophryotrocha labronica	Seawater-chrome LS (MAF)	100,000	6	6
	MDLS (MAF)	60,000	5	6
	HDLS (MAF)	100,000	5	6
	Seawater polymer	220,000	6	8
Neveis vexillosa	Kipnik-KC1 polymer	37,000	5	8
	Gel chemical XC	560,000	6	8
	KC1-XC-polymer	41,000	5	8
	Weighted shell polymer	23,000	5	8
	Weighted gel XC-polymer	320,000-560,000	6	8
	Imnak gel-XC-polymer	200,000	6	8
TELEOST FISH	Imco LDLS/SW	56,500-175,000	5-6	1
Menidia menidia	Imco Lime	43,000-53,000	5	1
	Imco non-dispersed	345,000-385,000	6	1
	Saltwater gel	100,000	6	2
	LDLS-SW/FW	48,500	5	2
	FCLS	100,000	6	2
	FCLS/FW	3,000-29,000	4-5	3
Oncorhynchus gorbuscha	FCLS/FW	100,000-200,000	6	3
Leptocuttus armatus	CMC-Gel	120,000	6	4
Myoxocephalus quadricornis	CMC-Gel-Resinex	50,000-70,000	5	4
	XC-Polymer	50,000-215,000	5-6	4
	XC-Polymer (supernatant)	250,000	6	4
	Lignosulfonate	350,000	6	4
	CMC-Gel	200,000	6	4
	XC-Polymer	57,000-370,000	5-6	4
Coregonus nasus	XC-Polymer (supernatant)	100,000-250,000	6	4
	Lignosulfonate	0-100,000	6	4
	CMC-Gel	170,000-300,000	6	4
	XC-Polymer	250,000	6	4
Elegonus naraga	Lignosulfonate	200,000-250,000	6	4
Boreogodus saida	Lignosulfonate	85,000-1,000,000	6	4
	Spud mud (MAF)	100,000	6	5
Coregonus autumnalis	Seawater-LS (MAF)	100,000	6	5
Fundulus heteroclitus	MDLS (suspended whole mud)	15,000	5	5
	MDLS (MAF)	100,000	6	5
	HDLS (suspended whole mud)	15,000	6	5
	HDLS (MAF)	100,000	6	5
	Kipnik-KC1 polymer	24,000-42,000	5	8

Appendix A. Acute Lethal Toxicities of Used Drilling Fluids and Components to Marine Organisms (cont.)

Test Organism	Fluid Description[a]	Criterion Value (ppm)	Toxicity Rating[b]	Reference[c]
Salmo gairdneri (juvenile)	Seawater polymer	130,000	6	8
	KC1-XC polymer	34,000	5	8
	Weighted shell polymer	16,000	5	8
	Pelly gel chemical-XC	42,000	5	8
	Weighted gel XC-polymer	18,000-48,000	5	8
	Imnak-Gel XC-polymer	42,000	5	8
	Kipnik-KC1 polymer	29,000	5	8
	Seawater polymer	130,000	5	8
Oncorhynchus kisutch (juvenile)	KC1-XC polymer	20,000-23,000	5	8
	Weighted shell polymer	4,000-15,000	4-5	8
	Pelly Gel chemical-XC	28,000-130,000	5-6	8
	Weighted gel XC-polymer	24,000-190,000	5-6	8
	Imnak-Gel XC-polymer	23,000-30,000	5	8
	Kipnik-KC1 polymer	24,000	5	8
O. keta (juvenile) *O. gorbuscha* (juvenile)	Kipnik-KC1 polymer	41,000	5	8
DRILLING FLUID COMPONENTS				
Skeletonema costatum	Barite	385-1,650	3-4	2
	Aquagel	9,600	4	3
Arcartia tonsa	Barite	590	3	2
	Aquagel	22,000	5	2
Pandalus hypsinotus	Barite	100,000	6	3
	Aquagel	100,000	6	3
Molliensias latipinna	Barite	100,000	6	13
	Calcite	100,000	6	13
	Siderite	100,000	6	13
	Chrome lignosulfonate	7,800-12,200	4-5	14
	Quebracho	135-158	3	14
	Lignite	15,500-24,500	5	14
	Sodium acid pyrophosphate	1,200-7,100	4	14
Penaeus setiferus	Hemlock bark extract	265	3	15
	Polyacrylate	3,500	4	15
	$CaCO_3$ workover additive	1,925	4	15
	Chrome-treated lignosulfonate	465	3	15
	Lead-treated lignosulfonate	2,100	4	15

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
SPP = Suspended particulate phase
SP = Solid phase
LP = Liquid phase

SW = Saltwater dispersed
FW = Freshwater dispersed
LS = Lignosulfonate
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

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		350			1 9	
	5	(after 14-d depuration)	2.2			1.8	
	50	(after 14-d depuration)	29			2.2	
	Barite						
Carapace	(500)	8 days post-ecdysis,	7.7			1.2-2.5	
Hepatopancreas	(500)	range = 8-21	13			1 9-2.8	
Abdominal muscle	(500)	(48-hour replacement)	12			1.5-2 8	
	Barite						
Carapace	(500)	106	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			
	Layered solid phase	4, daily replacement		4.3			
		(after 1-dy depuration)		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 (soft tissue cont.)	12.7 lb/gal 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	(1,000)	28	8.8	2.6			
Adductor muscle	(1,000)	28	10	1.2			
	Low density lignosulfonate fluid						
Kidney	(1,000)	14		1.6			
		27		2.1			
		(after 15-dy depuration)		2.3			
Adductor 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.

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 gutted	5	7, 48-hr replacement	150			1.3	
	50		350			1.9	
	5	(after 14-d depuration)	2.2			1.8	
	50	(after 14-d depuration)	29			2.2	
	Barite						
Carapace	(500)	8 days post-ecdysis,	7.7			1.2-2.5	
Hepatopancreas	(500)	range = 8-21	13			1.9-2.8	
Abdominal muscle	(500)	(48-hour replacement)	12			1.5-2.8	
	Barite						
Carapace	(500)	106	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			
	Layered solid phase	4, daily replacement		4.3			
		(after 1-dy depuration)		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						
(soft tissue cont.)	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	(1,000)	28	8 8	2 6			
Adductor muscle	(1,000)	28	10	1 2			
	Low density						
	lignosulfonate fluid						
Kidney	(1,000)	14		1 6			
		27		2 1			
		(after 15-dy depuration)		2.3			
Adductor 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.